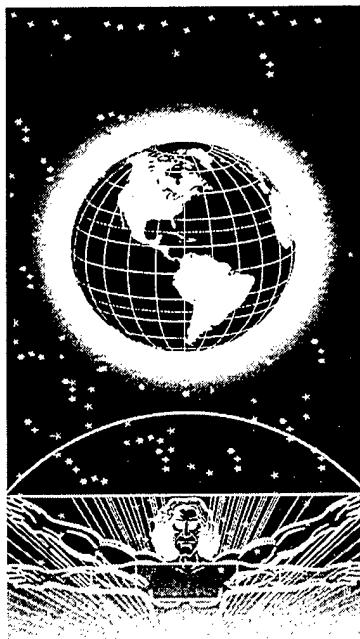




UNITED STATES AIR FORCE RESEARCH LABORATORY

Advanced Cargo Handling System Concepts

Donald R. Loose
James M. Walters

Battelle Memorial Institute
5100 Springfield Pike, Suite 110
Dayton, OH 45431-1261

June 2000

Final Report for the Period April 1999 to February 2000

20011011 131

Approved for public release; distribution is unlimited.

Human Effectiveness Directorate
Deployment and Sustainment Division
Sustainment Logistics Branch
2698 G Street
Wright-Patterson AFB OH 45433-7604

NOTICES

When US Government drawings, specifications or other data are used for any purpose other than a definitely related Government procurement operation, the Government thereby incurs no responsibility nor any obligation whatsoever, and the fact that the Government may have formulated, furnished, or in any way supplied the said drawings, specifications or other data, is not to be regarded by implication or otherwise, as in any manner licensing the holder or any other person or corporation, or conveying any rights or permission to manufacture, use, or sell any patented invention that may in any way be related thereto.

Please do not request copies of this report from the Air Force Research Laboratory. Additional copies may be purchased from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161

Federal Government agencies registered with the Defense Technical Information Center should direct requests for copies of this report to:

Defense Technical Information Center
8725 John J. Kingman Rd., Ste 0944
Ft. Belvoir, VA 22060-6218

TECHNICAL REVIEW AND APPROVAL

AFRL-HE-WP-TR-2001-0127

This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER


ALBERT S. TORIGIAN, Lt Col, USAF
Deputy Chief
Deployment and Sustainment Division
Air Force Research Laboratory

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE June 2000		3. REPORT TYPE AND DATES COVERED Final - April 1999 - February 2000
4. TITLE AND SUBTITLE Advanced Cargo Handling System Concepts			5. FUNDING NUMBERS C: F33615-99-D-6001 DO: 05 PE: 62202F PR: 1710 TA: D0 WU: 09	
6. AUTHOR(S) Donald R. Loose, James M. Walters				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Battelle Memorial Institute 5100 Springfield Pike, Suite 110 Dayton, OH 45431-1261			8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Air Force Research Laboratory, Human Effectiveness Directorate Deployment and Sustainment Division Air Force Materiel Command Sustainment Logistics Branch Wright-Patterson AFB OH 45433-7604			10. SPONSORING/MONITORING AGENCY REPORT NUMBER AFRL-HE-WP-TR-2001-0127	
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) The Air Force Research Laboratory identified four areas where technology development and integration hold significant promise in enabling today's Expeditionary Aerospace Force to achieve its objectives. They are: (1) Rapid aircraft off-load and on-load devices; (2) Low cost, small footprint, highly reliable ground movement devices; (3) Cargo flow and resource optimization technologies, and (4) Portable information display and input devices for mobility personnel. The goal of the task was to develop multiple cargo movement technology system concepts compatible with military aircraft that will at once have reduced footprint; will have improved reliability, maintainability and availability (RM&A); will have the ability to operate in austere environments; will have reduced cost over current cargo movement systems; will be rapidly deployable; and will significantly increase the cargo flow rate from aircraft to end user (to include reduced cargo loading, unloading, and ground movement time) during operational deployments. The contractor evaluated the alternative system concepts that meet the system design requirements stated and that incorporate the development areas stated using appropriate analysis methods, including modeling and simulation.				
14. SUBJECT TERMS Cargo Handling Cargo Movement Transportation Technology			15. NUMBER OF PAGES 74	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT UL	

THIS PAGE INTENTIONALLY LEFT BLANK

Advanced Cargo Handling System Concepts

EXECUTIVE SUMMARY

Current material handling equipment (MHE) and access to transportation information systems are cumbersome and lack the flexibility needed to meet the stringent mobility requirements of the future. The Air Force requires an integrated set of physical movement technologies and information/communication technologies that will:

- have reduced deployment footprint;
- be rapidly deployable;
- have improved reliability, maintainability and availability;
- have the ability to operate in austere environments;
- have reduced cost over current cargo movement systems;
- significantly increase the cargo flow rate from aircraft to end user (to include reduced cargo loading, unloading, and ground movement time) during operational deployments.

A team of experts from Battelle Memorial Institute, Litton - The Analytical Sciences Corporation; Object Oriented Technologies, Inc., and the Air Force Research Laboratory explored technological opportunities to increase the rapidity and efficiency of cargo movement for an Air Expeditionary Wing (AEW) during deployment. The team focused on the first three days of debarkation in an austere environment.

The study team visited three air-cargo-handling locations – Dover AFB DE, Charleston AFB SC, and Fort Polk LA – to observe operations and interview subject matter experts. The team also assembled and reviewed a bibliography of current practices.

The team reviewed the information collected, then formulated key problem areas providing potential opportunities for improvement.

The team spent several “technology days” at Battelle Headquarters reviewing the state of the art in a variety of possibly applicable technologies. In free ranging discussion, the team subsequently generated possible applications of these and other technologies to air cargo handling.

The study team created nine new advanced cargo handling system concepts by prioritizing and integrating their lists of Air Cargo Handling problems and technological opportunities for improvement. Four of these used information technologies and five used physical movement technologies.

The study team explored these concepts in the following way:

- First they searched the air-cargo-handling industry and technology-development projects to collect information on the current products that could come the closest to meeting the needs of these proposed systems. In some cases, the technology already exists and just needs to be carefully applied. In other cases, some further technology development would be needed.
- Next they applied the new concepts, when appropriate, to a discrete event simulation of an AEW deployment at an austere location, in order to predict the effects of each concept on cargo throughput.
- Next they ranked the system concepts according to the following measures of merit: rapidity of deployment, deployment footprint, development cost, development risk, feasibility within the state of the art, manpower requirements during deployment, system operating cost, and utility in an austere environment.

- Finally, based on current technology and the possibilities for ACH improvement, the team assessed the key research issues necessary to implement each concept.

The nine system concepts were:

Information Technologies

- Personal Digital Assistant Network
- Cargo Inspection Aids
- Electronic 3D Planning Aid
- MHE Prognostics

Physical Movement Technologies

- Simple Lifter and Walkable Pallet Transport
- Self-Loading Multi-Pallet Loader
- Elevating Dolly
- Mule Pallet Carrier
- Wheeled Pallets

None of the Physical Movement Technology Concepts offered a clear advantage in all the above criteria. Most offered significant improvements in one or more areas, but have disadvantages in other areas that would have to be addressed during development. Which concept one would choose to develop depends on how one prioritizes the above criteria. The best approach may be a combination of two concepts: the Mule Pallet Carrier and Wheeled Pallets. This combined approach would use near-term technology, would yield an improvement in throughput early in the deployment, and would yield improvements such as low procurement cost and reduced deployment footprint. In addition, the Mule Pallet Carrier could readily serve multiple vehicle requirements, thus quickly facilitating operations in an austere environment.

All of the Information Technology Concepts have merit, but the one most impacting the focus of this study – early deployment at the point of debarkation – is the personal digital assistant network. The hardware and software technology to support this concept is presently available. However, substantial research would be needed to develop the information architecture and a set of user-interface/information-presentation standards to support effective application in the cargo handling arena.

Table of Contents

1. INTRODUCTION

1.1 REQUIREMENTS	1
1.2 SCOPE	1
1.3 TECHNOLOGICAL OPPORTUNITIES	1
1.4 STUDY TASKS.....	1
1.4.1 BASELINE CURRENT PROCESS.....	1
1.4.2 DETERMINE OPTIMAL USE OF EXISTING TECHNOLOGIES.....	1
1.4.3 DETERMINE NEW SYSTEM CONCEPTS.....	2
1.4.4 EVALUATE NEW SYSTEM CONCEPTS.....	2
1.4.5 ASSESS TECHNOLOGY DEVELOPMENT REQUIREMENTS	2
1.5 RELATION TO PREVIOUS WORK	2
1.5.1 BIBLIOGRAPHY	2
1.5.2 PREVIOUS STUDY	3
1.6 OVERVIEW OF THIS EFFORT	4

2. METHODS

2.1 THE RESEARCH TEAM.....	6
2.2 FIELD VISITS.	6

2.2.1	SITES VISITED AND PERSONNEL INTERVIEWED.....	6
2.2.2	NON-INTERVIEW INTERACTION..	6
2.2.3	THE USE OF STRUCTURED INTERVIEWS	6
2.2.4	THE INTERVIEW METHOD	7
2.2.5	THE INTERVIEW QUESTIONS	8
2.3	TECHNOLOGY SURVEY.....	8
2.4	SYNTHESIS	8
2.5	CONCEPT EXPLORATION.....	8
2.6	CONCEPT SIMULATION	9
2.7	CONCEPT RANKING.....	12

3. RESULTS

3.1	PROBLEM AREAS IN CURRENT AIR CARGO HANDLING OPERATIONS.....	13
3.1.1	COMMUNICATION AND INFORMATION DISTRIBUTION ISSUES	13
3.1.2	SCHEDULING AND PLANNING ISSUES.....	17
3.1.3	TRAINING ISSUES	19
3.1.4	CARGO ISSUES	20
3.1.5	MHE ISSUES	22
3.2	TECHNOLOGY REVIEW.....	24
3.2.1	CONTAINERIZATION.....	24
3.2.2	PACKAGING.....	25
3.2.3	HYDRAULICS.....	26
3.2.4	POLYMER PRODUCTS DESIGN	26
3.2.5	SMART CARD TECHNOLOGY	26
3.2.6	COGNITIVE SYSTEMS	27
3.2.7	TRANSPORTATION SYSTEMS.....	27
3.2.8	ACH SUBJECT MATTER EXPERT (SME) REACTIONS	27

3.3 TECHNOLOGICAL OPPORTUNITIES TO IMPROVE ACH	28
3.3.1 EXPERT SYSTEMS AND DECISION SUPPORT	28
3.3.2 IMPROVED CARGO INSPECTION.....	29
3.3.3 IMPROVED MATERIAL HANDLING EQUIPMENT	30
3.4 ADVANCED AIR CARGO HANDLING SYSTEM CONCEPTS.....	30
3.4.1 PERSONAL DIGITAL ASSISTANT (PDA) NETWORK	32
3.4.2 CARGO ID AND INSPECTION MONITORS	36
3.4.3 ELECTRONIC 3D PLANNING AID.....	39
3.4.4 MHE PROGNOSTICS	40
3.4.5 THE SIMPLE LIFTER AND WALKABLE PALLET TRANSPORT	41
3.4.6 THE MULE PALLET CARRIER.....	44
3.4.7 SELF-LOADING MULTI-PALLET TRANSPORTER	46
3.4.8 ELEVATING DOLLY	47
3.4.9 WHEELED PALLET CONCEPT	49
3.5 CONCEPT SIMULATION	50
3.5.1 SCENARIO ASSUMPTIONS	50
3.5.2 BASE CASE	51
3.5.3 SIMPLE LIFTER-WALKABLE PALLET MOVER.....	51
3.5.4 SELF-LOADING MULTI-PALLET MOVER	51
3.5.5 MULE PALLET CARRIER	51
3.5.6 ELEVATING DOLLY	52
3.5.7 RESULTS	52
3.6 CONCEPT RANKING.....	53
3.6.1 SIMPLE LIFTER-WALKABLE PALLET MOVER.....	53
3.6.2 ELEVATING DOLLY – SINGLE/DOUBLE	53
3.6.3 SELF-LOADING MULTI-PALLET MOVER – FOUR/SIX.....	53
3.6.4 WHEELED PALLET MOVER.....	53
3.6.5 MULE PALLET CARRIER	53
3.7 COMPARISON TO BASELINE.....	53
3.7.1 SIMPLE LIFTER-MULTIPLE PALLET MOVER.....	53
3.7.2 MULE PALLET CARRIER.....	54
3.7.3 SELF-LOADING MULTI-PALLET MOVER.....	54
3.7.4 ELEVATING DOLLY.....	54
3.7.5 WHEELED PALLET MOVER.....	54
3.7.6 PICK AND CHOOSE.....	54

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 MHE CONCEPTS.....	56
-----------------------	----

4.2 INFORMATION CONCEPTS.....	57
-------------------------------	----

APPENDIX A AIR CARGO HANDLING SYSTEM (ACHS) CONCEPTS SIMULATION PLAN.....	58
APPENDIX B COMPLETE RESULTS FROM SIMULATION RUNS.....	64

Table of Figures

FIGURE 2-1. ACH SIMULATION LOGIC FLOW.....	9
FIGURE 2-2. REPRESENTATIVE CARGO OFF-LOAD AREA.....	11
FIGURE 3-1. AIR MOBILITY COMMAND INFORMATION SYSTEMS – PRESENT STATE	14
FIGURE 3-2. AIR MOBILITY COMMAND INFORMATION SYSTEMS --TRANSITIONED STATE	15
FIGURE 3-3. PERSONAL DIGITAL ASSISTANT CONCEPT	32
FIGURE 3-5. ELECTRONIC 3D PLANNING AID CONCEPT	39
FIGURE 3-6. SIMPLE LIFTER CONCEPT	41
FIGURE 3-7. WALKABLE PALLET TRANSPORTER CONCEPT	42
FIGURE 3-8. MULE PALLET CARRIER CONCEPT	44
FIGURE 3-9. SELF-LOADING MULTI-PALLET TRANSPORTER CONCEPT	46
FIGURE 3-10. ELEVATING DOLLY CONCEPT	47
FIGURE 3-11. SGV 2000.....	48
FIGURE 3-12. WHEELED PALLET CONCEPT.....	49
FIGURE 3-13. SIMULATION RESULTS.....	52

Advanced Cargo Handling System Concepts

1. Introduction

1.1 Requirements

Current material handling equipment and access to transportation information systems are cumbersome and lack the flexibility needed to meet the stringent Air Expeditionary Force (AEF) mobility requirements of the future. In order to meet AEF and other objectives, the Air Force requires an integrated set of (1) physical movement technologies and (2) information technologies that will achieve the following:

- have reduced deployment footprint;
- be rapidly deployable;
- have improved reliability, maintainability and availability;
- have the ability to operate in austere environments;
- have reduced cost over current cargo movement systems;
- significantly increase the cargo flow rate from aircraft to end user (to include reduced cargo loading, unloading, and ground movement time) during operational deployments.

1.2 Scope

The objective of this effort was to develop and evaluate technology system concepts that would increase the rapidity and efficiency of cargo movement for an Air Expeditionary Wing during deployment.

1.3 Technological Opportunities

The Air Force Research Laboratory (AFRL) identified four areas where technology development and integration hold significant promise in enabling the AEF to achieve its objectives:

- Rapid aircraft off-load and on-load devices;
- Low cost, small footprint, highly reliable ground movement devices;
- Cargo flow and resource optimization technologies, and
- Portable information display and input devices for mobility personnel.

1.4 Study Tasks

- 1.4.1 Baseline Current Process. Investigate and document Air Force cargo movement processes and technologies (including material handling equipment and applicable information systems) currently used during deployment operations.
- 1.4.2 Determine Optimal Use of Existing Technologies. Determine optimal cargo movement system concepts using existing Air Force cargo movement technologies (including the two technological development areas specified in par. 1.1) used during deployment operations.

- 1.4.3 Determine New System Concepts. Develop new cargo movement technology system concepts that achieve the system performance characteristics and incorporate the technological development areas listed in para. 1.1 when used during deployment operations.
- 1.4.4 Evaluate New System Concepts. Explore these new system concepts using appropriate analysis methods including modeling and simulation. The analysis shall include cost, reliability, maintainability, availability, footprint reduction, cargo throughput, and development risk. Based on this analysis, develop the highest payoff system concepts and generate preliminary functional requirements for all system components.
- 1.4.5 Assess Technology Development Requirements. For the highest payoff system concepts, specify the areas of technology development required. Identify which portions can be met with existing or emerging technologies and which portions require additional research and development.

1.5 Relation To Previous Work

1.5.1 Bibliography

The following references are relevant to understanding how air cargo is currently handled in the Air Force and what the Air Force is considering for the future.

1.5.1.1 Technical Reports, Articles, & Theses

- 463L Pallets and Dunnage System Evaluation, Final Report to AFRL Contract F22657-92-D-205510101, Battelle Memorial Institute, 1997
- The Logistics of Waging War, Volume 2, 1982-1993, The End Of "Brute Force" Logistics, Capt Thomas Snyder & Capt Stella Smith, Air Force Logistics Management Agency
- Airlift Reality Check, John A Tirpak, Air Force Magazine, December 1999, pp. 31-36
- Operational Utility Evaluation, FMC Commander 30 Universal Loader, Final Report, Air Mobility Command, December 1998
- Measuring the Effect of Radio Frequency Identification Technology on Movement of US Army Re-supply Cargo, Capt Leigh E. Method, Air Force Journal Of Logistics, Winter 1998, pp. 7-13
- Deploying and Sustaining an F-117A Expeditionary Fighter Squadron: Why Agile Combat Support Is Needed Now, Capt Jamie D. Allen & 1Lt M. Brian Bedesem, Air Force Journal Of Logistics, pp. 33-37
- Intra-Theater Cargo Movement Costs, Michael T. Conley, Air Force Logistics Management Agency, August 1997
- Military Air Cargo Containerization (Graduate Research Paper), Maj Joseph W. Mancy, Air Force Institute of Technology, May 1996
- Benchmarking Practices of Air Cargo Carriers: A Case Study Approach (Thesis), Capt Mila D. Abalateo & Capt Joni R. Lee, Air Force Institute of Technology, September 1993

1.5.1.2 Presentations

- Aircraft Off/On-Load System, George Lewis, Battelle and Lockheed Martin, June 1998
- Transportation Research, Sam Kuper, Sustainment Logistics Branch, Air Force Research Laboratory

- Aircraft Loader Modernization, Major Mike Crupe, Plans and Programs Directorate, Air Mobility Command, 1999
- Truck-Aircraft Loading, Off-Pavement (TACLOP), Advanced Transport Vehicles Inc., Presentation to HQAMC, 16 September 1998

1.5.1.3 Military Manuals, Pamphlets, and Operating Instructions

- Field Manual 55-9, Appendix D, 463L Cargo System & Appendix H, Material Handling Equipment
- Preparation of Freight for Airlift Transportation, Air Force Pamphlet 71-8, December, 1991
- Military Airlift – AMC Aerial Port Mobility Units and Aerial Delivery Flights, Air Mobility Command Instruction 24-101, Volume 18, 1 October 1998
- Military Airlift Air Terminal Operations Center, Air Mobility Command Instruction 24-101, Volume 9, 15 August 1996
- Air Command and Control Operations, Air Mobility Command Instruction 10-202, Volume 1, 13 February 1995
- Air Mobility Planning Factors, Air Force Pamphlet 10-1403, 1 March 1998
- Methodology and Procedures for Aerial Port Deliberate Planning, Capt. Travis E. Condon & Capt. Deborah McKenzie, Air Transportation and Plans Division, HQ Air Mobility Command, January 1999

1.5.2 Previous Study

This effort directly followed another AFRL sponsored study on air cargo handling, Transportation Research for the Next Generation Cargo Movement System Analysis, performed by Synergy Inc. Their scope was considerably larger than this effort, examining both military and civilian movement of cargo by air, from embarkation to debarkation. In contrast, this study's focus is specifically on the initial debarkation of an Airborne Expeditionary Wing at a remote, austere site.

Synergy conducted visits and interviews at many military and civilian ACH organizations. Opinions were gathered on the challenges they currently face and ideas for technological solutions. They were solicited for both formal and informal needs, followed by an assessment of potential technology solutions. Synergy also performed an efficiency analysis of current debarkation practice assuming different complements of MHE. Therefore, the Synergy effort strongly addressed the world of ACH, as it exists now, not the development of future ACH concepts.

Nevertheless, several responses from the field interviews addressed possible future uses of technology.

- The Combined Arms Support Command (CASCOM) is very active in the limited application, experimentation, and evaluation of transportation technology for full Army use. They see the areas of greatest transportation potential to be information technology and "intellectual technology." Terminals and their sorting activities were characterized as major bottlenecks of the transportation pipeline. Principal causes of poor cycle-time performance are air and seaports of debarkation. CASCOM highlights the following current and future transportation thrusts:
 - The next generation of radio frequency tags
 - Radar responsive tags
 - A real-time cargo asset control tracking system
 - Cargo configuration schemes

- Containers and palletized loading systems
- General cargo movement design
- Joint transportation experts identified a need for a stronger “marriage” between extended logistics functions (maintenance, procurement, transportation, supply, etc.). Automated identification technologies are a key area of interest. Information technology is the biggest transportation problem, followed by MHE. Areas for MHE improvement are collapsible containers, Army capability to move 463L pallets on helicopters and trucks, and common vehicle and lift systems between military and commercial carriers. Information technology areas of improvement include smart cards, RF tags and transponders, web-based technologies, and microburst satellite communication.
- Air Mobility Command cited contamination of cargo and aircraft and the difficulty in decontamination using today’s pallets and netting. The need for coordination with commercial and other services continues to increase. Areas for technology research include:
 - Remote controlled robotics for cargo movement
 - New pallet lifting capability
 - The use of wheeled pallets with current airframes
 - Interface between army PLS and aircraft
 - Stacking cargo higher on the plane to allow more weight per aircraft
 - Reducing the types of loaders as the types of aircraft are reduced
 - Use of a space station as a depot
- Other ideas expressed by transportation experts include:
 - Wireless and microwave communication
 - Enhanced Global Positioning System
 - Logistics optimization models
 - Electric vehicles
 - Collision warning systems
 - Safety monitoring of hazardous/sensitive freight

1.6 Overview Of This Effort

To meet the above requirements of this task order, a team of Air Force and contractor personnel performed the following subtasks:

- Literature Review. The team performed a literature review to understand current air cargo handling practices and problems.
- Field Data Collection. The team visited three aerial ports to observe air cargo handling and to interview subject matter experts about problem areas with current equipment and practices.
- Technology Review. The team spent several days at Battelle Memorial Institute receiving presentations on the state-of-the-art of technology areas that might be applicable to air cargo handling.
- Team Evaluation. Using everything learned to that point, the team held a series of discussions to summarize and prioritize air cargo handling problems, and to perform unconstrained brainstorming on technological possibilities to address those problems.

- Concept Creation and Exploration. The team prioritized and combined their technological ideas into nine new advanced cargo handling system concepts, four in the information area and five in the physical movement area. The team then explored how well current technology could support these concepts.
- Concept Simulation. A discrete event simulation was used to explore the impacts of various cargo handling concepts in the early days of an AEW deployment. The measure of merit was cargo throughput (off-loading) at a remote, austere location.
- The team then used all the information learned during this task to rank-order the physical handling technology concepts according to measures of merit specified by AFRL.

The methods used for each subtask are described in Section 2. The results from each subtask are presented in Section 3. Section 4 contains conclusions and recommendations.

Advanced Cargo Handling System Concepts

2. Methods

2.1 The Research Team

The collection of relevant data, review of possibly applicable technologies, creation of new system concepts, creation of an air cargo movement simulation, and analysis of the system concepts was a team effort, in terms of both organizations and individuals. The participants invested hours of give-and-take discussion in group meetings. The wider the range of perspectives brought to the discussion; the better was the chance of generating useful concepts.

2.2 Field Visits

The ACHSC team began their research with on-site visits to aerial ports to both observe loading/unloading operations and to interview the personnel responsible for air cargo handling (ACH) as SMEs. Visitation goals were to:

- Baseline current real-world ACH operations via observations and interviews.
- Attain SME perceptions regarding impediments to more efficient ACH.
- Get initial reaction to possible technological approaches to improved ACH.

2.2.1 Sites Visited And Personnel Interviewed (under condition of non-attribution)

- Dover Air Force Base, DE: Information Controllers, Ramp Controllers, Materiel Handling Equipment (MHE) Maintainers, and Load Team Personnel
- Charleston Air Force Base, SC: MHE Maintainers, Load Planners, Aircraft Services Personnel, Mobility Flight Personnel, Capability Forecasters, and an Air Terminal Operations Center (ATOC) Duty Officer (also called a Squadron Port Director of Operations)
- England Air Park, LA: Loadmaster/Trainer, Aerial Port Squadron, and Joint Airlift Inspectors

2.2.2 Non-Interview Interaction. Notes were taken during the following activities and included in the analysis (below).

- The interview team was able to observe some ACH operations.
- The interview team often did preliminary briefings to the headquarters staff of the squadron personnel to be interviewed. This usually led to a free-ranging discussion of some of the topics covered in the more formal interviews.
- After the structured interview was completed, several of the technological concepts under consideration were described to the SMEs to get their initial reaction.
- The interview team toured an MHE maintenance facility and discussed problems with the designs of current loaders.

2.2.3 The Use of Structured Interviews

SME experience and opinions give valuable perspective into how better tools and procedures could improve the execution of their tasks. By definition, each expert has unique knowledge to offer. Yet the

knowledge we require is to benefit many personnel doing similar jobs. How does a researcher distinguish between a uniquely valuable perspective and just a personal preference? Would experience and opinions from several experts in the same tasks agree?

Given access to SME time, one could interview as many SMEs as possible, with the ideal of obtaining statistically significant agreement between responses to relatively superficial questions. Or one could interview a few SMEs in depth, looking for deeper insight into the issues, while assuming that most SME opinions will be generally relevant.

- To gain access to a sufficiently large sample of SMEs for statistical testing would require querying SMEs at many locations via a written survey. The challenge with such surveys is motivating the SMEs to spend sufficient time and concentration to provide significant insight, as well as to ensure each respondent interprets each question the same way.
- An open ended face-to-face conversation with each SME would allow the interviewer to pursue any interesting insights that may arise. Extended conversations can trigger further consideration and memories from each SME. However, if there are no controls on the questions asked each SME, it is difficult to interpret responses that apparently disagree.

A structured interview takes a middle ground between both approaches.

- Face-to-face interaction builds rapport between the interview team and the SMEs. The interviewers can more easily convince the SMEs of the importance of the study in general and of their answers in particular.
- Face-to-face interaction can more easily evoke candid responses from the SMEs when anonymity is assured.
- The interviewer reads the questions verbatim from a structured questionnaire that the interview team has authored and revised. Thus, each SME hears each question the same way at first. And each SME receives the questions in the same order.
- Each question, however, is considered to be open ended. If a respondent misinterprets the question, clarification is allowed. Furthermore, answers are not limited in length. If the question triggers a line of discussion yielding relevant information, the discussion is allowed to continue within the constraint of the overall time allotment for the interview.
- Another member of the interview team – not the member presenting the questions – records the answers on a notebook computer. Before the end of the interview session, the recorded answers are verified with the SME.

2.2.4 The Interview Method

The structured interview process was set up to clarify and, if possible, to resolve SME differences of opinion during the interview. Features of this process are:

- SMEs are interviewed together in groups of two or three.
- SMEs are asked to assume the perspective of the typical experience of their unit, rather than of themselves individually.
- The interviewer also acts as discussion facilitator in the resolution of differences of opinion. Since each SME is representing the same unit, open discussion about differences of opinion reveals more relevant information, and sometimes leads to consensus. The facilitator's goal is consensus, not the dominance of one opinion over others.
- Interviews conducted in dyads or triads often yield synergistic responses as one SMEs comment triggers further thoughts and comments from another.

2.2.5 The Interview Questions

The questions covered the following topics:

- What is your relevant professional experience?
- To your unit, what is the most important thing you do in your job?
- In your job, how do you know what needs to be done next? Later? When you have several things to do, how do you prioritize them?
- How do you know when or if you've done your previous task correctly?
- What tasks take the longest time to perform, under both normal and surge conditions? What tasks take the most preparation?
- What things about your job are the most confusing? The most frustrating? What "eats your lunch?" What is the worst thing you've seen go wrong when doing your job?
- If you could redesign your job, and the equipment that supports it, how would you make it more efficient?
- What do you think of this new technology we are considering?

2.3 Technology Survey

In parallel with the field visits, the ACHSC team began reviewing technology areas that seemed capable of positively impacting air cargo handling.

The Battelle team members organized two "technology days" during which status of possibly relevant technology was reviewed. The areas covered were:

- Cognitive Systems
- Packaging
- Hydraulics
- Smart Cards
- Transportation Systems
- Polymers

Summaries of these reviews are presented in section 3.2, below.

2.4 Synthesis

The team held further free-ranging "brainstorming" discussion sessions to generate ideas for technology application to address the general problem areas defined after the field data collection. Ideas were listed independent of political, financial, or technological constraints. Summaries of these ideas are presented in section 3.3, below.

These ideas were eventually grouped into nine advanced technology system concepts judged to be worthy of further exploration. Five of them incorporated physical movement technologies and four of them incorporated information/communication technologies

2.5 Concept Exploration

This study was tasked to address both the improvements that could be made today using current technology and those that might be made in the future with technology development. For each of the nine

advanced technology concepts, Battelle and TASC-Litton searched for means of implementation using current technology and noted where research was still needed. Currently existing technology somewhat close to the advanced technology concepts was also useful to provide realistic data for concept simulation/analysis later this study.

Detailed descriptions of each advanced technology concept and the results of concept exploration are presented in section 3.4, below.

2.6 Concept Simulation

A discrete event simulation was used to examine how each of the advanced concepts based on physical movement technologies could affect cargo throughput during a deployment. A comprehensive simulation plan underwent a series of reviews and revisions by the Air Force Research Laboratory and Headquarters Air Mobility Command (HQAMC) before the simulation was implemented. The final version of the plan is at Appendix A.

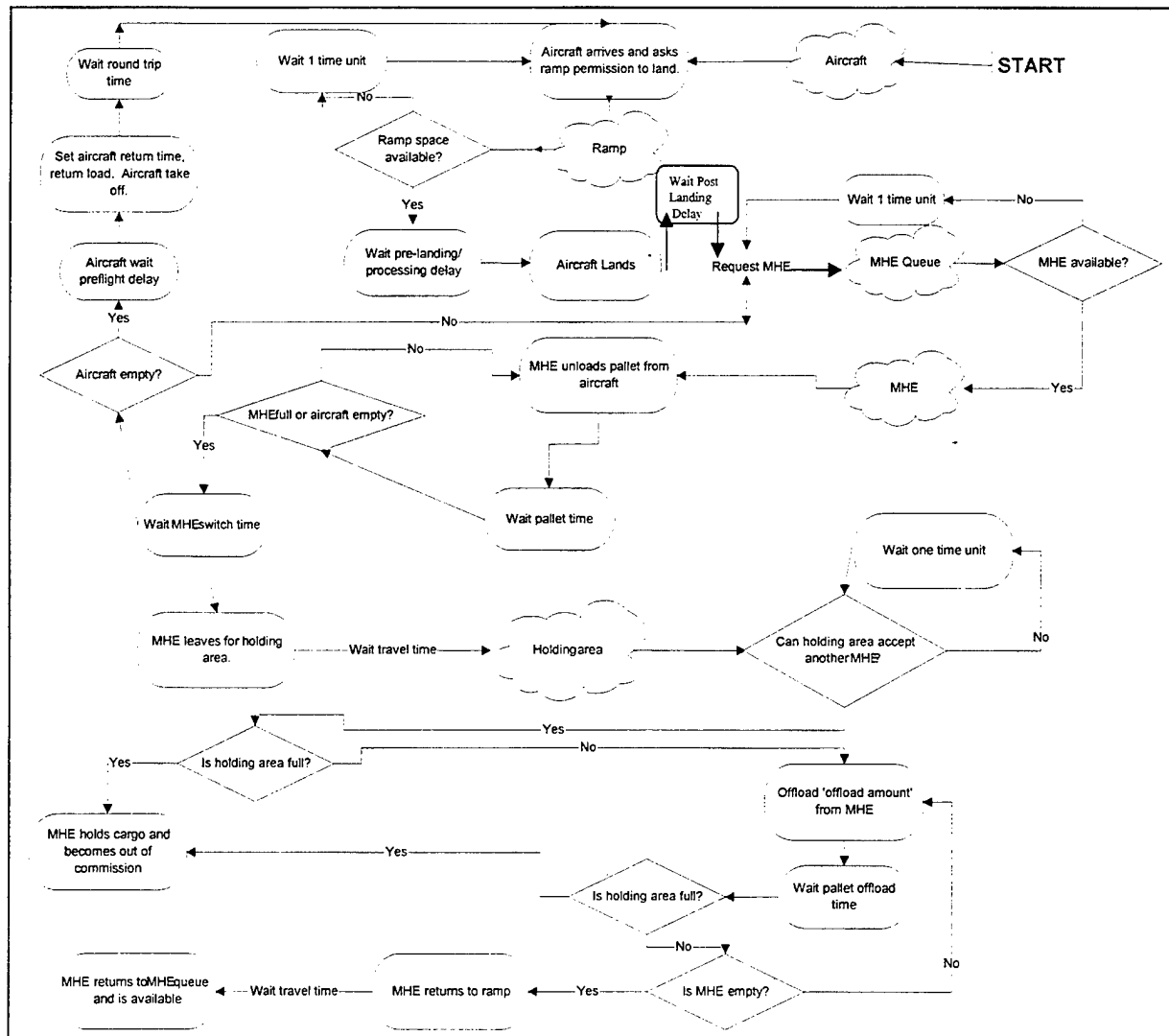


Figure 2-1. ACH Simulation Logic Flow

In this simulation, aircraft arrived at a deployed location in periodic intervals. A ground crew with appropriate equipment unloaded their cargo and transferred it to a holding area, after which the aircraft took off. The deployment operation was broken into tasks and subtasks for which times were assigned. The times were based on our field observations and any data we could acquire from real equipment somewhat similar to the concepts we were examining.

We used the following definitions and assumptions in this simulation.

- **Material Handling Equipment (MHE) Availability.** At any point, when the MHE reaches its mean time between failures, it sets a flag to indicate that it is broken. Then, once back at the ramp, it is unavailable for the mean time to repair, at which time it becomes available again. It will never stop working during duty. We assumed all future concepts will have availability as good as the current state-of-the-art, i.e., the predicted performance of the still-under-development Next Generation Small Loader. That availability is 21.5 hours a day.
- **Travel Time.** The travel time for the MHE in minutes is the distance of the holding area to the ramp in miles divided by the MHE speed in miles per minute. We assumed the latter for the base case to be 0.15 miles per minute, or 9 miles per hour. On domestic runways the typical MHE ramp speed would be 15 miles per hour, but speeds will be slower over the uncertain surfaces of an austere environment. We assumed the holding area to be 1 mile from the ramp based on our observations at aerial ports. See figure 2-2. Subject matter experts whom we interviewed predicted a similar airfield geometry at remote sites.
- **Off-load Amount.** The amount of cargo off-loaded is a value used to constrain the holding area based on the forklifts available for off-loading cargo from the MHE. It is the number of pallets that can be off-loaded from each at one time. We assume that off-loading 3 pallets at one time takes 2 minutes, based on our observations.
- **Holding Area MHE Capacity.** The holding area can process one transporter at a time. This is done on a first-come/first-served basis.
- **Holding Area Pallet Capacity.** For this study we assumed the holding area to be unlimited in the number of pallets it can hold. During a deployment all the cargo WILL be deposited somewhere.
- **Ramp Space Availability.** There will typically be five ramp positions available at a remotely deployed site, according to a Rand study of remote austere deployment. (Rand performed its own simulation of a similar scenario to ours. We initially duplicated the Rand study's conditions to validate our own simulation. We retained their finding about ramp positions.) Each aircraft takes one position with the exception of the C-5, which takes 1.667. If the ramp is full, planes will circle waiting to land. Reference: discussions with HQAMC personnel.
- **Round Trip Time.** In reality many cargo aircraft would be used for a deployment, but from the view of the simulation, 12 planes being recycled creates the same workload when sharing five ramp positions. This simplifies the simulation. As soon as one of the twelve planes leaves the point of debarkation it is put in the queue of arriving planes and given a full load of cargo. The round trip time allows us to delay the return of a plane with more cargo in order to vary the air traffic density. For this simulation we set the round trip time to 0. This ensured there were always planes waiting to return and that the maximum off-loading capacity was simulated.
- **The Pre-landing/Processing Delay.** The pre-landing/processing delay represents the time between when the plane requests to land until it is told where to land and actually does so.
- **The Post-landing Delay.** The post-landing delay represents the time after the plane lands before it begins to unload.
- **MHE Queue.** Each ramp has an MHE queue. The MHE queue holds all the available MHE.

- **MHE Object.** The MHE object represents the loading devices. Each piece of MHE is assigned to one MHE queue. Our baseline assumed two next generation small loaders (NGSLs) were on site, each with a three-pallet capacity.
- **Pallet Time.** The pallet time represents the time it takes to load 1 pallet onto a loader or lifter from the plane. Our baseline assumed 1 minute based on our field observations.
- **MHE Full/Aircraft Empty.** When a transporter or loader is full or the aircraft is empty, the MHE withdraws from the aircraft to go to the holding area. When the aircraft is empty, it prepares to take off.
- **MHE Switch Time.** The MHE switch time represents the time required for the MHE to back away from the aircraft. Our baseline assumed 2 minutes based on our field observations.
- **Preflight Delay.** The pre-flight delay represents the time between completion of unloading and actually taking off. Our baseline assumed 24 minutes based on our field observations.
- **Holding Area Object.** The holding area is associated with multiple pieces of MHE. These pieces take their cargo to that holding area throughout the simulation.
- **MHE Empty.** When the MHE is empty, it may return to the ramp. This will also free up a spot in the holding area for another MHE to begin off-loading its cargo.
- **Cargo Full.** If the holding area is constrained to a certain number of pallets, when it is full, the MHE will simply hold its cargo and in effect become unavailable. Since the holding area is not constrained to a certain size in this simulation, this never happens.
- **Pallet Off-load Time.** This represents the time it takes to off-load the number of pallets from the MHE that is defined by the off-load amount.

The following figure shows the layout of one of the aerial ports we visited. According to the personnel we interviewed, this is also typical of the layout of a deployed site.

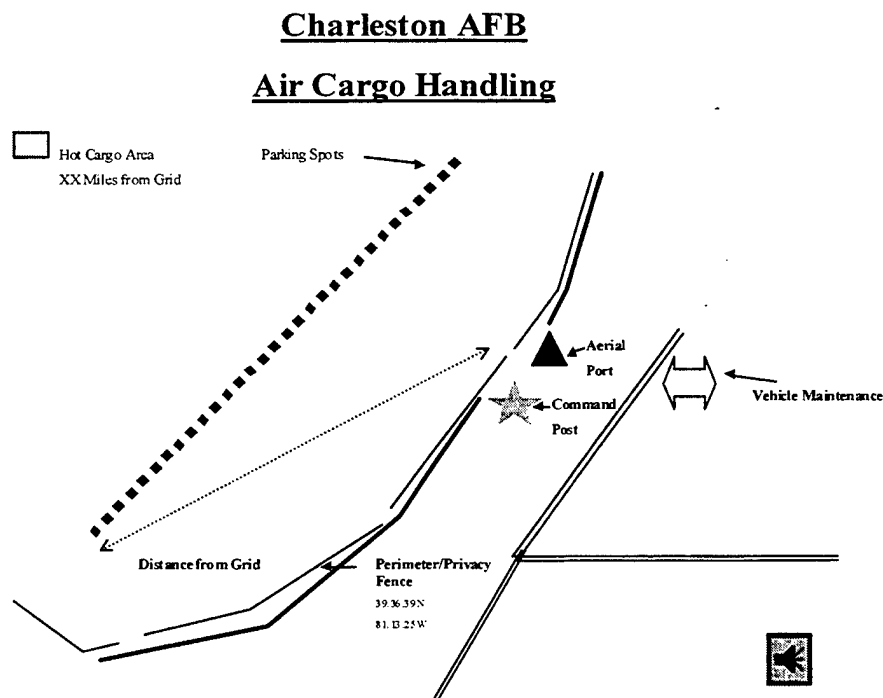


Figure 2-2. Representative Cargo Off-load Area

One of the physical movement technology concepts, the wheeled pallets, was not simulated. The concept was sufficiently new to prevent a good estimate of the time it would take to deploy the wheels on each pallet, and that time would heavily influence simulation results.

2.7 Concept Ranking

Once four of the physical movement technology MHE concepts were explored and simulated, the ACHSC team met to discuss all that was learned about all of the physical movement concepts, and then rank order them on the following measures of merit:

- Rapid Deployment: the amount of cargo that could be processed through the debarkation site in the first three days of deployment, as revealed by the simulation.
- Deployment Footprint: the number of pallet positions required to transport the MHE.
- Technical Risk: Feasibility With The Current State Of The Art
- Manpower Requirements During Deployment: The amount of manpower precluded from performing other tasks while aircraft are being unloaded.
- System Operating Cost: procurement and development cost.
- Utility In An Austere Environment; i.e., whether the MHE would have other usefulness besides its primary task.

Two of the five MHE concepts were each considered in two cases of load-carrying capacity, so there were seven total options to be ranked by each of the team members. A rank of seven meant the concept was most favorable; a rank of one met the concept was least favorable.

The rankings were summed into a total score and only the most obvious patterns were noted. Since the rankings were subjective (based on the expertise of each team member) and non-parametric (based only on rankings) we did not look for quantitative verification via statistical tests. In many cases the evaluators disagreed substantially, as revealed by similar summed ranking scores. In other cases, however, some clear preferences in ranking stood out, and those were noted.

Advanced Cargo Handling System Concepts

3. Results

3.1 Problem Areas in Current Air Cargo Handling Operations

After reviewing the notes and interview data of the field study, the ACHSC team compiled and discussed the information gathered. Problems with current operations were evaluated for severity and general applicability, then were prioritized and grouped. The issues and observations deemed significant were:

- Communication and Information Distribution Issues (section 3.1.1)
- Scheduling and Planning Issues (section 3.1.2)
- Training Issues (section 3.1.3)
- Cargo Issues (section 3.1.4)
- Materiel Handling Equipment Issues (section 3.1.5)

3.1.1 Communication and Information Distribution Issues

It is imperative that aerial port personnel know what they should be doing, as well as the status of equipment for which they are responsible. Producing and distributing information efficiently can help these personnel to best perform their job. However, there are issues that must first be resolved.

3.1.1.1 Problems with current information systems

The fundamental problem with the current information systems used by the Air Force is that there are too many interdependent systems that do not communicate efficiently with each other. The information systems are also hard to access, difficult to use, and not universally available.

Even when confining the scope of interest to major systems that support cargo movement, there are many interdependent information systems (See Figure 3.1). Over time, different systems have been inserted to support evolving information needs. However, recent advances in computer and communication technologies make it feasible to satisfy the demands of the users we interviewed by providing a smaller number of fast, user-friendly, common-interface systems that efficiently communicate with users and amongst themselves. In fact, the Air Force is already taking a step toward this approach by attempting to replace the C2IPS (Command and Control Information Processing System) and the APACCS (Aerial Port Automated Command and Control System) with GATES (see Figure 3.2). The GATES (Global Transportation Network) approach, being developed by the Standard Systems Group at Gunter Annex of the Montgomery AFB, AL, is presently being tested at Charleston AFB, SC.

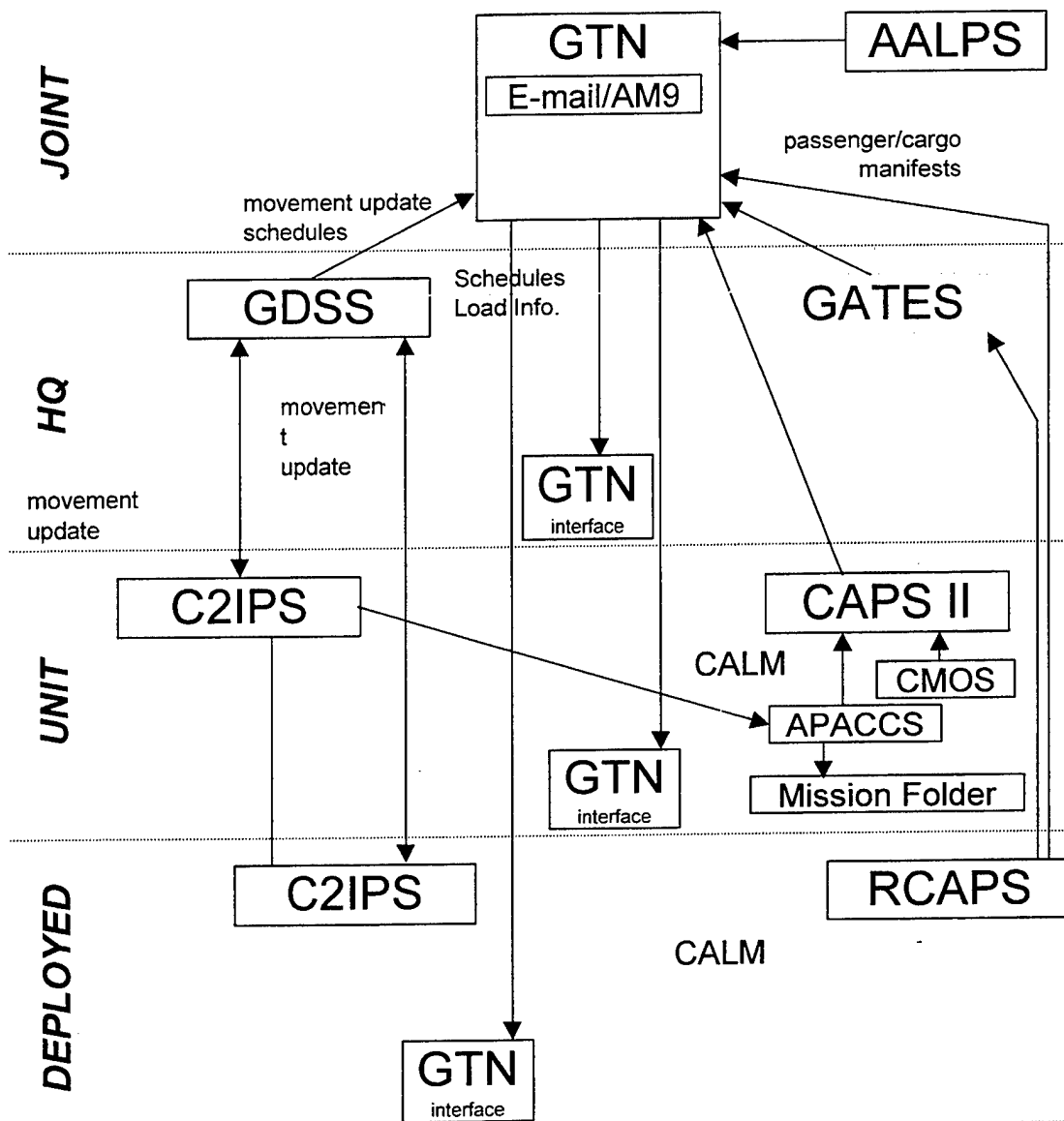


Figure 3-1. Air Mobility Command Information Systems – Present State

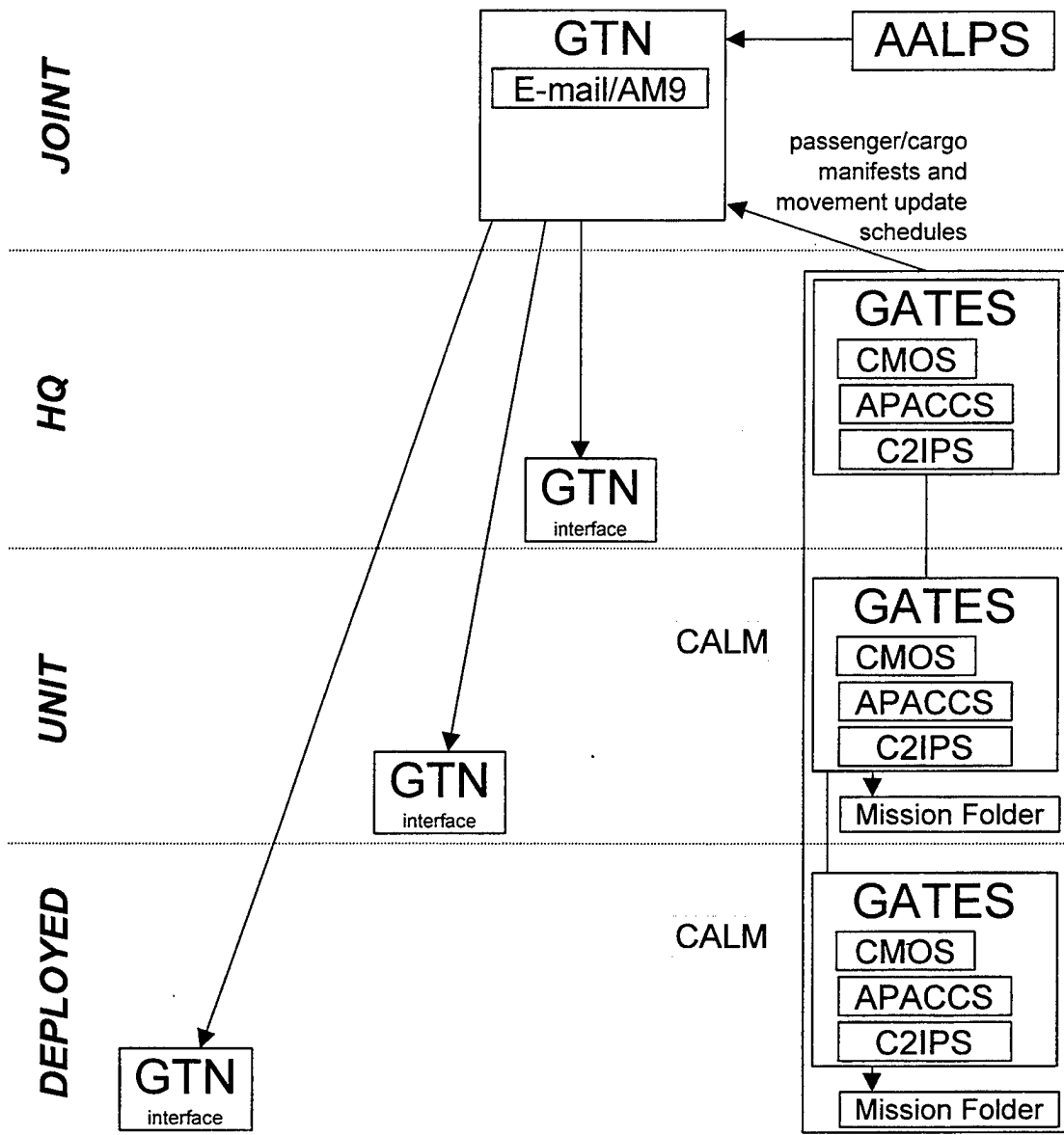


Figure 3-2. Air Mobility Command Information Systems - Transitioned State

One potential advantage of reducing the number of information systems related to cargo movement is that problems arising from unsuccessful information flow between information systems could be mitigated by managing data within a smaller number of systems. Presently, the C2IPS feeds information into the GDSS (Global Decision Support System) and the APACCS. The C2IPS primarily includes mission-tracking information, while the APACCS is an aerial-port automated-processing communications-system. The GDSS is similar to the APACCS, but is more globally accessible. It cannot trace missions, but can track cargo Tracking Control Numbers (TCNs) via mission folders. The flow of information from the C2IPS to the GDSS and the APACCS should be smooth, but several problems have been noted.

First, users may experience duplicate details in recipient information systems. For example, a trip with multiple legs in the C2IPS can be automatically transformed into multiple trips in the GDSS. Knowing this risk, a burden is put upon information controllers to verify that the C2IPS information was transferred

correctly. If it was not, they must then spend the time to find and remove all extra trips, and adjust the remaining trip in the GDSS so that it represents the cargo transfer actually made. A factor complicating the identification of duplicate information in recipient information systems is that duplicate information may contain false attribute information. During the information transition, details are literally force-fitted into the recipient information systems. If the attribute information being sent does not make sense, or breaks certain rules, it will be randomly modified in such a way that it will be accepted. This feature accounts for falsely identified trip and aircraft number attributes.

Second, data may not always be received by recipient information systems. For example, in-transit visibility information does not always make it to the GTN from the CAPS (Consolidated Aerial Port Subsystem) system, via the GDSS. Users we interviewed referred to these occasions as "ITV clogs." Once again, this situation requires effort to be spent verifying that data was sent and updating recipient information systems when it was not. Unfortunately, we learned that sometimes data must be re-entered a number of times to linked information systems before it is accepted into all desired information systems. This behavior breaks a fundamental rule of good database design, which protects users from entering the same information multiple times in the same or different locations.

Another potential advantage of moving toward unified information systems is that communication and refresh speeds (i.e., data currency) may be increased. Users we interviewed complained that some systems are slow, especially during peak use times. This could present a problem with respect to delay codes, which are displayed in the Command & Control Information Processing System (C2IPS) within 15 minutes of departure if the C2IPS is not told that schedule activities are proceeding as planned. Another problem was that if a number of people attempted to use the GDSS locally, information would be displayed with a time differential (delay in reporting) and, in some instances, would disappear from the displays. In addition to standardizing the information systems, reducing or unifying the number of the information systems may encourage wider use of these systems. Presently, some aircraft cargo on-load sites do not possess the GTN or the C2IPS. Aircraft cargo off-load sites accepting cargo from these locations may not get information from inbound aircraft. Also, information systems do not currently involve all persons who are part of the cargo movement process. The next generation of information systems should include the participation of personnel closest to the movement of cargo.

A shared concern of many users we interviewed is that the information systems need to be made easier to use. This includes the provision of better front-end user-interfaces that are linked to the user's job. Our interview data contains complaints of users who do not like scrolling through numerous menus to get to their job interface. If the solution includes a number of systems, they should ideally have similar interfaces and they should behave similarly. Users were less than enthusiastic about embracing another new information system if it imposed a different interface from what they already know.

3.1.1.2 Over reliance on voice communication

Most often, voice communication is utilized to relay status queries. Voice communication, whether accomplished in person, by two-way radio, or by cellular phone, is an expedient form of communication for the sender/inquirer. An attractive feature is that it does not require an infrastructure to support it. For these reasons, it is not likely to be abandoned. However, based on our interviews and observations we learned that there are problems with voice-based communication. First, it places a burden on the recipient/respondent. Persons most likely to receive status queries are those who are performing the work being questioned. Voice communication interruptions restrain personnel from completing their work. However, it is a necessity in some cases. In these situations, hands-free communication devices should be considered. A factor that can exacerbate this condition is status uncertainty. Uncertainty about the status of a job increases the frequency with which status queries are executed.

A second problem with voice communication is that generally it serves only one individual, when, potentially, a number of people could benefit from responses to a status query. For example, numerous individuals in the Logistics Operations Center chain of command could benefit from the answer to a question from one of its staff. Unfortunately, in the one-to-one voice communication approach, the recipient/respondent will likely field queries from each of them individually – accounting for a large percentage of time spent off the job. This is exacerbated during surge periods, because higher-ranking individuals or Crisis Action Team personnel will increasingly be interested in obtaining status reports, effectively making themselves additional layers of supervision that must be supported. Another example of when extra coordination is required is to support the transportation of special loads, such as distinguished visitors, prisoners, FBI personnel, mission capable cargo, or ammunition. Also, customs and/or agriculture notifications may need to be made.

Finally, there is a problem with data currency. Because there are a number of persons who possess knowledge about the status of a person or job, and because not all of them obtain and provide simultaneous updates (or even updates from the same source), each could present a different account of status to the same query when asked. This could cause guidance conflicts. For instance, two different lines of authority could provide conflicting guidance to a ramp worker, based on different status report information from different sources.

3.1.1.3 Key people need to be co-located

Although the two primary forms of communication about cargo movement are voice communication and information systems, we learned through our interviews and observations that it is advisable to co-locate certain personnel. Because the information they require is so similar, and because they can quickly benefit from observing each other's actions and decisions, the ramp controller, the port duty officer (see other names), and the information controllers should be positioned in close proximity to one another.

3.1.2 Scheduling And Planning Issues

Scheduling and planning issues emerged from our interviews and observations as another area of cargo movement operations in which improvements should be considered.

3.1.2.1 Load planning issues

Load planning consists of selecting, sequencing, and monitoring aircraft loads, as well as initiating and ensuring that all cargo manifests are prepared. Optimizing aircraft utilization requires efficient communication, information fusion, and decision support. Presently, planners suffer from "information gaps," and must perform their own background research to adequately perform their job. For example, when built-up load pallets are "bumped," planners must find "equivalent" pallets to replace pallets removed from built-up loads. CAPS II, which will be replaced by the Automated Air Load Planning System (AALPS) module of the GATES, can be used to identify and select pallets with similar heights and weights. However, there are several considerations for selecting cargo, including system entry time, movement priority, aircraft status, space availability, weight and balance factors, and hazardous material implications.

Making these considerations requires, among other things, that the load planners have an intimate and current knowledge of different aircraft designs, configurations, and limitations. In addition, load planners need to have timely information about aircraft status so that "heartbroken" aircraft (i.e., those requiring maintenance) are not loaded. This knowledge helps to avoid erroneously loading inoperative aircraft, unloading cargo from the broken aircraft, and re-loading the cargo onto an available and operational aircraft (i.e., "tail swaps"). Also, load planners who make inspections must be knowledgeable about

managing hazardous cargo materials. This is important enough that they receive certification and recurrent training. Additionally, load planners must be organized administratively. For example, inbound/outbound planning for explosives is generally required 14 days in advance of moving this cargo.

In fact, in order to perform their responsibilities, load planners must obtain and integrate guidance from a host of sources, including initial and recurrent training, reading documentation, keeping written forms, gathering information from voice communications, and using software programs such as the CAPS. It was conveyed to us during the interviews that it would be ideal if an information/decision support tool could be made available that could do everything required to pull a load and "put it on the aircraft" too.

Short of this aggressive implementation, it would seem logical to provide decision support tools for load planners that bring together all of the information they require in one platform/interface. For example, it would be helpful if cargo preparation guidance (e.g., checklists, regulations, etc.) and inspection paperwork (e.g., joint air load inspection forms) could be presented and linked together in an automated configuration. Stored information from the inspection could then be used to prepare weight and balance calculations and initial load plans. Additionally, the same mechanism providing this capability could also present load details to load planners soon enough to keep the schedule. To complement such a tool, better cargo labeling and identification techniques could contribute to quicker inspections, as well as cargo in-transit visibility (see Cargo Issues, section 3.1.4, below).

3.1.2.2 Scheduling constraints

Other factors that can constrain the movement of cargo are related to the resources needed to physically move cargo. These factors include the operating hours at the airfield to which cargo will be transported, special events during which cargo is not moved (e.g., transportation of the deceased), the duty limitations and rest requirements of cargo movement team members, and the duty limitations and rest requirements of maintenance personnel. Although these scheduling constraints are less likely to affect AEF deployments, they are nonetheless factors that generally affect the efficiency with which cargo can be transported.

Another aspect of load planning relating to scheduling constraints is that it requires preparation time for events, including consideration of the number of personnel that should be scheduled on shifts to manage planned loads. A potential competing rule is that, to the degree that mission priorities permit, workload should be spread out to the extent possible. Finally, scheduling cargo movements should not be performed too early; in order to accommodate the movement of additional cargo identified at the last moment.

3.1.2.3 Sequences of events

A sequence of cargo movement events (SOE) is listed in the C2IPS, and is accessible by different cargo movement workers via different C2IPS interfaces. However, this sequence is not always followed strictly. One reason is that all personnel may not have the most current information about cargo movement priorities. The consequence of a priority change is that it causes a progressive ripple effect throughout the remainder of the sequence. Everyone who is not aware of changes in priorities is at risk for performing inappropriate activities to ensure that an event, which has changed in priority, is accomplished next. It is hoped that the Computer Assisted Load Manifesting (CALM) system will assist with load planning and re-planning when the SOE changes.

However, personnel may benefit from the provision of a tool that displays sequence information at a lower level. For example, activities, goal information, processes, and delays could be presented as a way to direct the accomplishment of events. Likewise, information about the status of activity

accomplishment could be retrieved using this same display mechanism. Such a tool may help different sections keep to the scheduled sequence, as well as keep abreast of temporary priorities such as quick order tasking.

3.1.2.4 Cargo transport and off-load optimization

One of the duties of load planners is to consider the availability of equipment that supports cargo on-load operations. Another is to consider the ease with which cargo can be off-loaded. However, reviewing MHE availability that can be used to off-load cargo, as a way to plan aircraft loads or sequence aircraft off-loading, is not presently done by anyone. The speed with which cargo can be off-loaded could potentially be optimized by knowing the MHE availability at the receiving off-load zone. This information could be used to help determine the airflow schedule and/or load plans. Another tool that optimizes off-loading operations would be a loadmaster decision-support tool. This tool could provide off-load location-specific details that would help the loadmaster determine the most efficient plan for off-loading cargo at the next off-load location.

3.1.3 Training Issues

Some of the forms of job guidance mentioned by interviewed personnel included: documented policies, training guidelines and other training documentation, apprenticeships or on-the-job training (OJT), briefings, checklists, and experience. Among these forms of guidance, the most frequently called out, and most relied upon, form of job guidance was experience. Several factors facing the Air Force provide challenges for training personnel to perform jobs that support the transport of cargo.

3.1.3.1 Short-term on-the-job for many personnel

The cargo handling field experiences rapid turnover. Many are mobility augmenters. This is a function of the recently imposed "lean" approach to staffing Air Force positions. Unfortunately, around the time augmentees learn their jobs they are rotated to another location. Their posts are often filled by less experienced people. Second, opportunities within the civilian job market are enticing.

3.1.3.2 Promotion of inexperienced personnel

Another consequence of personnel turnover across the diverse range of Air Force transportation jobs is that unqualified or inexperienced personnel will be promoted into positions they are not well prepared to perform. For example, a master sergeant from a motor pool may suddenly become an aerial port supervisor. Personnel pushing cargo for many years are not necessarily gifted with supervisory and planning skills. Once again, if the promotion of inexperienced personnel is not a phenomenon that can be restricted, a method for rapidly training these personnel is imperative. Job aids would probably benefit these individuals as well.

3.1.3.3 Insufficient training

Because personnel are being utilized to perform multi-tasking, less of their time is available for training in each of those jobs. In interviews, we learned that several training courses have been shortened from the length of time dedicated to training in the past. As a result, individuals are forced to obtain expertise on the job – sometimes without adequate supervision to ensure that they are progressing toward proficiency. For example, short time reservists are sometimes put into the position of dispatching, without knowing the sequence of events. Also, we were told that drivers of material handling equipment (MHE) need

better maneuvers training, so that they do not crash expensive equipment into obstacles because they do not fully understand how the equipment behaves.

Another example is load-team personnel. When new to the job they cannot possibly know all of the numerous aircraft limitations for each aircraft type from which they will load and unload cargo (e.g., roller limits, aisle clearances, height restrictions, load-shorting requirements, how to manage heavy loads and odd-shaped loads, etc.). Even more lengthy training courses do not teach everything there is to know. For example, the two-week course that certifies aircraft services personnel on hazardous materials only educates them on how to behave in optimum conditions.

The risk of insufficient training is that cargo movement personnel will break things out of ignorance, or make poor decisions that could jeopardize the safety of fellow cargo movement personnel or themselves. Because traditional methods of classroom training are limited in scope and must be shortened, alternate forms of training, such as distributed training and/or portable training tools, should be considered. Since there seems to be an expectation for OJT, portable job aids seem to hold promise.

3.1.4 Cargo Issues

A number of issues related to the cargo itself were identified through the process of conducting interviews and making observations.

3.1.4.1 Cargo identification and labeling

Cargo transporters need a more easily accessible and manageable identification system than is presently used. One of the minimum requirements of the new labeling system is that it should identify cargo by name, content, movement priority, shipper, recipient, and other data that help to uniquely identify the cargo (weight, dimensions, etc.). Such details could help answer questions about the cargo, such as where it is presently located, when it was sent, etc. It could also prevent situations in which aircraft are loaded in ways that exceed their weight and/or balance limitations, based on incorrectly labeled pallets. When labels are created, all required information would be checked to ensure that important identification details are not omitted. This would help to solve the present identification problem of cargo missing TCNs. It would also help to solve the problem of what to do with frustrated or inappropriate cargo.

Presently, this cargo sits in warehouses longer than it should, and consumes precious storage space. If a label-making device were available, it could be lent to users for whom the Air Force delivers cargo. Use of this device would help to standardize labels, and could also potentially serve as the mechanism by which users track cargo.

Label should be readable without requiring a relative line-of-sight situation between the label and the reader. Also, labels should be firmly affixed to cargo (either at the parcel, the pallet, or both) to ensure that all cargo can easily be identified. These requirements facilitate simpler pallet identification via scanning, and improve the time spent inspecting cargo loads. Presently, inspecting palletized loads is a difficult, time-consuming chore because parcels and, therefore their identification labels, can be hidden from the visual inspector. Even if a parcel is visible, it is possible that the label will be hidden, or at least positioned differently than the labels of adjacent parcels. Scanned cargo details can be electronically stored and sent along to users who need to know about it. For example, the electronic verification of cargo whereabouts can be queried to support in-transit visibility and prepare cargo recipients with better details of what they are going to receive beforehand. Pallet level labels should be re-useable so that when the composition of the pallet load changes, the label can be changed to reflect this without having to replace the label.

3.1.4.2 Problems with moving cargo for non-Air Force users

The Air Force commonly ships non-Air Force material. Often this material is inadequately identified. First, the identification labels can fall off and be lost if not properly affixed. Second, multiple labels describing different loads can be placed on the same parcel, causing confusion as to what the parcel contains. Third, the user can omit information from or provide wrong details on the label. A standardized label-manufacturing system could be employed to minimize these shipper integrity issues.

Shippers also neglect appropriate shoring, jacks, pumps, etc. for rolling stock. Shoring is required to secure low clearance stock. Often the user neglects to provide what is needed and load team personnel end up becoming occupied with locating the correct tools and accessories to secure user cargo. Finally, users are supposed to drain fuel tanks on rolling stock before entering the Air Force air cargo system. Often, the Air Force must purge fuel, introducing delays and additional workload at the aerial ports.

3.1.4.3 Non-standard/unique cargo issues

The Air Force is responsible for shipping everything from letter-sized mail to outsized cargo, odd shaped cargo, or extremely heavy cargo. Most private sector cargo carriers are limited in the size, shape, or weight of the cargo they can carry. For example, helicopters can only be carried in C-5 and C-17 aircraft, which are operated only by the Air Force. Yet the Air Force also air ships military mail, a mission that could be performed by commercial carriers. As well, because mail takes longer to process than other cargo, handling it discounts tonnage of cargo moved per time metric, a popular measure of the efficiency of Air Force cargo movement operations.

Additionally, the Air Force must transport hazardous materials. Properly transporting hazardous materials is more time consuming than transporting non-hazardous materials. Most private sector carriers cannot handle such cargo. For example, during the Kosovo operation it took more than two weeks for electric batteries to be transported from Korea to Ramstein AB, Germany because commercially chartered carriers refused to handle hazardous material. Another constraint upon the Air Force is that they must dynamically manage the movement of cargo with changing priorities. For example, a Colonel can "green sheet" a cargo item to ensure that it is identified as an immediate priority for movement and will be carried with the next military mission. The Air Force must accommodate such modifications in cargo movement priority through dynamic planning.

3.1.4.4 Cargo inspection tools are inadequate

Interview and observation data clearly indicate that cargo inspection tools and processes are inadequate and inefficient. The cargo inspection process could benefit from the development of an inspection tool. Presently, cargo loads must be "walked" (i.e., visually inspected) several times. This is necessary because the status of palletized cargo can change based on moving it. It can shift into an unsafe orientation or be inadvertently damaged by cargo loading equipment. Cargo can even shift on its own by settling over time. One of the dangers for departing aircraft is that leaky cargo can be loaded onto an aircraft, even though that cargo has checked out okay during load inspections.

An inspection tool could reduce the number of times that cargo must be inspected, reduce the amount of time spent inspecting the cargo, and also more reliably determine the status of cargo containment. A particularly useful feature of such a cargo inspection tool, as with the labels, would be that it would not require line-of-sight. This would simplify the problem of inspecting hidden parcels. It is likely that some visual inspection will still be required to catch insufficient packing, but hard-to-detect containment conditions would no longer require visual inspection methods.

Another example of an inefficient process is weighing pallets during cargo processing. This is a separate procedure in which pallets must, serially, be moved by forklift to a weigh station, and then back to the location in which the cargo previously resided. Weighing pallets might become a more efficient process if forklifts can be modified such that they incorporate reliable scales. This would eliminate the need for making extra transfers of cargo to and from weigh stations, as cargo can be weighed while it is being transported. Additionally, it is reasonable to expect that center of gravity and center of balance readings may also be obtained in this manner.

Another useful device would collect and provide all cargo movement paperwork electronically in a single interface. This could include paperwork that indicates what has been received via paper walkthroughs, information from the loadmaster, details that can be used to help ensure that the manifest is correct, and information needed to perform pre-coordination arrivals, such as paperwork for distinguished individuals. If this device were made to be portable, it could serve personnel who need to send and receive this information (such as the loadmaster, ramp controller, etc.) while they work in the ramp area. It would also increase the transmission speed of these details. It might make sense to package this tool together with the cargo inspection and/or cargo labeling tools.

3.1.5 MHE Issues

A number of issues related to material handling equipment (MHE) used to move cargo were identified through the process of conducting interviews and making observations.

3.1.5.1 Incompatibility of MHE and aircraft in the Air Force fleet

The biggest factor influencing incompatibility between MHE and aircraft being used is that much of the currently available MHE cannot load/unload wide-body Civil Reserve Air Fleet (CRAF) aircraft at forward locations.

Only two types of material handling equipment can be used to accomplish this task: 1) the Wide Body Elevator Loader (WBEL)/Cochran loader, and 2) the relatively new 60,000 lb. capacity Tunner loader. The biggest problem with the WBEL/Cochran loader is that it consumes a large amount of time to build up and tear down for transport. However, it is also cumbersome to load and unload when being transported. It requires wooden planks to protect it from contacting the ramp during on/off-loading. Further, it requires a minimum of two missions to deliver or remove it. Also, WBELs only load or off-load cargo from aircraft; they do not transport cargo. Because WBELs are in short supply, sending them out is contingent upon the amount of workload they will support. Smaller missions are less likely to acquire WBELs.

The Tunner is an improvement over the WBEL because it requires little if any time to build up or tear down for transport, it does not require specialized loading equipment, it can be transported in a single mission, and it can quickly move six pallets at a time. In the future, the Tunner will be complemented by the 18.5-ft. vertical reach Next Generation Small Loader (NGSL). It will have a 25,000 lb. loading capacity via three pallet carrying positions, will require no specialized loading equipment or preparation time, and will be capable of operating on rough terrain.

3.1.5.2 Shortages of miscellaneous loading equipment

A common problem identified by interviewed personnel working at the sites we visited was shortages of miscellaneous loading equipment. We have defined this equipment to include pallet nets, shoring, ramp extenders, dunnage, and any other equipment used to assist with on- or off-loading cargo and equipment

from aircraft. These materials are to be provided by the user when the Air Force is transporting equipment for them. However, in practice, few users provide all of the required loading equipment.

Even when the Air Force is transporting cargo for itself, there are shortages of necessary loading equipment. For example, load teams sometimes find themselves short of pallet nets, which are separate from the pallets they contain. One reason for the shortage is that there is no designated storage location for, and no organization plan for, unused pallet nets. Another is that these nets become unusable over time due to age and weather. Another example is dunnage. It tends to get hoarded by bases because it is useful for many purposes, and units want to avoid being caught short. Each piece of dunnage is supposed to be accounted for. However, because it is not serial numbered or otherwise tagged, it is difficult to know to whom it belongs.

3.1.5.3 MHE maintenance issues

Maintaining and repairing MHE can be challenging, especially at deployed locations. Two of the issues we learned about were the difficulty with procuring parts, and the lack of service guidelines.

In the past, military supply was good for obtaining day-to-day types of parts and COPARS (Contractor Operated Parts Stores) were good for all other part types. However, military supply has closed, making the procurement of day-to-day parts difficult. A standardized method for obtaining replacement parts is needed. When deployed, maintenance will often attempt to procure parts locally. However, acquiring parts for older MHE can be difficult whether deployed or not. A factor that exacerbates this situation is that maintainers often do not know where hard-to-find parts have been procured previously. No record keeping system exists for this purpose and maintainers do not have time to keep track of where parts were obtained.

Another contributing factor is that supplier lists can contain bad part numbers and/or omit OEM references. If the part cannot be procured, or another interchangeable part used, maintainers are sometimes forced to make replacement parts themselves. This problem has the potential to worsen. Newer MHE like the Tunner are complex pieces of machinery with many parts. Unlike the older Oshkosh 40K loader, many of the parts are not interchangeable. Obtaining service information for older MHE suffers from the same types of constraints. Getting sufficient documentation on older MHE can be difficult. Also, records regarding the way a maintenance procedure was previously done are lacking.

3.1.5.4 The 60K Tunner loader

The Tunner is the newest MHE being operated by the Air Force. Tunnors are more difficult to maintain than other MHE because they are more complex - a liability in deployed scenarios. Maintainers would prefer basic, modular-series MHE designs. The procurement of parts is also an issue for the Tunner. Because it has so many unique parts, repair shops must go to the supplier for replacements. Compared to forklifts, the delivery of parts for the Tunner is much slower. Some parts, like for the steering control system and the platform rollers, were originally made by a 3rd party equipment manufacturer that has gone out of business. These parts cannot even be obtained through the supplier. Another factor that strains the parts issue is that transportation readiness spares kits (collections of spare parts that support MHE for 30 days of operation) are no longer being purchased due to budget cuts.

An indicator for performance of the Tunner is maintenance planning. Preventative maintenance is being performed twice as often as originally planned, and scheduled maintenance is being performed ahead of time to prevent the need for unscheduled maintenance. It may be that this behavior is preventing the Tunner from breaking more frequently. The components most susceptible to breakage, we were told, are the Tunner's hydraulic components (hoses, seals/fittings, and motors). Some unique characteristics of the

hydraulic system are that there are no shut-off valves, the hydraulic runs are not independent (only the pumps have redundancy), and there are numerous size hydraulic lines that are not interchangeable (like the hydraulic lines on the 40K loader). Probably one of the more questionable design characteristics, however, is that the hydraulic fittings are not flared like most hydraulic systems. Instead, a thin gasket seals these fittings and it must be tightened with the correct torque to avoid the seal leaking or blowing out.

Another characteristic of the Tunner is that it is susceptible to damage from dirt and sand. When it performed in desert deployment settings, sand was found to clog injectors and other parts of the air system. After a certain amount of foreign debris enters the air system, a failure in the steering control Foreign debris ingestion has been found to occur when the trundle valve sticks open. The temporary solution for this problem is to replace the air system trundle valve once every three weeks.

Two other apparent, but less critical, issues for the Tunner are vehicle abuse by inexperienced drivers and weak platform end-rollers. Vehicle abuse, which is believed to stem from insufficient operator training, may contribute to the reliability problems of the Tunner. The outcome is that the operator bumps the Tunner into things because they are not familiar with the turning characteristics of the vehicle. The platform end rollers are believed to break frequently because of the construction material selected. Normally platform end-rollers are constructed of steel, but the rollers on the Tunner are constructed of pot metal – presumably to save weight. These rollers fracture when the platform (which is aluminum mounted to a steel frame) flexes.

3.2 Technology Review

A literature review and interviews with technology experts produced some concepts that might improve cargo handling. These are described below:

- Containerization (3.2.1)
- Packaging (3.2.2)
- Hydraulics (3.2.3)
- Polymer Products Design (3.2.4)
- Smart Card Technology (3.2.5)
- Cognitive Systems (3.2.6)
- Transportation Systems (3.2.7)

3.2.1 Containerization

Commercial shipping has long since gone to containerized cargo transport. The AF cargo handling system relies on pallets. Cargo is tied down with nets to a standard floor or platform that can then be slid into and out of an aircraft cargo bay by means of a standardized roller system. Rigid containers completely enclose the cargo to secure it, and therefore provide a more efficient use of aircraft cargo space.

The AF has considered changing to a containerized system, but has decided the changeover would be too costly. The 463L cargo system includes an investment in some 180,000 pallets, and there is a need to retain ability to move outsized cargo. Nevertheless, for most cargo movement under most conditions, a containerization system would offer a significant increase in efficiency.

In particular, a major manufacturer of pallets, AAR Cadillac Manufacturing, manufactures a series of military-compliant containers using the 463L pallets as their floors. We can use this as a baseline to compare the advantages and disadvantages of a containerized system compared to pallets:

3.2.1.1 Containerization advantages

- Durability of cargo. Cargo is less susceptible to MHE damage, vandalism, weather damage, and general movement or shipping damage.
- Security. Containers can reduce pilferage.
- Efficient cargo handling. At aerial ports of embarkation, pallets are typically broken down, sorted, stored, and built up for shipment. Ideally each container would be shipped from source to user, door-to-door without breakdown. Containers could be weighed and cleared only once at the source.
- Labeling. Containers provide for easier mounting and protection of tracking devices such as radio frequency tags, bar-coded labels, or documentation.
- Multi-modal use. Containers can efficiently transfer cargo to and from other modes of transportation such as flatbed truck or rail car.
- Special handling. Specially designed containers could more easily provide special handling when needed for cargo such as explosives, perishables, or liquids.
- Less documentation required in route.
- More throughput. Case studies have shown that more cargo can be carried per aircraft and it can be moved on and off more quickly.

3.2.1.2 Containerization disadvantages

- Storage and backhaul. 52 pallets – the number typically carried on four C-141 aircraft – when empty and stacked for backhaul, take up the space of a single AAR Cadillac container.
- Tare weight. While 13 empty pallets weigh 3900 pounds, 13 empty containers weigh 22,880 pounds. This increases required fuel by 3%, shortens aircraft range for a non-refueled C-141 by 660 nautical miles, increases aircraft takeoff and landing distances, and decreases aircraft weight carrying capacity.
- Space efficiency. Several different sizes of container are necessary to optimally use the space available in some cargo aircraft, while pallets fit into everything.
- Durability of the containers. Containers by their nature are more susceptible to damage than pallets. Forklifts can damage the sides while excess weight can be placed on top deforming their shape.
- Cost. Each 463L pallet costs about \$1000 while each AAR Cadillac container costs approximately \$6500.

For an AEW deployment, the efficiency at which they can be off-loaded and the amount of cargo they can carry could outweigh their disadvantages of cost, backhaul, increased fuel requirements, etc.

3.2.2 Packaging

Packaging for the current ACH system is of two types: vendor and 463L. Vendor packaging is usually not tampered with by ACH personnel unless there is evidence it is not sufficiently protecting the materiel. 463L packaging consists of tying down materiel onto pallets using netting designed for the purpose. If the Air Force adopts a containerization system for air cargo transport, new packaging concepts will become relevant for placing materiel inside the containers.

Material used for packaging can include films, non-wovens, coatings, paper and paperboard, inks, adhesives, foams and polymers. Current technology for graphics and security includes various printing technologies, holograms, micro-printing, invisible inks, and micro-encapsulation. Packaging must be environmentally friendly, meet design life goals, withstand temperature and humidity, function under varying atmospheric pressure, protect against UV exposure, be lightweight, and meet standards of permeability and strength.

Packaging is usually custom designed for the specific item being transported, and is often disposable after single use. Any packaging adopted for AF ACH must be easily reusable and easily adapted to a diverse range of items. For example, Styrofoam popcorn is easily reusable but it may not hold items rigidly enough. Pallet sized shrink-wrap is adaptable to a diverse range of items, but is not reusable.

New packaging concepts will likely not be needed for continued use of the 463L transport system, but may become useful if containerized cargo is ever adopted.

3.2.3 Hydraulics

MHE operates under hydraulic power. Hydraulic systems enable highly flexible application of force and movement. They, nevertheless, have problems. Hydraulic fluid is toxic to the environment and hazardous to the skin. Disposal, cleanup of leaks, and handling during routine service take special care. Hydraulic systems can be vulnerable to sand, dust, water, and corrosion. They can also require high maintenance for critical components such as seals.

Current research in hydraulic systems includes successfully adapting them to an extreme environment, such as for the manipulator arms of deep submersible undersea explorers. This involves water, pressure, corrosion, and temperature stress. Research continues on water-based hydraulic systems. These have proven to be reliable, safer, and easy to maintain, and almost always near an infinite supply of fluid. But they require new designs for a wide range of components such as cylinders, rotary actuators, valves, pumps, and motors. Other research has been in high-volume mixing and delivery systems for chemical foam.

Hydraulic systems are so prolific that it's easy to take their functioning for granted, yet MHE requirements are more severe than common usage. The knowledge exists to make the hydraulics for the next generation of MHE more reliable and durable, if all of the unique functional requirements of MHE are considered in the early design stages.

3.2.4 Polymer Products Design

Advanced materials based on plastics, elastomers, polymer matrix composites, and metals are used in industrial and aerospace applications that must resist failure over their useful lives. Such materials often experience large deflections in service. The relationship between deformation, strains, and stress is often non-linear, time-dependent, and affected by load history. Yet designers of critical products such as pressure valves, diaphragms, gaskets, seals, tubing, etc. must be able to predict their performance or failure under a wide variety of conditions.

Battelle has developed extensive facilities to measure and model the reaction of these materials to stress using special finite element algorithms. The performance of critical components of MHE could be better predicted using these models during design.

3.2.5 Smart Card Technology

Today personal credit cards and membership cards carry a magnetic strip that contains basic information about the owner, which can be automatically read during use. Smart cards can hold much more information in a more sophisticated memory and can update that information during use. Could smart cards be used as ID tags for cargo? Not only could they contain labeling information, they could log the travel and inspection history of the cargo.

Smart cards are limited in functionality, however, to being read via physical contact. To be useful in an aircraft loaded with cargo on pallets or in containers, they would have to be remotely query-able and updateable. While there are remotely readable ID technologies like bar codes and RF tags, they can carry relatively little information. Remotely readable smart cards might be sufficiently complex to negatively impact reliability and cost.

3.2.6 Cognitive Systems

The concept of decision aids for scheduling airlift flights and for coordinating ramp activities was mentioned during field interviews. Cognitive systems draw on the new discoveries being made in neuroscience, cognitive science, and biology, as well as the rapid advances underway in computing technology. Cognitive systems are commonly implemented with neural networks, fuzzy logic, evolutionary computation, and expert systems, but also draw upon the wealth of existing experience in statistics, classical control theory, signal and image processing, and artificial intelligence. While traditional computing technologies are quantitative in nature and emphasize precision and sequential order, cognitive systems exploit the tolerance of imprecision, uncertainty, and partial truth found in biological systems to achieve tractability, robustness, and low cost solutions to decision making challenges.

A second relevant application for cognitive systems is in equipment prognostics – predicting when an essential piece of equipment will probably fail based on its individual history of use and stress.

3.2.7 Transportation Systems

3.2.7.1 Global Positioning System (GPS)

GPS receivers can be used to track the position of a vehicle or cargo movement resources (MHE, cargo, or even personnel) in real time. Through a small antenna, the GPS receiver collects data from a requisite number of Navstar satellites, and calculates at a given date and time, a position fix and other performance variables. Navstar is a constellation of satellites maintained by the DoD (Department of Defense). Although the signals from these satellites are purposely degraded for civilian use, military-grade receivers can be used to get “pin-point” accuracy.

3.2.7.2 Geographical Information Systems (GIS)

Geographic Information Systems can be used to display real-time or collected GPS data. This position data can be overlaid onto any other interesting geographic data, such as a flight-line ramp area, including parking spots, staging areas, etc. Powerful geographic information systems require a PC, or workstation platform. However, lighter versions of GIS systems can be made to operate on less sophisticated platforms (e.g., moving map displays have been tied directly to GPS receivers).

3.2.8 ACH Subject Matter Expert (SME) Reactions

3.2.8.1 The interview brought along an example of a personal digital assistant (PDA) being used on another Battelle research project dealing with transportation systems. It had GPS, GIS, and communications capabilities. Interviewees said such devices could be used for:

- Calls to the unit
- Calls for medical emergencies
- Equipment tracking – inputting received items
- Bar-coding activities
- Load planning (to see next pallet ID)
- Army load planning in the field
- Manifest delivery and billing (you would no longer need COM guys to set up webs)
- Monitoring personnel, equipment readiness, and inbound in-transit visibility
- Information support specifically tied to the user's job (you would no longer need to scroll through 10 menus to get to your job's interface)
- Supporting both normal and contingency operations with a single system to avoid retention problems during contingency deployments.

3.2.8.2 Other technology comments:

- Descriptions of the DARPA/Battelle tank prognostics program using artificial neural networks yielded acknowledgement that such a system would be useful.
- Rapid packing/collapsible containers would be useful.
- The single pallet mover might alleviate some of the deployment footprint required by MHE to be carried in the first plane.
- Headsets and voice recognition technology would allow more efficient operations.
- Laser alignment guides could speed up MHE approaches to aircraft and cargo while improving safety.

3.3 Technological Opportunities to Improve ACH

The ACHSC team performed unconstrained "brainstorming" of technological approaches to solving ACH problems, based on the totality of its relevant experience of that point in time. The ideas were then grouped together by the subjects they addressed. They fell within three general topics:

- Expert Systems and Decision Support (3.3.1)
- Improved Cargo Inspection (3.3.2)
- Improved Materiel Handling Equipment (3.3.3)

3.3.1 Expert Systems And Decision Support

3.3.1.1 Expert systems based on studying experienced personnel could be created to train additional duty personnel and new supervisory personnel in ACH operations.

3.3.1.2 To prepare personnel for supervisory tasks, simulations of aerial port operations could be created as a set of computer games for ACH personnel to play during idle times. Real-world challenges such as resource allocation, communication and coordination, human error, and widely varying incoming traffic rates could be explored in a problem-solving game that could be more interesting than dry course work. Personnel could compete for higher scores while developing skills for future responsibilities.

- 3.3.1.3 Operators of MHE receive training, but not enough to avoid mistakes in equipment operation. A handy and concise electronic checklist for equipment operation could avoid problems.
- 3.3.1.4 Decision support systems and better information presentation could aid with the following tasks, but just don't require two-strippers to update them.
- Prioritizing loader use, cargo assignment
 - Scheduling/planning
 - Crew planning/manning
 - Load configuration optimization
- 3.3.1.5 *Autonomous* monitoring of loading status could be provided for supervisors. One low-tech approach would be a closed-circuit video network linked to aircraft cargo bays, ramps, loaders, etc.
- 3.3.1.6 A decision-support tool could support the off-loading of inbound aircraft based on things such as weather conditions, holding area capacity, etc.
- 3.3.2 Improved Cargo Inspection
- 3.3.2.1 The following status information of air cargo is of use to ACH personnel:
- Verification of content as initially labeled by the supplier or packer
 - Confirmation that the materiel is packed correctly
 - Confirmation that the materiel is tied down properly within the aircraft after loaded
 - Leak detection
 - Materiel that is hazardous
 - Materiel that requires special handling (VIP personnel, body bags)
 - Correct cargo weight and balance
- 3.3.2.2 A hand-held inspection aid would be ideal. It would query electronics labels, verify contents, and provide guidance for special circumstances when needed. This concept is referred to as a "tricorder" alluding to the broad functionality required of it
- 3.3.2.3 A system to automatically identify cargo at the parcel and pallet level would avoid many mislabeling mistakes. Such a tool would automatically update cargo manifests. It would perhaps work with the Computer-Assisted Load Management system, which would at once output a manifest and a load plan.
- 3.3.2.4 Remotely sense-able pallet tags would greatly speed up cargo inspection. The tags would list any relevant special interest items such as hazardous material, flammable items, items containing liquids, items with unusual weight or balance, or items containing explosives.
- Ideally items would be tagged the furthest upstream – at the manufacturer. When labeling identical items in quantity there would be less likelihood of confusion and mistake.
 - The more complete the remotely sense-able labels, the less sophisticated could be the tricorder reading them. Within a cargo bay a tricorder could query, "Where is (fill in blank) type of item?" and all appropriate tags would flag.

3.3.3 Improved Material Handling Equipment

3.3.3.1 A simple, inexpensive cargo lifter:

- Would include a turbo-wrench to help with stuck pallets (a powered Johnson bar)
- Would allow side loading
- Would have integrated capabilities to measure cargo weight and size.
- Would operate on rough terrain
- Would be stackable for deployment

3.3.3.2 A hand-guided walkable motorized pallet pusher could inexpensively transport cargo to the holding area.

- Motorized pallet jacks already exist in the warehouse, but not on the flightline. They can move single or double pallets at one time.

3.3.3.3 A pallet tram & tug could transport many pallets at once to the holding area without tying up an expensive loader.

3.3.3.4 Alternative loader/transporters could reduce purchase and maintenance costs.

- Attach a gurney type lifting mechanism to a HMMV
- Attach cargo pallets to US Army "mules".

3.3.3.5 Pallet-mounted Rubbermaid-type containers could provide miscellaneous storage for smaller items. Large containers could contain color-coded, inside compartments with individual access.

3.3.3.6 Pallets could be modified for improved usability.

- Pallets with integrated and retractable nets. (They would have to be tough.)
- Pallets that collapse when unloaded.

3.3.3.7 Remote health monitoring could streamline logistics support requirements for MHE. A Radio Frequency link would automatically provide information to suppliers when maintenance problems arise or are anticipated.

3.4 Advanced Air Cargo Handling System Concepts

After generating these unconstrained ideas, Battelle and TASC further investigated the technologies required to implement them, and concepts already in use in commercial cargo handling. Commercial analogs were important for any concepts to be simulated, to aid in credibly predicting concept functionality and performance.

After considerable further discussion among the ACHSC team the following nine advanced technology system concepts were chosen for exploration. The first four concepts use information/communication technology, the latter five use physical movement technology. Of the latter five, four were analyzed in a discrete event simulation and compared against predictions of performance for the Next Generation Small Loader (NGSL). The final concept, wheeled pallets, was sufficiently new to prevent a reasonable estimate of critical task times, thus preventing a credible simulation.

Information/Communications Systems

- Personal Digital Assistant Network
- Cargo Inspection Aids
- Electronic 3D Planning Aid
- MHE Prognostics

Physical Movement Systems

- Simple Lifter and Walkable Pallet Transport
- Self Loading Multi-Pallet Loader
- Elevating Dolly
- Mule Pallet Carrier
- Wheeled Pallet

3.4.1 Personal Digital Assistant (PDA) Network



Figure 3-3. Personal Digital Assistant Concept

3.4.1.1 Description

The PDA would be a combination handheld digital book, Palm Pilot, and wireless fax machine, using already existing technologies integrated in a unique way to support the ACH mission.

A local network of PDAs could be employed to support more efficient air-land aircraft off-load operations. Conceivably, this network and its devices could also support on-load operations, but that will not be explored here. The local PDA network would be designed to serve a number of work centers simultaneously. Work centers are teams of personnel who have distinguishable common roles and responsibilities associated with air-land cargo off-load operations, and who are required to coordinate with other work centers regarding these operations. Work centers could include, but are not limited to, ATOC equivalents, air crews*, load teams, RampCos, MHE maintenance, A/C maintenance, command and control element, border clearance agencies**, etc.

***NOTE:** Because of the transient nature of aircraft and their air crews, PDAs may be assigned to air crews at the time of their arrival and retrieved prior to their departure. Additionally, if the need is proven, it is conceivable that the PDA network could transmit and receive information to air crews via alternate means.

****NOTE:** Because border clearance agencies may be situated in remote locations, they may need to be excluded from the PDA network.

Each work center would have access to one or more PDAs. A work center information leader would be responsible for using the work center PDA as the primary means for sending and receiving off-load operations information to other work centers within the network. Also, a PDA network administrator would need to maintain the network, maintain the PDA equipment (this would not include activities such

as recharging batteries – this is information leader's responsibility), and ensure the equipment is appropriately keyed (see "Between work centers communication aid", section 3.4.1.2.2, below).

The goal of the PDA network is to support more efficient off-load operations in three ways: 1) it would act as the primary method of unified communication of status and scheduling information between work centers, 2) it would facilitate the collection and completion of within-work center information related responsibilities, and 3) it would serve as a portable training aid.

3.4.1.2 Usage

3.4.1.2.1 Within-work-center information-collection-and-completion aid

The PDA approach offers at least two features that support users who must communicate status and scheduling information in support of cargo off-load operations. The first feature is a chronologically ordered set of input forms. These input forms may either take the form of a simple electronic checklist (if only the completion of listed activities are to be reported) or of forms that are specifically designed for reporting details about the information activities. The names of both types of input forms would be provided in a hierarchically (if necessary) and chronologically ordered table of contents as a memory aid for determining what activities must next be performed.

Only information-input forms that apply to the work center currently using the PDA would be displayed. The table of contents would also display the completion status of listed information input forms. A bookmark feature would allow users to specify where they left off in the table of contents and on individual information input forms during interruptions. Additionally, users could make modifications to previously input information without having to complete an entirely new form.

A second feature, which could be accessed from either applicable information input forms or from a stand-alone location in the table of contents, would be the provision of electronically stored reference documentation. Such documentation might include regulations, military guidance, calculation tables, or even work-station-specific notes. This information could be stored in the internal or removable memory onboard the PDA, or could be transmitted to the PDA from a PDA network server on demand. The idea here is that up-to-date reference materials could be accessed on demand via the same device used to facilitate the completion of required information activities.

3.4.1.2.2 Between-work-centers communication aid

A set of business rules could be employed to automatically extract from completed within-work-center input forms (and submitted modifications to those forms – however that would be made) and display information that should be communicated to other work centers. The PDA network would ensure that only work centers that could utilize extracted input information would view this information so that no superfluous information is forced upon work centers.

Different views may be required to display different types of information. For example, completed information activities of one work center that must precede those of another could be listed in a time-stamped activities sequence view. Alarms could be employed to warn information leaders when a new status message is submitted. Ideally, they could be coupled with instructions regarding how this affects their work center (i.e., one or more activities are now required and must be done by X time). A different set of views could be provided that allow PDA users to proactively review the status of other work centers (e.g., aircraft maintenance, load team, etc.). The possible views might be dependent upon the work center identity.

3.4.1.2.3 Portable training aid

PDA's could also serve as portable training aids. A "practice" mode could be engaged, temporarily disabling only the transmit functions of the PDA. All other within- or between-work-center functions would remain enabled. This would allow inexperienced users the opportunity to familiarize themselves with the informational demands of the job, as well as the tools available to help them perform the job tasks. This would include the ability to access training and reference documentation, such as regulations, guidance documents, and even workstation notes. Because of the portability of PDA's, they could be loaned to personnel being trained, and used in a time and place of their convenience. Personnel training on the job could then monitor PDA's in operational mode, once they have familiarized themselves with its functions and features.

3.4.1.2.4 Other notes about the PDA network

The network administrator to the work center that they serve would key PDA's.

In the case that a PDA became inoperable, a signal would be sent to (or the lack of a signal detected by) the network administrator that indicates a repair is needed. This indication is also provided to other network users so that they know that alternate communication channels must be used for this work center.

3.4.1.3 Potential For Mission Improvement

The PDA network is not intended to entirely replace the traditional means for coordinating and communicating required off-load associated information. Instead, it would serve as the primary source for doing so, with traditional channels serving as secondary sources in case PDA devices or the PDA network becomes inoperable. This approach relieves presently congested communication/coordination channels (i.e., phone, two-way radio, etc.) and helps to reserve them for addressing questions and making confirmations. Further, it helps to ensure that the amount of communication/coordination is reduced by broadcasting up-to-date status and sequence information to the applicable work centers. Some additional benefits to using the PDA network are:

- PDA's are mobile and can be ruggedized for use on-the-job.
- PDA's in this network provide work center users with job aids for completing and reporting information activities (i.e., chronologically ordered checklists and input forms, table of contents, with completion status details, bookmarks, access to reference documentation, automatic equipment status communication, etc.)
- Once the system is developed, the individual PDA's would likely be relatively inexpensive.
- PDA's are not susceptible to the frequency congestion experienced by aural information transmission media

The following are information activities/responsibilities that must be performed by ATOC Information Controllers (ICs) that would be facilitated with a PDA network:

- The IC provides current approach information
- Maintains knowledge of aircraft maintenance status
- Maintains knowledge of aircraft configuration changes
- Maintains knowledge of parking spots
- Assigns tentative availability times
- Provides aircraft load briefing (note: must have loadmaster equivalent available if not phase II)

- Provides hazardous cargo notification
- Provides hazardous cargo briefing
- Maintains knowledge of passenger deviations
- Maintains border clearances
- Coordinates with CCC
- Collects in-bound documentation via the ATOC rep.
- Provides outbound documentation
- Handles brief life-and-death urgency shipments
- Coordinates special category passengers
- Allowable Cargo Load (get from loadmaster/figure)
- Provides transportation delay reporting

ATOC information controllers could use the table of contents to access and review the maintenance status page periodically (as time permits), and would be warned when a new event was placed in the activity sequence that required review (or perhaps a course of action on their part could be suggested). As required, information controllers could make inquiries and sequence/status modifications via the PDA network and by phone/two-way radio if needed.

3.4.1.4 Current Technology

The following are brief descriptions of commercially available products, or products in development, that could be key to the design, construction, and operation of a PDA network such as the one described above.

- PDAs (personal digital assistants) are an excellent example of a commercial-off-the-shelf (COTS) product. They would serve as the portable terminals of the PDA network described above. Common features of interest that can be found on PDAs include back-lit touch-screen interfaces, long-life rechargeable batteries, expandable memory, communications capabilities (e.g., cellular, infrared, serial, etc.), developer-friendly operating systems, and ruggedized/weather-proof casings.
- Methods and rules employed in presently developmental electronic checklist software could be adopted by the graphical user interface (GUI) software designed for the PDA network. Useful functions employed by this software would include user-friendly navigation and display techniques for checklists and forms (especially useful if checklists or forms are inter-related), sophisticated search logic for electronic documentation, and other features, such as book marking and automated calculations, which help users avoid excessive "hand-jamming."
- A network, such as the Aircraft Communications Addressing and Reporting System (ACARS) VHF-based aviation information network, is needed to serve as the data link for the PDA network. ACARS, the largest data link network, is timely, reliable, capable of processing multiple sources and types of information, and accessible worldwide. These are requirements for the PDA network.

3.4.1.5 Research Issues

Because many of the products and technologies required to make this concept a reality already exist in the world, albeit to varying degrees of maturity, the largest challenge for developing an application for this concept is successfully integrating COTS technologies. Another challenge will be to find the optimal balance of available technologies. For example, what medium of communication is the cheapest, most reliable, and most secure method (cellular, satellite, VHF, etc.). Finally, it could be the case that

commercially available equipment does not satisfy every requirement of the PDA network. For example, although PDAs are becoming rich with desirable features, there is no guarantee that all of the required features will be available in the same unit. Units satisfying most of the PDA network requirements may not be rugged enough for field use. In this case, modifications to an existing PDA, or the development of a new product, may be required.

To combat the challenges and potential pitfalls of this concept, a graduated approach to development should be followed. The first step in proving this concept would be to develop the functional and design requirements for such a network. An exhaustive equipment search would then be performed to identify COTS equipment that satisfies the detailed requirements. Next, equipment development/modification recommendations would be made, as required. Finally, a PDA network would be built and tested in an operational setting to prove the concept.

3.4.2 Cargo ID And Inspection Monitors

3.4.2.1 Description

Remotely Readable Item Identification Tags. Attached to each item or packaged lot of items inside a pallet would be a query-able identification tag. It would identify the package contents and contain information about the manufacturer, the quantity of items within, and whether the contents included non-standard materiel, hazardous cargo, or materiel requiring special handling. The latter specifically would include identifying materiel that is:

- Fragile
- Highly flammable
- Explosive
- Containing high voltages or currents
- Containing liquids
- Containing contents under pressure or vacuum
- Containing corrosive material
- Containing environmentally hazardous material
- Having an unusual center of mass/balance
- Possessing a high sensitivity to humidity and temperature changes

The inspectors would carry a hand-held remote tag-querier, colloquially referred to as a tricorder, which could operate alone or be bundled with other functions into a convenient portable digital device such as the PDA. The tricorder would page all the label tags within a specific range (in feet or yards) and accumulates the responses. It could thus tabulate all the contents within an aircraft cargo bay, or within an isolated pallet.

Remote Cargo Status Checker. This cargo-condition inspection device would not require the opening of pallets or container to inspect the condition of their contents. It would specifically check to ensure that the pallet contents are:

- Packed for shipment according to specification.
- Currently intact. Are there leaks? Has the balance shifted?

The technology might include X-rays or nuclear magnetic resonance or bionic smellers. If possible, it would be part of the portable tricorder carried by inspectors. It would search for signs of breakage, leakage, contents shifting, and cargo contamination.

3.4.2.2 Usage and Potential or Mission Improvement

In order to off-load and on-load cargo to aircraft, those handling the cargo must know what the cargo contains, its condition, and its destination. This information theoretically arrives before the cargo to facilitate load planning. But it is often incomplete, not current, not sufficiently detailed, or wrong. Cargo handlers must therefore inspect the cargo to ensure it is safe for further transport and to log the progress of its shipment.

Remote Cargo Status Checker. Certain types of materiel require special attention or special handling to reduce the risk of damage to the cargo itself, or of collateral damage to neighboring cargo, personnel, and the transporting aircraft. Were the labeling of the materiel inside the pallets 100% reliable and were the packing 100% effective at preventing cargo damage, inspections would not be needed. In reality, loadmasters and crew chiefs are not content to trust the words of others.

If the inspections are performed superficially or skipped altogether, there is no impediment to cargo throughput until a catastrophic failure. In a catastrophic failure, the cargo can no longer be transported because it has or will damage its surroundings. This causes a bottleneck until the problem cargo is dispensed from the unloading/loading process and collateral damage is repaired. This type of occurrence is hard to simulate accurately.

Comprehensive time-consuming inspections of the cargo during the unloading/loading process to verify pallet contents and their conditions require the pallets to be opened for visual inspection. This is time consuming. The above two technologies would eliminate the requirement to thoroughly visually examine the contents of each pallet.

Remotely Readable Item Identification Tags. The vendors of the items would affix the remote identification tags. Since the vendors will be manufacturing many copies of the same item rather than aggregating a diversity of items into a pallet, there is less chance of mislabeling. Furthermore, any mislabeling would be limited to just one type of item at a time rather than a whole pallet of supplies.

3.4.2.3 Current Technology

Remotely Readable Item Identification Tags. There are several technologies in use today that might be adapted to remotely readable ID tags, but none fully meet our requirements. Smart cards can carry much information and even store new information, but they require physical, if not visual, contact to read. Conductive paint on item packaging can code stock numbers, but it must also be read with physical contacts.

Radio frequency tags are remotely readable, but they carry relatively little data. A radio frequency tag consists of a stretch of wire that acts as a $\frac{1}{4}$ or $\frac{1}{8}$ wave antenna along with compensating electronics. The electronics are passive; they store the energy from the querying radio signal and then reradiate it with a coded number. That number can then be referenced to a database.

In order to confirm whether any of the materiel within a load of pallets fell into any of the special-attention categories listed above, an inspector would query a pallet or a cargo bay with his tricorder, a stock number would be read, then the inspector would have to log into a database containing all possible stock numbers. Such a database could reside in the tricorder if it could be frequently updated. This

remote labeling system would not provide for any unique descriptors about the specific items in front of the inspector (design changes, quantity, configuration, etc.) but it would allow instant determination of the type of contents inside.

Remote Cargo Status Checker. While there are a variety of technologies to remotely detect specific substances, there is no currently available technology that would detect general leaks of indeterminate kind, as an inspector would need to determine whether any breakage occurred. Without a remote status checker, any cargo labeled for items that contain liquids or hazardous materiel would have to be visually inspected inside of the pallets, as they are now.

Two technologies do appear promising, however. The first is the use of ultrasound to determine a sealed container's contents without exposing personnel. NILAD is a system developed by Battelle for the Army. The unit's backpack computer allows operator control entirely from the calipers. In a matter of seconds, the operator can determine whether the liquid in a container is harmless, or poses a potential hazard. NILAD can also be utilized during waste site clean up to classify exposed liquid containers or during treaty verification inspections to monitor stored materials. Again, the inspector would have to make contact with each container, but would at least not have to open any.



Figure 3-4. NILAD

The second technology is an advanced re-locatable radiographic inspection system that's portable, yet large enough to role pallets through. The technology works similar to a large scale airport x-ray machine and could examine the position and shapes of loads within pallets. The pallet transporters would move the pallets to and through the inspection device.

3.4.2.4 Technical Risks And Research Issues

The technical risks for these candidate technologies are all moderate. The main challenge will be to identify and inspect pallets and their contents from a comfortable and precisely definable distance. The technology to do so is not here yet.

3.4.3 Electronic 3D Planning Aid



Figure 3-5. Electronic 3D Planning Aid Concept

3.4.3.1 Description

The Electronic 3D Planning Aid is a combination simulation, training aid, and game for personnel to use during idle times. Often cargo handling personnel are augmentees, reservists, or newly promoted from positions requiring dissimilar skills. The cargo handling personnel have no way to rapidly learn the skills necessary to plan and manage air cargo handling.

The Electronic 3D Planning Aid would run on a computer and would include a discrete-event simulator like the one in this study. The resources and constraints of a deployed air cargo handling site would be simulated while cargo aircraft arrivals would be simulated in appropriate mixes at varying rates. Simulated personnel and MHE would have real-world availability. Information provided to the decision-maker (the player) would be of similar type, quantity, and reliability as is typically available within the unit. Level of difficulty could be tied to aircraft arrival rates, human error, equipment failure, or other variables.

Players would play individually but would earn scores, and therefore could compete with each other for higher scores. The games could be saved for later analysis and discussion with experienced personnel or instructors. There could optionally be a live component where the computer could display the actual status of things currently on the flightline.

3.4.3.2 Potential for Mission Improvement.

Personnel could get on-the-job training on an individual basis suiting their personal schedules. This system could lessen on-the-job or formal training requirements. Personnel could explore “what if” scenarios and better understand how their jobs are interdependent with others.

3.4.3.3 Current Technology

Development of such a computer simulation/game is well within the state of the digital art. Understanding and accurately representing the everyday flightline activities will be the challenge.

3.4.3.4 Risks and Research Issues.

A challenge is to make the game sufficiently fun to motivate voluntary rather than obligatory use. An appropriate development platform must be chosen. Accurately modeling real-world processes at the deployment site, including the typical confusion and error would require much data collection and review. Graphic presentation of the simulation must be carefully designed for the player. Efficient software support on site must be addressed. A complex issue is how to structure a sequence of levels of difficulty that logically coincide with the skills to be trained

3.4.4 MHE Prognostics

3.4.4.1 Description And Use

Whatever the MHE configuration chosen for an Airborne Expeditionary Wing deployment, only the minimum required will be taken in order to minimize its deployment footprint. MHE would ideally be perfectly reliable, but in reality backup is needed for times when specific MHE is not available, and maintenance resources must also be deployed to return any failed equipment to operation. Deployment planning, therefore, could be more precise if MHE failures could be better predicted.

Traditionally, equipment failures are predicted statistically for a model series as a whole. But recent research funded by DARPA through the U.S. Army and performed by Battelle is investigating failure predictions of individual equipment items as a function of the items' individual histories. The equipment item is fitted with sensors that measure the unit's environmental exposures, operating history, and internal conditions. This information is then processed with an artificial neural network, which have been trained on real-world failures.

3.4.4.2 Current Technology

Such systems are currently being investigated on tanks and could likely be adapted to MHE with sufficient field data for training the supporting artificial neural networks.

3.4.4.3 Potential for Mission Improvement

Knowing probable future failures could lead to better planning of which MHE units to deploy and which spare parts and tools to take along. Once deployed, real time prognostics would continue to anticipate the need for maintenance parts and supplies. As failures do occur, the prognostics could aid the diagnostics. With better baselining of MHE performance, extended warranties may be possible. Also, improved operating procedures might be prescribed for individual equipment items.

3.4.4.4 Risks and Research Issues

The development of an artificial neural network for predicting behavior of a new type of equipment requires research into what sensors to draw data from and how best to integrate those sensors into the equipment. The neural net must be trained with real data from the field – the more data, the more accurate it can become. This involves data collected on individual equipment items over a period of time.

This would preclude rapid deployment of a new prognostic system or applying MHE prognostics on a new design until it had some history in the field. Another issue is where the system should reside -- at the deployed site or back in the US. If at the deployed site, the efficient training of personnel to use the system is an issue.

3.4.5 The Simple Lifter and Walkable Pallet Transport

Off-loading cargo from aircraft at an airfield requires two main tasks: (1) removing the cargo from the aircraft cargo bay, and (2) transporting the cargo off the flightline to a staging area. MHE called "loaders" do both functions while "lifters" and "transporters" each do only one. For this concept we combine a lifter concept with a transporter concept.

3.4.5.1 Descriptions

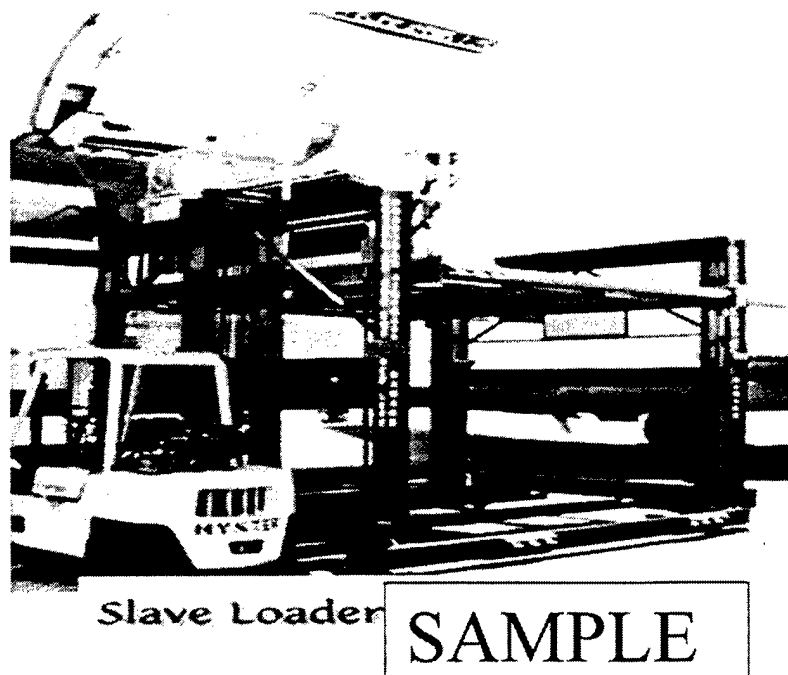


Figure 3-6. Simple Lifter Concept

The Simple Lifter. The simple lifter would be capable of rapidly lowering one fully loaded pallet (or the equivalent size and weight of unpalletized materiel) from any airlift aircraft, including those in the civil reserve air fleet (CRAF), to the ground or any position between the ground and the aircraft cargo floor level. It would have a roller system compatible with the military 463L system and could handle 463L pallets, Type V platforms, LD containers, and ISO containers. The simple lifter would have the capability to unload from either head-on or the side without being reconfigured. It would require no more than one person to operate it under any conditions. It could be towed over unprepared surfaces carrying one fully loaded pallet (or equivalent weight in unpalletized materiel). The simple lifter would require no assembly/disassembly to be deployed/shipped and would collapse such that at least three could be stacked one on the other. While thus stacked, the set of three could be rolled/towed into and out of airlift aircraft as rolling stock and would require no more than two pallet positions in the aircraft.

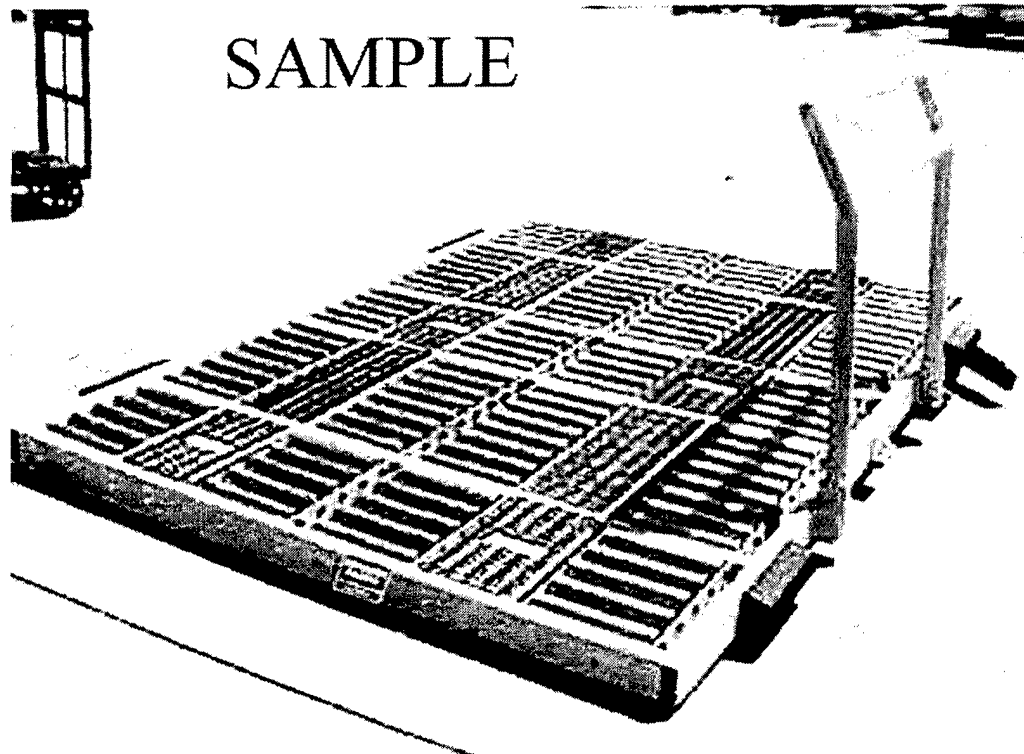


Figure 3-7. Walkable Pallet Transporter Concept

The Walkable Pallet Transporter. The walkable pallet transporter would be capable of moving two fully loaded pallets under its own power. It could move them across unprepared surfaces at normal human walking speeds while being operated by no more than one person. At any time the walkable pallet transporter would be able to stop, set its load on the ground, leave the load, and move away without the need for people (other than the single operator) or equipment to facilitate that activity. It would require no assembly/disassembly, although it may be collapsible, to be deployed/shipped. It could be stacked one on the other (or otherwise configured while fully assembled) allowing a minimum of 10 to occupy no more than two pallet positions in an airlift aircraft. The stacked or otherwise configured sets could move under their own power into and out of roll-on, roll-off airlift aircraft while being operated by a maximum of one person. The walkable pallet transporter would have 1000 hours MTBMA and 3000 hours MTBF.

3.4.5.2 Current Technology

The Simple Lifter could be based on a modified commercial SL-20 loader manufactured by Renmark Pacific of Los Angeles, CA. The SL-20 can handle one 463L pallet and lift it to the lower lobe of commercial aircraft or to floor level of military cargo aircraft (e.g. C-130, C-141, C-5, C-17). It could be modified to reach the main deck of wide-body commercial cargo aircraft. The SL-20 would require some disassembly to be airlifted. It has a mean time between failure of approximately 500 hours. Normal preventive maintenance, lubes, etc. can be performed by a qualified forklift mechanic. The SL-20 costs approximately \$50,000 (not including modification to reach the main deck of wide bodies and wheels that would allow it to be moved over rough, semi-prepared surfaces).

The Walkable Pallet Transporter would be a larger, slightly more complex version of walkable motorized dollies. It would have rollers for taking the cargo from the simple lifter, plus a means to secure the cargo in place. It would need a small amount of lift capability to raise and lower pallets from dunnage. It would also need a method of ensuring a four-corners view of the cargo and its environs by the operator/walker.

3.4.5.3 Usage

The SL-20 is moved to the aircraft by connecting it to a forklift, lifting one end slightly, and pushing it utilizing casters or the opposite end of the loader. It could be modified with wheels that would allow it to be moved short distances over rough, semi-prepared surfaces. It is operated by first connecting its hydraulic system to the hydraulic system of either a small (8K) forklift or a medium-sized tug using quick disconnect hoses. The loader is then operated by one person from the walkway on the loader itself. The SL-20 can lower a pallet from the lower lobe of a commercial aircraft in less than one minute and can raise it from ground level to the lower lobe of a commercial aircraft in less than two minutes. When loading/unloading is complete, the SL-20 is moved away from the aircraft using the forklift in the same manner as it was positioned. One simple lifter could load a series of walkable pallet transporters ferrying cargo from the aircraft to the staging area.

3.4.5.4 Team Evaluation And Potential For Mission Improvement

This combination of MHE might *increase* the unloading time of aircraft when compared to the use of a large-capacity loader, because of the additional cargo handling required between the lifter and transporter, and because speed of the transporter would be limited to 4 MPH – the speed of brisk walking. This combination was also ranked third poorest in manpower because many personnel would be tied up walking the pallet carriers the approximately one-mile distance between aircraft and holding area, and back. Because of the complexity of set-up, this combination was ranked lowest in rapid deployment factor.

Its advantages are lower cost and deployment footprint. The simple lifter and walkable transporter would be cheaper to manufacture and simpler to carry to deployed locations compared to a large capacity loader. Thus, many more could be deployed immediately. This might offset some of the disadvantages

3.4.5.5 Risks And Research Issues

The configuration of the walkable pallet mover for addressing safety and human factor issues would be the biggest challenge. Methods to speed up and refine the set-up at each aircraft should also be addressed. There are no technology requirements exceeding the state of the art.

3.4.6 The Mule Pallet Carrier

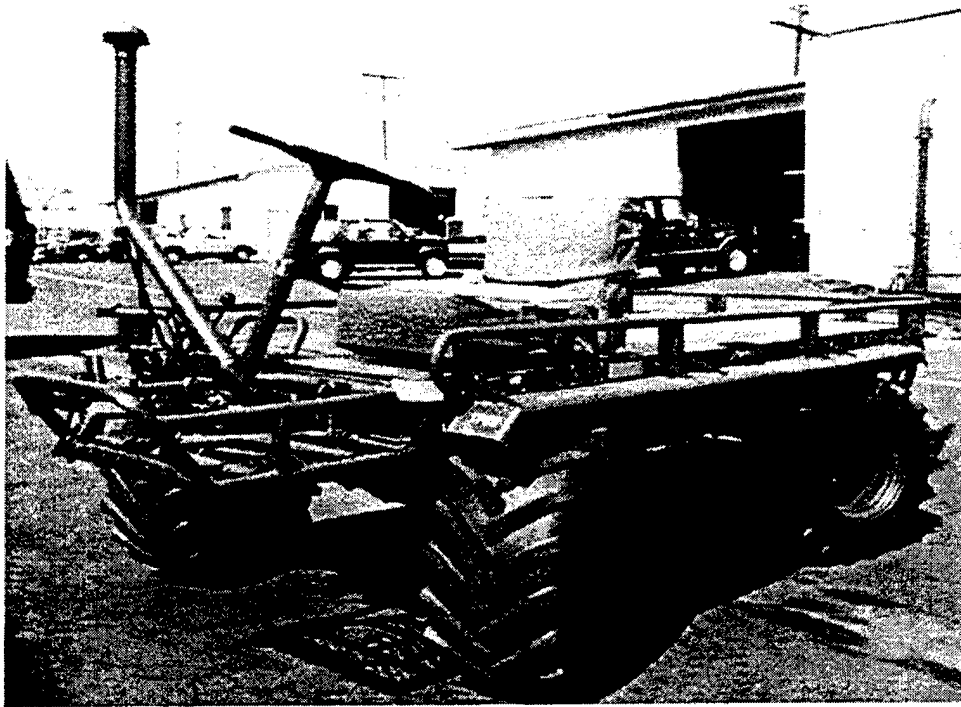


Figure 3-8. Mule Pallet Carrier Concept

3.4.6.1 Description

This unit would be a motorized all-terrain vehicle similar in design and operation to the U.S. Army Mule. The Mule Pallet Carrier would be capable of carrying one 463L pallet containing no more than 5000 lbs. of cargo over unprepared surfaces. It would have a cargo-carrying table that has a roller system compatible with the military 463L system and can handle 463L pallets, Type V platforms, LD containers, ISO containers, and rolling stock. The cargo-carrying table would be adjustable to the floor height of a USAF roll-on, roll-off cargo aircraft. It would be equipped with a self-contained capability for one person to lock or otherwise secure a pallet, LD or ISO container, or rolling stock to the vehicle without use of tools in two minutes or less. The Mule Pallet Carrier would be capable of driving onto and off of a USAF roll-on, roll-off cargo aircraft with a cargo door of sufficient size while carrying a fully loaded 463L pallet. It could be secured in an airlift aircraft for deployment/shipment while carrying the fully loaded pallet. Once secured, it would occupy no more than one pallet position. This may diminish maximum cargo capability of pallets so carried.

The Mule Pallet Carrier would be capable of sustained speeds of 25 miles per hour while carrying a full load. It would be operated by one person and have a multi-fuel engine capable of using all grades of aviation, diesel, and automotive fuels interchangeably without requiring adjustment to the engine. The Mule Pallet Carrier could be stacked on another Mule Pallet Carrier for deployment/shipment. The Mule Pallet Carrier has an estimated MTBMA of 1000 hours and an MTBF of 3000 hours.

After off-loading cargo, the mule pallet carrier could be reconfigured to perform other functions, such as tow wheeled cargo or load bombs. The mule pallet carrier would belong to the deployed unit, not the transportation unit.

3.4.6.2 Current Technology

The heart of the mule pallet carrier would be a common, small, multi-use, utility vehicle such as the Army M274 Mule. It would be modified with a means of carrying a pallet.

3.4.6.3 Usage

Every pallet to be shipped during an initial AEW deployment would be shipped on a mule pallet carrier. While it would be impractical to provide a sufficient number of carriers for every pallet to be shipped during the full duration of a deployment, their relatively low cost would make them practical for the time-critical deployment's first days.

3.4.6.4 Team Evaluation And Potential For Mission Improvement

They would provide three advantages: (1) providing close to optimal cargo unloading speed by turning every pallet into rolling stock, (2) providing versatile use for combat troops once they've completed their initial function as cargo carrier, and (3) the elimination of the need for transporting large loaders during early deployment. Additionally, they would be reusable for further pallet carrying if shipped back to point of embarkation. Consequently they ranked best in rapid deployment, footprint, and multipurpose use. In the simulation (below) they doubled the number of aircraft unloaded.

Their main disadvantage is that to achieve the rapid aircraft off-loading; there must be one person available to operate each carrier, or one person per pallet in the aircraft. Hence they rated poorest in manpower. Another disadvantage is the requirement for a forklift to off-load them at the holding area. Possibly they could be designed to self off-load, but that would impact their size and cost.

3.4.6.5 Risks And Research Issues

There is little engineering risk related to state-of-the-art technology, but there are nevertheless some research challenges. Primary is the configuration of the vehicle to (1) carry a pallet, (2) fit within a pallet footprint, (3) be reconfigurable to multi-purpose use, and (4) still be safe to the operator. Manpower issues must also be addressed. One could argue that until three days worth of cargo arrives, there will be relatively little for deployed personnel to do and therefore they would be available for vehicle operation. But that might change after the first aircraft was unloaded.

3.4.7 Self-Loading Multi-Pallet Transporter

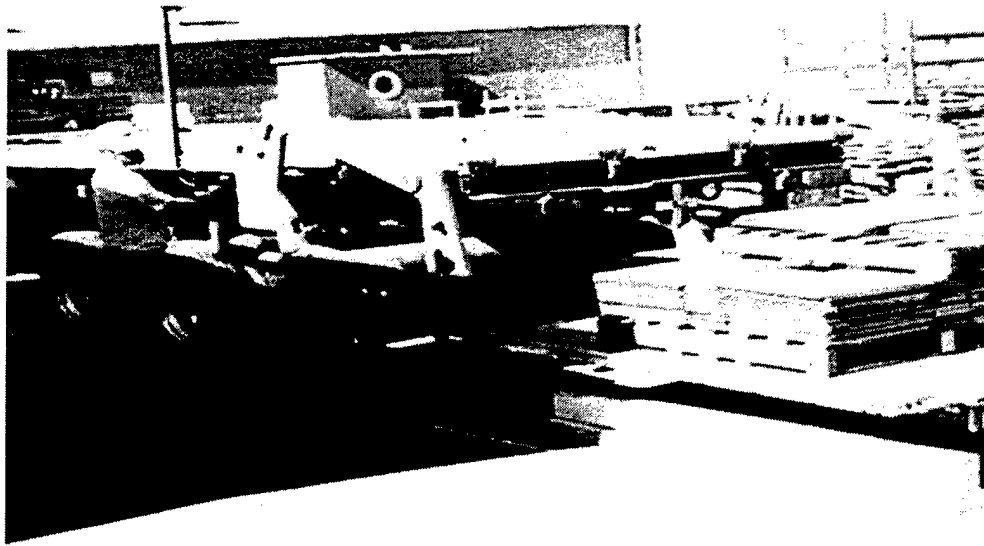


Figure 3-9. Self-Loading Multi-Pallet Transporter Concept

3.4.7.1 Description

The Truck, Aircraft Loading, Off Pavement (TACLOP) multi-pallet mover is a 54K loader capable of all-terrain operation. It has an integrated rear-mounted forklift that enables it to lift fully loaded 463 pallets from the ground to load/unload itself and it can transfer pallets to/from low-deck military airlift aircraft such as the C-130, C-141, or C-17. It can also transfer pallets to/from the C-5 in its kneeling position; a modification is available to enable it to transfer pallets to/from a C-5 that is not kneeling. It can be driven on and off all those aircraft while partially loaded and can be operated by only one person. It can carry five fully loaded 463L pallets on its main deck and an additional 4600 lbs. on the forklift.

TACLOP has 8-wheel drive as well as 8-wheel steering that enables it to maneuver both forward and in reverse as well as at angles. It has a commercial Perkins diesel, multi-fuel engine and is capable of achieving speeds of 15 miles per hour with a full load. TACLOP also has a loading winch and portable loading/unloading ramps. TACLOP costs approximately \$550,000, has an MTBFF of 900 hours, an approximate MTBMA of 350 hours, and is designed for a 20-year life.

For this study we're assuming both the original configuration of the TACLOP and a smaller configuration capable of carrying three fully loaded pallets plus what is on the forklift.

3.4.7.2 Usage

The self-loading multi-pallet transporter can perform all the functions of a lifter, transporter, and forklift. No other equipment is needed. Combined with its ability to carry over five pallets at once, it minimizes the time required to put MHE into place. Two transporters working sequentially provide very efficient unloading with minimal manpower requirements. During deployment the transporter would be driven off its carrier and be instantly ready to work.

3.4.7.3 Team Evaluation And Potential For Mission Improvement

Because a single operator could operate the loading, transport, and unloading functions of each TACLOP it was rated first in manpower utilization. It was rated second best in rapid deployment, and in the simulation it led to a modest gain in the number of aircraft unloaded.

Its disadvantage for an AEW deployment is its cost and size. It is sufficiently large to occupy an entire cargo bay of a C-141 during deployment. It, therefore, rated last in deployment footprint.

3.4.7.4 Risks And Research Issues

The required technologies do not push the state of the art. Because this loader is big and complex, its reliability is a constant concern. And if any function fails, the entire loader loses availability.

While it may simplify the off-loading procedure, the fact that each one requires the cargo capacity of an entire aircraft to transport must be traded off. Research should attempt to identify a more optimal, smaller size that better trades off footprint with manpower and cargo throughput.

3.4.8 Elevating Dolly

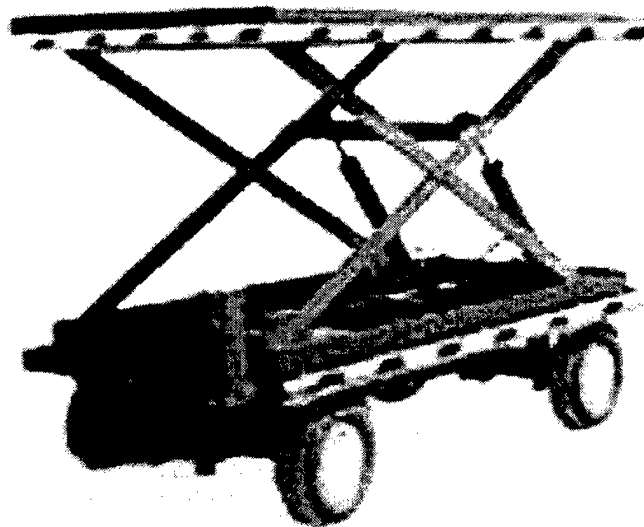


Figure 3-10. Elevating Dolly Concept

3.4.8.1 Description

The elevating dolly might best be thought of as a simple loader, or as a small, simplified multi-pallet mover. It would have a simple lifting mechanism and be self-powered. In its simplest form, it would be autonomous, not requiring operator control, except perhaps a termination points – at the aircraft and at the holding area. It could be self-guided by using a GPS receiver or, more simply, by following a guide wire that could be quickly looped across the ramp. However, an operator station might be used. In its simplest form, a forklift would be needed to unload them at the holding area. However, they might be built to be self-unloading, at the cost of increased complexity, cost, and footprint. The dollies would each carry one or two pallets. Many could be stacked for deployment in one or two pallet positions.

3.4.8.2 Use

The key concept of the elevating dolly is to stay relatively simple, enabling it to be cheap, reliable, and easy to deploy. That is, there would be sufficient numbers to set up an "assembly line" of transporters back and forth between the aircraft and holding area so that as soon as a loaded dolly leaves the aircraft, an empty one moves into position to continue unloading.

3.4.8.3 Current Technology

FMC's SGV2000 modular vehicle design might form the basis of an elevating dolly system. The vehicle starts with a standard control cabinet design concealing the latest electronic controllers and guidance systems along with the vehicle's battery. The rear of the vehicle can be fitted with a variety of attachments depending on the application. FMC currently offers six vehicle configurations illustrated below.

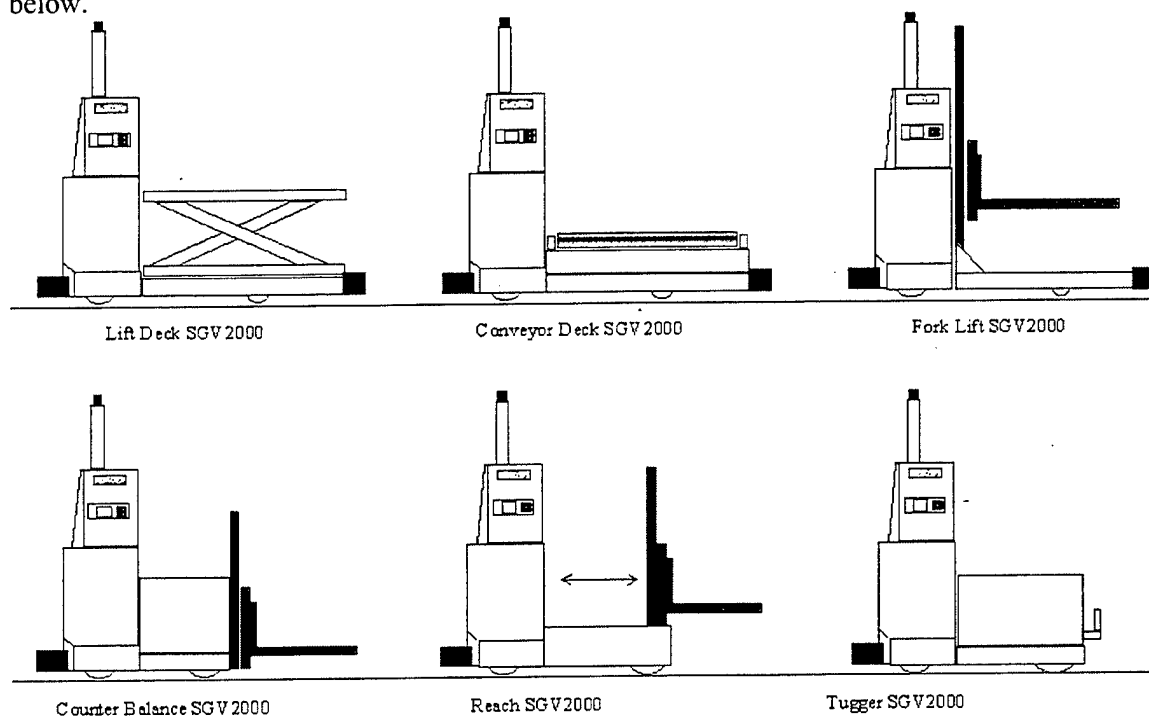


Figure 3-11. SGV 2000

Its mechanical features include:

- A. A large single front drive wheel capable of handling up to a 4000-lb. (1800kg) load.
- B. A modularly designed upper control cabinet to contain all electronics and a lower cabinet to contain the battery.
- C. The front of the vehicle stays the same for all applications; the rear changes according to function.

Its electronic features include:

- A. An off-the-shelf radio frequency modem card for reliable communication.
- B. A steering encoder for self-calibrating, accurate steering/driving-position feedback.

- C. A new laser-guidance system with a 115ft (35m) range and requiring fewer targets to navigate accurately.
- D. A user-friendly, menu-driven 1/4 VGA operator screen.
- E. An RS232 or USB port on the display to download the latest software directly from your laptop PC, or download the vehicle code directly from the host computer, via the RF modem card.

Its software features include:

- A. Includes new A+ code to move the vehicle around the plant. It is easily adjusted and quick to install.
- B. Compatible with computers running Windows NT® operating systems.
- C. Communication with the host via a new 2.4-gigahertz wireless local-area-network RF communication hardware.

3.4.8.4 Team Evaluations And Potential For Mission Improvement

The potential advantages of the elevating dolly would be significant procurement cost reduction, reduced deployment footprint, small manpower requirements for the autonomous version, and improved cargo throughput due to never having to wait for available MHE. However, the requirement to line up a dolly to the aircraft for each pallet or two removed might lengthen cargo-unloading time. The team ranked this concept middle of the road for most measures of merit. However it ranked lowest in throughput. The simulation (below) showed a reduction in cargo throughput, but it only assumed 10 dollies were in use. The increased unloading time was due to waiting for dollies to return from the holding area, a situation that could be avoided with more autonomous dollies.

3.4.8.5 Risks And Research Issues

One issue is how many dollies would be needed for “assembly line” efficiency under various ramp layouts. Another issue is whether they could be subsequently reconfigured for other uses. Also the terrain, speed, and lift requirements must be determined. The autonomously guided capability needs to be studied; safety and human factor issues are evident with so many small, autonomous units in action.

3.4.9 Wheeled Pallet Concept

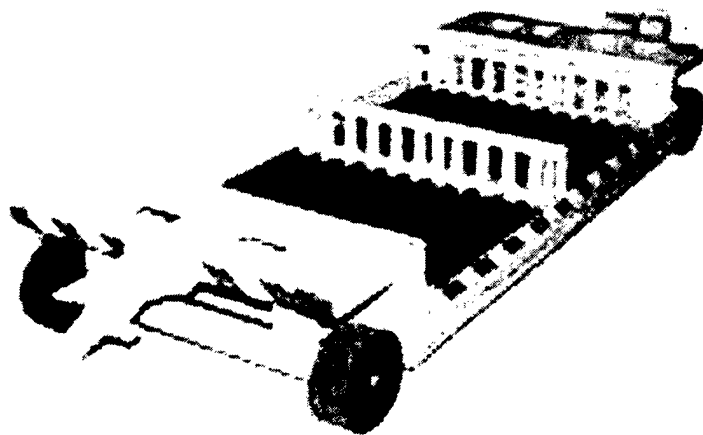


Figure 3-12. Wheeled Pallet Concept

3.4.9.1 Description

The wheeled pallet would be interchangeable with a 463L pallet, but it would have permanently attached, retractable wheels that, when extended, would allow it to be towed over rough surfaces. With the wheels retracted, the wheeled pallet would lock into existing cargo rails. The wheels would be quickly deployed with aircraft-supplied compressed air using pneumatic lifting technology. The pallets could then be towed off the aircraft to the holding area and stay on their wheels until time for return. The retractable wheels would somewhat reduce the total volume available for cargo on the pallet by approximately 15%.

3.4.9.2 Use And Current Technology

Such a system would eliminate the need to deploy large, expensive loaders; requiring instead only a few towing vehicles. Each wheeled pallet would require an additional couple minutes to deploy the wheels during cargo unloading, but there would be no time requirements for transferring cargo to a lifter, possibly a transporter, and then to a forklift at the holding area.

3.4.9.3 Rating And Potential For Mission Improvement.

Improvements would be gained in the low cost of procurement, reduction in deployment footprint, and decreased unloading time. However, manpower requirements might increase for operating the towing vehicles and deploying the wheels on each pallet. Consequently, the team ranked this concept best in footprint and operational cost, second best in development cost, but second poorest in manpower requirements.

3.4.9.4 Risk And Research Issues

The technical risk is low to medium. However, research would be required to determine how to remove a pallet if the wheels failed to deploy. The failed pallet could also block the unloading of others. The requirements for a backup system might offset the gains of the initial concept. Another research issue would be to lessen the increased manpower requirements. Perhaps the tugs could operate autonomously between the aircraft and holding area. A third issue is how best to integrate wheeled pallets into the current aircraft system. 463L pallets have always been hard to track because they are appropriated for other uses at the deployment site. The impact of the wheeled pallets not being returned might be less tolerable.

3.5 Concept Simulation

For four of the five physical movement technology concepts (i.e., those concepts for which we could credibly estimate task times) we simulated their effects on cargo throughput in the early days of an AEW deployment at a remote site. We also simulated the Next Generation Small Loader (NGSL) as a baseline concept. Currently in full-scale development and testing, it represents the current state of the art in air cargo handling concepts and equipment.

3.5.1 Scenario Assumptions (Also refer to section 2.6)

- The scenario focused on the first 24 hours of deployment with the goal of attacking targets within 72 hours, although two-day and three-day deployment progress was also explored.
- The scenario focused on the C-141 and C-17 aircraft mix as the most likely aircraft to be involved in initial deployment. Based on Air Force recommendations, 60% of the arrivals were C-141s and 40% were C-17s.

- The scenario addressed an austere environment in that there would be no prepositioned supplies, but that there would be an adequate length of paved runway. In the scenario were parking spaces for five aircraft (based on a RAND study) and a staging area one-mile from the parked aircraft (based on SME opinion). The rationale for these assumptions was based on combat aircraft receiving parking priority.
- One aircraft arrived every 30 minutes.
- Based on Air Force recommendations, 35% of the cargo was palletized and 65% was rolling stock. Mixes of 50% and 65% palletized cargo were also explored until the Air Force scenario was definitized.
- All future material handling equipment was available 21.5 hours per day – the current state of the art (i.e., as is projected for the currently-under-development Next Generation Small Loader.)
- Two forklifts each supported the unloading of the two MHE at the holding area. One would be picking up the cargo off the MHE while the other is depositing it. Additional forklifts would only speed the unloading a little, reasonably assuming transit time between the MHE and the drop point is only a small percentage of the total unloading time, and therefore additional forklifts would be wasting time in queues at either the MHE or drop point. Transportation of additional forklifts would also occupy precious transporter space.

3.5.2 Base Case

The simulation baseline case was two Next Generation Small Loaders (NGSLs) with a capacity of three pallets each. They represent the current state-of-the-art in MHE. The simulation flow chart in section 2.6 explains the movement of the MHE.

3.5.3 Simple Lifter-Walkable Pallet Mover

This concept assumes an unlimited number of walkable pallet movers available. This is realistic in that the equipment would be relatively inexpensive and have a small deployment footprint. However, this also assumes that many personnel would be available to walk the pallet movers until the AEW was sufficiently deployed to allow performance of their primary duties. The simple lifter would only need to be carefully positioned once at the aircraft, and positioning the walkable pallet movers at the simple lifter is no problem. At first five simple lifters were deployed at the ramp, one for each plane. The simple lifter unloads one pallet at a time.

3.5.4 Self-Loading Multi-Pallet Mover

Two self-loading multi-pallet movers were deployed at the ramp. They were treated as basically NGSL-acting MHE with the exception of the number of pallets they could hold. Two cases were simulated: in one case each mover could hold six pallets; in the other case, four. Since they are large and costly to transport in terms of precious pallet positions, only two would be initially deployed, one serving as a backup if the other breaks.

3.5.5 Mule Pallet Carrier

These basically turned all the palletized cargo into rolling stock. In the initial deployment, every pallet would be transported already attached to a mule so there will be as many mules as pallets. This provided for very fast unloading since there was no MHE to wait for. This concept assumed an unlimited supply of personnel to drive the carriers as needed.

3.5.6 Elevating Dolly

Each of these moves up to the plane, off-load a pallet or two, and take them to the holding area. Although simpler and cheaper in construction, they basically behave like an NGSL with one or two pallets. In this simulation there were 10 elevating dollies. Either they were autonomous in their transporting mode or sufficient personnel were available to drive them.

3.5.7 Results

The following figure shows the number of pallet positions processed during a one-day airlift for the four physical movement technology systems plus the baseline NGSL. Two of the concepts each had two cases.

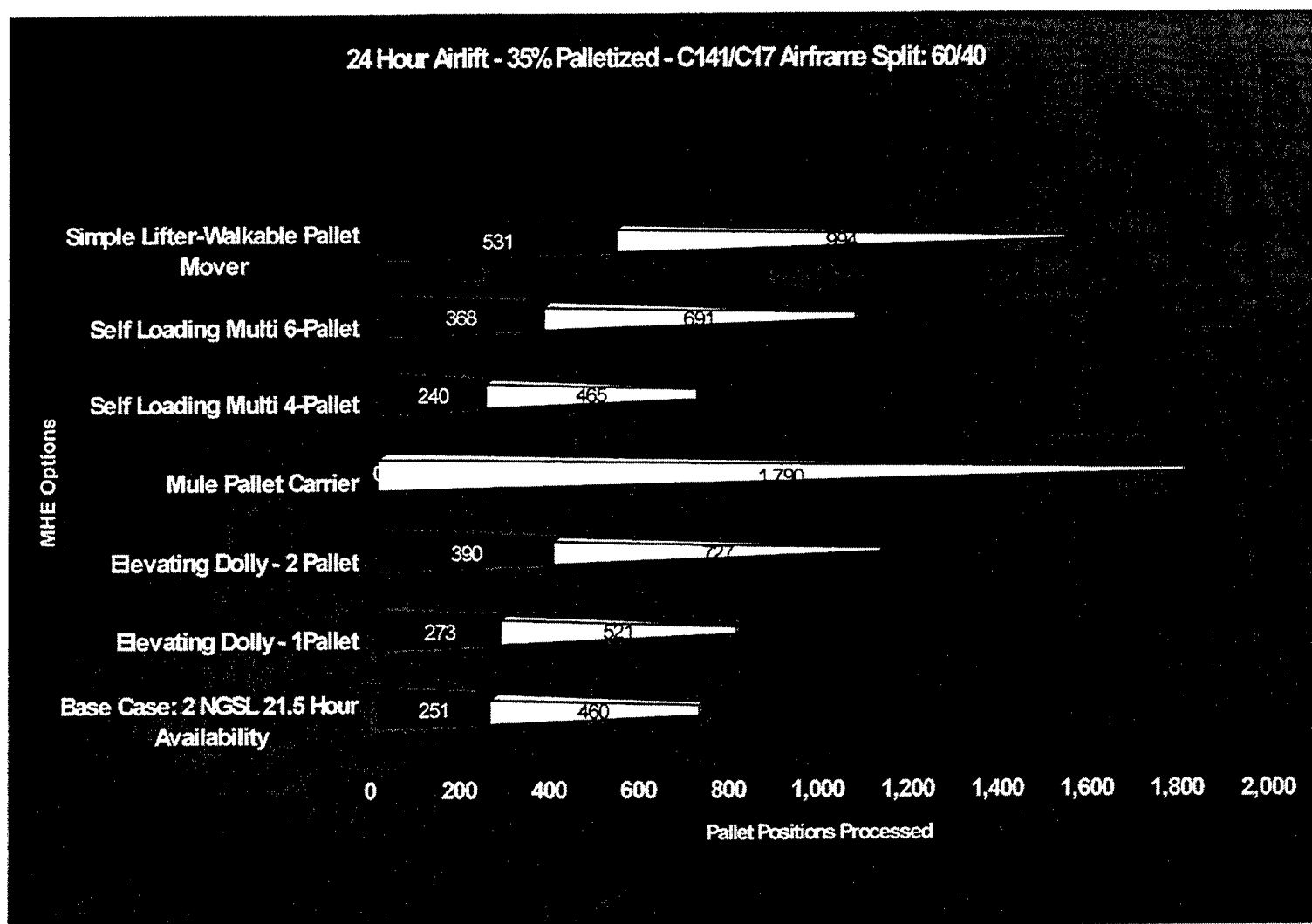


Figure 3-13. Simulation Results

Appendix B contains the results of simulation runs performed before the scenario was definitized; i.e. for two and three day periods with different mixes of pallets versus rolling stock.

3.6 Concept Ranking

With all the data in hand, the ACHSC Team met one final time to relatively rank the physical movement concepts according to each of the measures of merit directed by the government (ref. Section 1). These were a qualitative ranking only with no numerical significance. As the rankings of the team members were compared, some patterns of agreement stood out. These are summarized below. There was sufficient variation in the remainder of the rankings to be inconclusive.

3.6.1 Simple Lifter-Walkable Pallet Mover

- Ranked Third Best In Operational Cost
- Ranked Third Poorest in Footprint and Manpower
- Ranked Lowest in Rapid Deployment Capability

3.6.2 Elevating Dolly – Single/Double

- Ranked Lowest In Throughput (Assuming Only 10 Available)
- Ranked Middle-of-the-road Overall

3.6.3 Self-Loading Multi-Pallet Mover – Four/Six

- Modest Gain In Throughput
- Ranked Best In Manpower Utilization
- Ranked Second Best In Rapid Deployability
- Ranked Last In Footprint

3.6.4 Wheeled Pallet Mover

- Ranked Best In Footprint And Operational Cost
- Ranked Second Best In Development Cost
- Ranked Second Poorest In Manpower

3.6.5 Mule Pallet Carrier

- Ranked Best In Rapid Deployment, Footprint, State Of The Art, and Utility in Austere Environment
- Ranked Poorest In Manpower

3.7 Comparison to Baseline

Taking everything into consideration regarding the advanced physical movement concepts, do any of them offer significant advantages over the current state of the art, the NGSL?

3.7.1 Simple Lifter – Multiple Pallet Mover

These concepts appeared to be an attractive alternative to the NGSL in their simplicity of construction. They would be less expensive to procure and take less room to transport. And according to the simulation, they could double cargo throughput. However, the simple lifter would be cumbersome to set up, tear down, load, and unload from the airplane. And because the rate of walking is slow, many of the

multiple pallet movers would be required to be in service to compensate for the long transit times. This could offset the low procurement costs. Also manpower requirements would increase by as many movers as were in service. What might be practical for ramp positions close to the holding area becomes impractical for the transit distances of a mile or more that, we learned, would be typical of a remote deployment.

3.7.2 Mule Pallet Carrier

According to the simulation, the Mule Pallet Carrier could improve cargo throughput over the NGSL by 150%. Its deployment footprint was almost nothing compared to the NGSLs. As a bonus, once each has unloaded its pallet, it would be available for many other uses, again at no cost in pallet positions. Its procurement cost per unit would be much lower than that of an NGSL, but one would be needed for each pallet position during early deployment flights, so procurement costs might actually be similar. The mule pallet carrier would require roughly 10 times the manpower of the NGSL.

3.7.3 Self-Loading Multi-Pallet Carrier

According to the simulation, the 4-pallet version offered no cargo throughput improvement over the NGSL; the 6-pallet carrier offered a modest improvement. Its manpower requirements would be equivalent, i.e. minimal. Like the NGSL, it would be available for work immediately after arriving. Its procurement cost and deployment footprint would both be larger. While the self-loading multi-pallet carrier is an improvement over currently used MHE, it has no clear advantage over the NGSL.

3.7.4 Elevating Dolly

According to the simulation, the 2-pallet elevating dolly offered a moderate increase in cargo throughput over that of the NGSL while the 1-pallet version offered just a small improvement. Again, unit cost should be significantly lower than an NGSL, but many would be used - in this case, 10 - offsetting the low unit cost. Autonomous operation would alleviate the manpower requirement for the two NGSL drivers without adding requirements for dolly drivers, but autonomous operation might also lead to reliability or human factors problems. Development would have to involve considerable testing and refinement. The modest potential benefits do not seem to justify the development effort.

3.7.5 Wheeled Pallet Mover

While we had insufficient data to estimate the time necessary to deploy the wheels on each pallet and therefore do a credible simulation, assuming efficient wheel deployment could be developed, the concept appears to have several advantages over the NGSL. Wheeled pallets would be far less expensive to procure even in large numbers; part of their cost would have been spent anyway for procurement of ordinary pallets. And although a means for towing the pallets is required, a motorized Army mule would also be relatively inexpensive. Manpower requirements would potentially increase, both to deploy the wheels on each pallet and to tow each pallet to the holding area. However, manpower would no longer be required to manhandle pallets to a loader. Another large advantage would be no deployment footprint.

During a long deployment, means such as the NGSL would be required to off-load regular pallets, but wheeled pallets could be specified for all cargo for the early stages of a rapid deployment.

3.7.6 Pick And Choose

Since all advanced MHE concepts have both advantages and disadvantages compared to the NGSL, a combination of concepts might be worth pursuing. Specifically, the mule pallet carrier and the wheeled

pallets might prove synergistic. The cargo most critical in the initial deployment would be transported on the mule pallet carrier. Early in the deployment more personnel would be available for driving the mules off each aircraft since they can't perform their primary missions until their equipment is available. Subsequent cargo would be on wheeled pallets. The mules would be available to tow the pallets from the aircraft to the holding area. Fewer mules would be operated simultaneously thus reducing manpower requirements as the deployment progresses. This scheme would preserve the major advantages over the NGSL of significantly lower procurement cost and deployment footprint, and increased cargo throughput during the early stages of deployment.

Advanced Cargo Handling System Concepts

4. Conclusions and Recommendations

After a literature review, field visits, technology reviews, problem formulation, concept creation, concept simulation, and concept evaluation, the research team has created not one, but several promising advanced cargo handling system concepts that allow an Aerospace Expeditionary Wing to deploy lighter, leaner, or quicker.

4.1 MHE Concepts

For the scenario on which this study focused, the mule pallet carrier yields the highest throughput. It in essence converts every pallet to rolling stock and so can be off-loaded quickly. It requires little technology development and sufficient numbers for the scenario would be procurable at reasonable cost, because it is based on equipment already being manufactured. It offers the further advantage of multipurpose use once the cargo is off-loaded. However, once the scenario is extended beyond the initial three-day deployment, traditional MHE would be required. Each mule pallet carrier off-loads only one pallet and does not return home to transport another pallet on another flight. The simulation also assumed manpower was always available to operate the mule pallet carriers. Limited manpower might slow operations significantly.

The larger of the two versions of the self-loading multi-pallet transporter offers modest throughput advantage. Its combination of lifting and transporting capabilities while requiring little manpower to operate make it an efficient workhorse that would be used for the duration of the deployment. However, it is expensive to procure, the reliability of the version currently deployed – TACLOP – could be improved, and its deployment footprint is quite large – even when compared to the NGSL.

The elevating dolly concept, if implemented autonomously and if procured in large numbers, offers some increases in throughput without requiring an increase in manpower. It offers possible procurement cost and deployment footprint reductions depending on the simplicity of the implementation; the tradeoff is relatively lower unit cost times the need for many more units than the self-loading multi-pallet transporter or NGSL.

The simple lifter-walkable pallet mover could offer a substantial improvement in throughput, but its practicality is inversely proportional to the distance between the aircraft and the holding area. The transit time is lengthened by slow transit speed; for large distances many movers would be required to maintain availability at the aircraft. Significant manpower – one per mover – would be used only for walking back and forth. The simple lifter would also be cumbersome to set up, tear down, load, and unload.

Wheeled pallets could be implemented with near-term technology, offer great procurement cost savings and deployment footprint reduction. It is unknown what effect they will have on cargo throughput because we had insufficient data to simulate the wheel deployment task.

Since no one option stands out from the rest on its own, a combination might be worth pursuing. Specifically, the mule pallet carrier and the wheeled pallets might prove synergistic. The cargo most critical in the initial deployment would be transported on the mule pallet carrier. Early in the deployment more personnel would be available for driving the mules off each aircraft since they can't perform their primary missions until their equipment is available. Subsequent cargo would be on wheeled pallets. The mules would be available to tow the pallets from the aircraft to the holding area. Fewer mules would be

operated simultaneously, thus reducing manpower requirements as the deployment progresses. This scheme would preserve the major advantages of significantly lower procurement cost and deployment footprint.

Research issues involve the proper complement of each, the physical configuration of the mule, design for easy multipurpose use, operator training, and safety. Research issues for the wheeled pallets would be to optimize speedy deployment of the wheels once the cargo is ready to be off-loaded, and into an efficient backup system for removing a pallet whose wheels failed to deploy.

4.2 Information Concepts

All the information concepts are desirable for addressing problems noted during our field visits. Their benefits, however, are difficult to quantify. They will likely result in more efficient cargo off-loading, but indirectly by improving human performance. MHE prognostics and the electronic 3D planning aid decision makers to improve the planning and management of a deployment. Cargo identification and inspection aids, and the personal digital assistant will enable personnel directly handling cargo to perform their jobs more efficiently via better accessibility of the information they need. The tradeoffs here are technical risks and costs to implement.

For this study, we best ask which concepts have the most potential to improve an initial AEW deployment. Here the emphasis is not long-term training, and most of the planning has already occurred. The emphasis is getting cargo off aircraft quickly and safely during the initial deployment. The personal digital assistant could aid this. There would be no ambiguity as to their assigned tasks because the entire chain of command would be "reading from the same sheet of paper." Cargo handling personnel would have their up-to-the-second task list immediately accessible, and management personnel would know up-to-the-second progress. Any technical information needed would also be immediately accessible, so those without 100% skill retention on all the tasks may verify how to proceed.

Providing a single personal digital assistant network to all key personnel forces the addressing of current disconnects between different information systems or different chains of command. Thus, much of the research necessary to implement such a system would be to develop an information-architecture based on real-world operations. Much personal experience and expertise must be collected from the field in order to ensure each user of a PDA gets exactly the information needed in a user-friendly form. Process and information modeling tools such as IDEF may prove beneficial. Human factors research will also be needed into the characteristics of the PDA to create specifications for both the hardware itself and the way it presents the information.

If research to support AEF deployment extends to addressing sustained operations, the other information concepts are all worth pursuing.

Appendix A

Advanced Cargo Handling System (ACHS) Concepts Simulation Plan

Purpose

The purpose of this plan is to outline the objectives, assumptions, and methodology that will be used to support the design, setup, execution, and analysis of computer simulation experiments in support of the ACHS study. The experiments are intended to support the analysis of baseline and advanced concepts for cargo movement that can increase the rapidity and efficiency of cargo movement during Air Expeditionary Force (AEF) during deployments.

Task Background

Research is being conducted to determine if improvements can be made to the current cargo movement system through supplemental cargo loading, off-loading, ground movement technologies as well as enhanced information use, management, remote display and input technologies. The objective is to identify new technologies that can be integrated with the existing technologies and physical cargo movement devices to enable enhanced support for the AEF and other objectives. We believe that in order to meet AEF and other objectives, the Air Force requires an integrated set of physical movement and information technologies that will at once have reduced footprint; will have improved reliability, maintainability and availability (RM&A); will have the ability to operate in austere environments; will have reduced cost over current cargo movement systems; will be rapidly deployable; and will significantly increase the cargo flow rate from aircraft to end user (to include reduced cargo loading, unloading, and ground movement time) during operational deployments.

The Air Force Research Laboratory has identified four areas where technology development and integration hold significant promise in enabling the AEF related transportation process to achieve its objectives. They are: (1) Rapid aircraft off-load and on-load devices; (2) Low cost, small footprint, highly reliable ground movement devices; (3) Cargo flow and resource optimization technologies, and (4) Portable information display and input devices for mobility personnel. The objective of this simulation is to evaluate alternative possible future system concepts that meet the system requirements mentioned above.

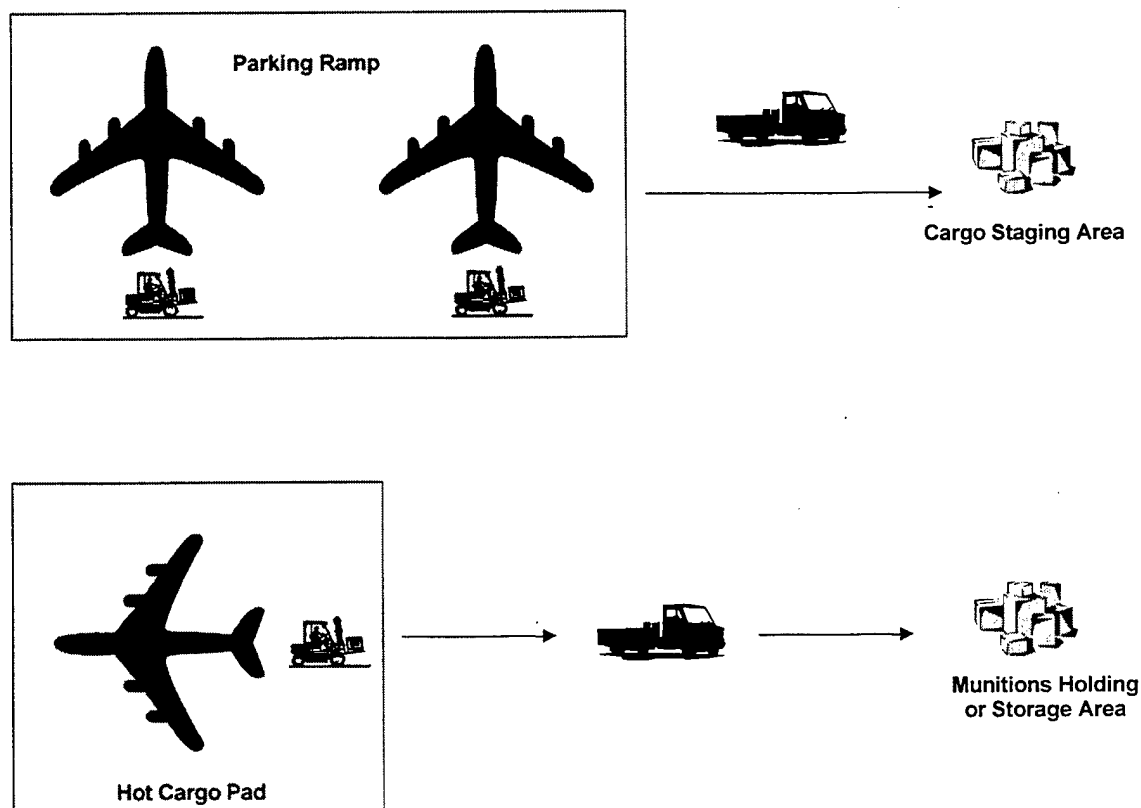
Simulation Objectives

The intent of the ACHS modeling effort is to provide a quantitative methodology for studying and comparing alternative cargo handling concepts. More precisely, the ACHS modeling effort will include an evaluation of advanced or alternative concepts for cargo handling (includes hardware and information systems) to determine how new technologies and processes can be leveraged to help improve cargo handling operations at AEF employment locations. The primary measure of merit that will be derived from the ACHS simulations to assess each concept is cargo throughput at the beddown or employment location (measured in terms of tons of cargo moved, over time, for both palletized cargo and rolling stock). Along with this measure, overall system reliability, availability and manpower requirements will be assessed and used to derive other measures such as mobility footprint and operating costs.

ACHS Scenario and Process

The general scenario that will be used to design and conduct ACHS simulation experiments is based on the deployment of a notional AEF core package and strike package, operating on an AEF timeline (24 hours strategic warning; 48 hours from execution order to bombs on target). The strike package will include 18 each F-16C/Ds (UTC 3FKM8), 18 each F-15Es (UTC 3FQKL), 6 each B52Hs (UTC 3BACL), and 6 each KC-135Rs (UTC 3YCA5) deployed from various CONUS locations to an OCONUS base beddown location in support of a real-world contingency in the EUCOM Area of Operations (AOR). For scenario purposes, the beddown location is assumed to be Decimomannu AB, IT.

Given this scenario, the particular part of the deployment process that will be focused on for modeling and evaluating baseline and advanced cargo handling concepts will start with the arrival of the first airlifter at Decimomannu AB, and end with the off-load of cargo and equipment (including transport to and placement on the ground in the respective holding or staging area) from the last airlifter at Decimomannu AB. Although cargo and equipment on-load activities occurring at the embarkation or deployment bases, as well as activities occurring during the transportation leg of the deployment between CONUS locations and Decimomannu AB are important, they will not be specifically addressed in the ACHS simulations due to the limited resources allocated to the ACHS modeling effort. Only the cargo off-load and movement activities at the beddown location (Decimomannu AB) will be addressed in the ACHS simulations. The figure below depicts the basic steps of the cargo off-load process that will be modeled.



Decimomannu AB Cargo Off-Load Operations

Assumptions

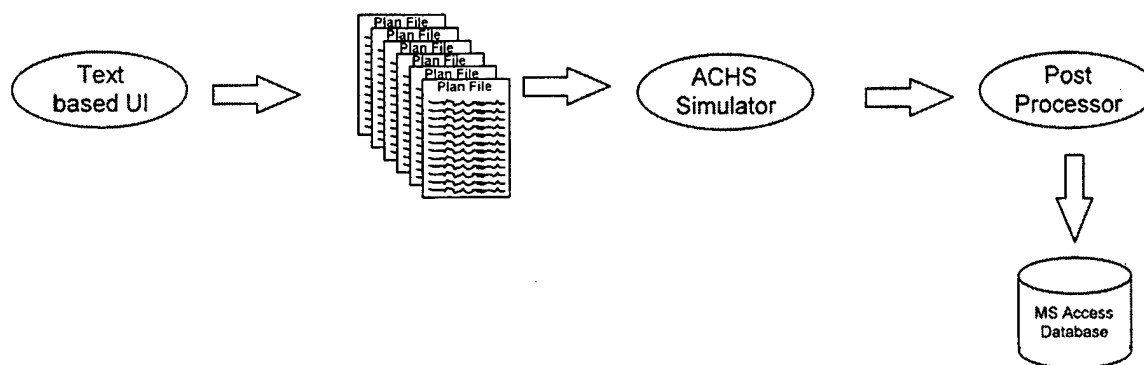
In order to control the scope and fidelity of the ACHS simulation experiments and accomplish the objectives outlined above, the following assumptions will be adhered to throughout the ACHS simulation design and analysis effort:

- Personnel requirements for unloading and transporting cargo and equipment will be addressed in the model, but not varied. This means an initial quantity will be specified for each two personnel types (MHE drivers and Cargo handlers) at the start of the simulation and used to support all cargo off-load operations during the simulation. This allows tracking of personnel utilization, as well as to determine when peak workloads for personnel occur. Specific personnel skill level requirements will not be addressed.
- The unloading, transport, and processing of personnel deploying to Decimomannu AB will not be addressed.
- MOG constraints at Decimomannu AB (provided by AMC) will be adhered to in the ACHS simulations.
- Although more than one type of MHE may be used to off-load pallets from an aircraft, we will assume that only one piece of MHE can be used at a time to off-load pallets from an aircraft. Once placed on the MHE and transported to the staging or holding area, another type of MHE may be used to remove the cargo from the transport MHE and place it on the ground.
- The activities associated with the processing and/or transport of cargo and/or equipment after off-load at the cargo staging or storage areas will not be addressed.
- MHE repair activities will not be specifically addressed in the simulations. When a piece of MHE fails, a random time will be drawn and assigned to the affected MHE to simulate equipment downtime.
- Seasonal, climatic, and environmental conditions at the beddown location will not be addressed.
- No CRAF assets (wide-body airlifters) will be modeled.
- The off-loading of non-palletized outsized or oversized cargo / equipment will not be addressed in the simulations.
- Aircraft ground support equipment will not be addressed.
- No distinction will be made in the ACHS model between day and night operations for cargo off-loading.
- Considering the scenario is looking at an austere, bare-base location, this may constrain the type of airlift aircraft that can be modeled.

A parametric series of simulations will be performed to assess the sensitivity of the ACHS simulator and to achieve a baseline model using actual data as a standard. Once the baseline model of the off-loading operation for the force package defined in the scenario is developed, additional simulation experiments will be designed and executed to assess the impact of process improvements that may result from the single or combined addition of new MHE, computer hardware or software, a revised procedure, and so on. Some sensitivity analyses will be done to look at the impact of varying certain simulation input parameters, such as R&M parameters for MHE, the in-place quantity of MHE at Decimomannu AB, the ramp travel speed for MHE assets, and aircraft off-load times (as a function of cargo and aircraft type) as appropriate. The outputs of all of the simulations will be compiled and summarized into a Microsoft Access database for further analysis and comparison.

ACHS Overview

The ACHS "engine" is based on the T-Sol type of discrete event simulator. The simulator uses a series of ASCII files, referred to as "plan files" to specify the simulation environment and variables. The complete simulator includes, in addition to the plan files, the actual ACHS simulator, a post processor and two Open Database Connectivity compliant databases. When used, the simulator user must edit the plan files with a text based editor. The simulator architecture is depicted below.



ACHS Simulator Architecture

ACHS Simulator Inputs

Airfield Characteristics (Decimomannu AB). Since the cargo loading and processing activities at the CONUS deployment locations is not part of the scope of this effort, only the airfield characteristics at the beddown location (Decimomannu AB) need to be considered for the ACHS modeling effort. This information should be obtained from AMC for Decimomannu AB. The characteristics include at least the following:

- Number of parking ramps supporting general cargo off-load
- Number of hot cargo pads for munitions off-load
- Maximum parking capacity, by aircraft type, for each ramp or pad
- Number of storage or staging areas for off-load of cargo
- Distance from each cargo holding area and hot cargo pad to each parking ramp
- MOG capacity of the airfield

Airlift Aircraft Types. The cargo aircraft types and quantities (TBD) identified below are proposed for designing and the ACHS model and simulations to support the movement of the four UTC packages. A notional airflow schedule will need to be developed with support from AMC. At a minimum, the schedule will need to identify the type of aircraft and the scheduled arrival time at Decimomannu AB and its load configuration (expressed in terms of number of pallets and rolling stock items).

Aircraft Type	Quantity
C-5	
C-17	
C-130	
C-141	

In addition to the aircraft types, the following aircraft related information is needed:

- Total number of occupied pallet positions
- Total number of pallet positions occupied by pallets (per flight)

It will be assumed that all occupied pallets positions not occupied by pallets, are occupied by rolling stock and that this rolling stock will be off-loaded prior to any pallets.

Material Handling Equipment. The MHE types, initial quantities, and R&M parameters identified below will be addressed in the ACHS simulations. The data used to derive MHE reliability (e.g., Mean Time Between Failure – MTBF or Mean Time Between Maintenance - MTBM) and maintainability (i.e. Mean Down Time - MDT) parameters for the ACHS model will be based primarily on MHE operational and R&M data provided by Major Suzuki at AMC/XPY (Source: "ProcessedDataModified.xls"). This data was originally compiled by WR-ALC and is based on field inputs. For simulation purposes, we will assume that MHE reliability (i.e. MTBF or MTBM) can be represented by an exponential distribution. Furthermore, we will assume MHE maintenance MDT can be represented by a lognormal distribution.

MHE Cargo Off-Load Times. The quantity and capacity of a specific piece of MHE, its associated travel speed, and the distance to the cargo off-load area affect the total off-load time for each aircraft. Hence, these parameters (identified in the table below) will be need to derived or obtained from AMC and used to develop the ACHS model. Please note that the ACHS simulations will be designed to model the off-load time associated with a "unit load" of pallets based on the type MHE available. For instance, if a 40K loader is used to off-load an aircraft, then the off-load time modeled will be based on off-loading five pallets (considered a "unit load" for a 40K loader based on the capacity specified in the table below). We will assume that off-load times (per MHE load) can be represented by a lognormal distribution.

MHE Type	In-Place at Decimomannu	463L Pallet Capacity	Travel Speed (mph)	Average Off-Load Time / Load	Standard Deviation
RT 4000		1	10		
RT 6000		1	10		
10K Forklift		1	10		
25K Loader		3	10		
40K Loader		5	10		
60K Loader		6	10		
40ft Flatbed		4	10	NA	NA
New Technology A					

New Technology B					
New Technology C					

Personnel. Personnel requirements will be addressed in the ACHS simulations. The model will need to consider the quantities of each type of personnel available, as well as crew sizes to perform an operation with a specific piece of MHE. This information will be pre-built into the ACHS model so when simulations are executed, the model knows exactly the type and quantity of personnel required based on the task requirements (e.g. type MHE used, safety constraints, physical requirements, etc.). This information will be developed based on inputs from AMC.

Process Events and Activities. As stated previously, the ACHS simulator will be focused on supporting an assessment of the cargo off-loading process ONLY. This process begins with the arrival of the first airlifter supporting the deployment of the four UTCs identified above, and ends with the off-load of the last airlifter and movement of its cargo to a respective staging, storage, or holding area. In gathering data to design the simulation and evaluate the baseline process, it will be important to capture the key events and activities that take place in the current (baseline) process for off-loading an aircraft (until the cargo or equipment is in the staging, storage or holding area). In essence, what information activities flows occur to support the coordination of activities or events? What physical activities involving personnel and MHE take place during the off-load process? What delays are incurred in the processes that need to be considered in the model? Once the key events and activities are identified (including delays), we can determine those that are relevant to the ACHS model and what level of detail (in terms of data and model design) will be required to accurately model the cargo off-load and movement process. From this point, we should be able to determine all the data or information that will be needed to actually build the ACHS model. The attached slide depicts a framework for capturing the events and activities that will be addressed in the ACHS model.

Note: Although not included in the ACHS model, it may also be important to identify what systems support information activities, what types of communications are used to support coordination and information activities (i.e. phone, computer, two-way radios, etc.).

ACHS Output Analysis.

Identify and define the various statistics and outputs that will be produced by the ACHS simulator for post -processing and analysis to support the assessment of cargo throughput and other measures of merit mentioned in the Simulation Objectives section.

Appendix B

Complete Results From Simulation Runs

Experiment	Pallets Pro- cessed	Rolling Stock Pro- cessed	Ave. Wait for MHE	Max. Wait for MHE	Average Aircraft Through- put Time	Ave. Ramp Space Occu- pancy	# Air- craft Un- loaded
50% pallet - 3 days							
Base Case	870	916	42	644	307	91.50%	78
Mule Pallet Carrier	0	4663	0	0	115	84.50%	212
Self Loading Multi 4-Pallet Loader	844	893	38	571	297	91.06%	83
Self Loading Multi 6-Pallet Loader	1204	1265	34	534	218	90.29%	120
Elevating Dolly - 1 pallet	343	379	46	961	710	94.46%	31
Elevating Dolly - 2 pallet	605	646	37	691	408	90.57%	57
Simple lifter - Walkable pallet mover	1689	1772	1	45	151	87.34%	161
35% pallet							
1day							
Base Case	257	469	29	486	116	94.42%	47
Mule Pallet Carrier	0	1858	0	0	63	85.06%	118
Self Loading Multi 4-pallet	248	495	50	748	166	93.26%	44
Self Loading Multi 6-pallet	375	712	48	614	114	92.47%	72
Elevating Dolly-1pallet	271	534	13	127	142	92.40%	49
Elevating Dolly-2pallet	398	775	10	103	100	91.86%	74
Simple lifter - Walkable pallet mover	532	1024	0	18	75	90.67%	99
2day							
Base Case	523	948	251	2680	346	96.49%	98
Mule Pallet Carrier	0	3795	0	0	65	87.56%	243
Self Loading Multi 4-pallet	492	958	49	748	174	96.21%	91
Self Loading Multi 6-pallet	773	1458	42	614	112	94.36%	147
Elevating Dolly-1pallet	555	1067	13	146	152	95.49%	104
Elevating Dolly-2pallet	816	1563	10	103	104	94.10%	152
Simple lifter-Walkable pallet mover	1078	2065	1	24	79	92.91%	201
3day							
Base Case	787	1422	79	2680	220	96.98%	147
Mule Pallet Carrier	0	5734	0	0	66	88.21%	369
Self Loading Multi 4-pallet	741	1449	49	748	175	96.91%	139
Self Loading Multi 6-pallet	1164	2200	42	614	114	95.24%	220
Elevating Dolly-1pallet	842	1615	13	168	155	96.40%	157
Elevating Dolly-2pallet	1238	2373	10	103	104	94.38%	230
Simple lifter - Walkable pallet mover	1633	3112	1	36	79	93.61%	305

65% pallet**2 day**

Base Case	584	291	34	609	202	95.01%	53
Mule Pallet Carrier	0	3795	0	0	65	87.56%	243
Self Loading Multi 4-pallet	611	313	60	1530	245	95.33%	53
Self Loading Multi 6-pallet	795	421	31	492	134	96.60%	75
Elevating Dolly-1pallet	573	300	18	837	273	96.71%	56
Elevating Dolly-2pallet	861	442	18	837	293	97.64%	86
Simple lifter - Walkable pallet mover	1577	801	2	130.	103	93.62%	152

3day

Base Case	877	431	30	609	190	97.05%	82
Mule Pallet Carrier	0	5734	0	0	66	88.21%	369
Self Loading Multi 4-pallet	920	467	58	1530	243	97.48%	82
Self Loading Multi 6-pallet	1185	621	46	2404	166	97.23%	113
Simple lifter-Walkable pallet mover	2429	1221	1	187	103	94.87%	235
Elevating Dolly-1pallet	896	454	18	294	180	96.12%	86
Elevating Dolly-2pallet	1353	687	18	590	181	97.09%	130