

**UNITED STATES AIR FORCE
ARMSTRONG LABORATORY**

**463L PALLET AND DUNNAGE SYSTEM
EVALUATION**

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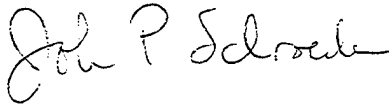
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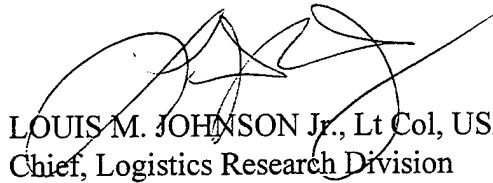
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LIST OF ABBREVIATIONS

| | |
|------|-----------------------------------|
| AFB | Air Force Base |
| AFMC | Air Force Materiel Command |
| AMC | Air Mobility Command |
| APOD | Aerial Port of Debarkation |
| CINC | Commander In Chief |
| DoD | Department of Defense |
| GSA | General Schedule Authority |
| HQ | Headquarters |
| IDEF | Integrated Definition Methodology |
| MNS | Mission Need Statement |
| PSI | Pounds per Square Inch |
| RF | Radio Frequency |

1. EXECUTIVE OVERVIEW

This report provides details and results of the pallet system study performed by Battelle Memorial Institute under the guidance and sponsorship of Armstrong Laboratory, Logistics Research Division (AL/HRG). The six-month study focused on the 463L pallet system, which is the core component of the air cargo mobility system. This pallet and support system was developed in the late 1950s and officially incorporated by the Air Force in April 1963, hence the designator 463 and "L" for Logistics. Most military operations depend on pallets to be readily accessible, as well as reliable.

In December 1996, Battelle was tasked to perform a system level examination of the current 463L operating environment. By collecting and reviewing relevant regulations and other applicable documents, Battelle began to understand the Air Force's transportation system. After this familiarization step, Battelle interviewed air mobility experts at several aerial ports to better understand the needs and problems associated with pallet users. From these site visits and discussions, all aspects of the 463L pallet system were analyzed. As a major subtask to this effort, recycled plastic lumber was examined as a substitute for wooden dunnage. Air Mobility Command requested this analysis be performed in order to properly evaluate several Form 1000 suggestions for such a substitution.

This study concluded that the current 463L pallet (Type HCU-6/E) has been effective at moving large amounts of cargo for decades. Despite this effectiveness, the pallet is susceptible to damage and, thus, frequent and costly repair. This repair takes the pallets out of service for extended periods of time. Additionally, pallets may be permanently lost, stolen, or used for unauthorized uses (such as bunkers) during contingency and humanitarian operations. If a substantial number of pallets are taken out of the system, a potentially serious impact on cargo movement actions could result. As a possible remedy to these problems, an improved pallet design could greatly reduce damage and subsequent repair costs. Likewise, a pallet tracking and recovery process could be developed that would return a large percentage of outgoing pallets.

The primary purpose of wooden dunnage is to raise pallets high enough to get forklift tines underneath them, as well as provide uniform support. Although effective, aerial ports have to replace the wooden pieces every couple of years due to rotting, splitting, infestation, or other forms of deterioration. This constant replenishment of lumber is expensive. The evaluation of plastic lumber determined it to be a technically and functionally appropriate replacement for wood. Recycled plastic dunnage eliminates all the drawbacks of wood; however, current designs are heavier and can be slippery when wet. In terms of life cycle cost, the plastic pieces are far superior to wood. Based on these cost savings and the lack of significant detrimental impacts to the mission, aerial ports have the option to use plastic lumber now available through the Air Force supply system.

2. INTRODUCTION

The Air Force uses 463L pallets for moving military cargo through its world-wide transportation system. These pallets carry materiel of every description into and out of military and civilian ports and warehouses for shipment by land, air, and water.

Since supplies and cargo are available when and where needed, it appears that the 463L pallet system usually accomplishes its objectives. Because of this efficiency, the internal effectiveness and cost (purchase, operation, and maintenance) of the pallet system components have not traditionally been questioned.

However, the 463L pallets have a history of becoming a scarce commodity during mobilizations. The shortages sometime become so severe that it threatens to impede the flow of material. Due to very stringent schedules during mass deployments and the time needed to unpack the pallet, a cargo plane is quite often forced to leave without its pallets. This leads to an excess of pallets at the deployment site which propagates the use of pallets for "alternative uses", such as temporary shelters and pavements. Sometimes, deployed units hold on to built-up pallets for rapid redeployment of combat forces, as highlighted during the famous "End Run" maneuver during DESERT STORM. The net result of these actions is a reduction in the number of pallets available for use at the deploying bases.

There have been previous attempts to solve the pallet shortage problem during contingency operations through management and/or command actions. These actions, such as requiring field commanders to specifically plan for pallet recovery, have yielded limited improvements. Additionally, concerted efforts to recover pallets always come at the expense of other, higher priority needs.

In January 1993, a Mission Need Statement for A Contingency Air Cargo Pallet was issued by HQ AMC/XRATA (AMC 008-91). The "Mission and Threat Analysis" and "Non Material Alternatives" sections of this document effectively described the issue of 463L pallet availability in peace time and during contingency operations. The following paragraphs have been included in this report because they present a clear definition of a problem that still exists and probably will become critical in the next large contingency operation. The italicized text is directly quoted.

1. Mission and Threat Analyses

- a. The 463L pallets are critical elements of the airlift system. They are used extensively throughout DOD to transport non containerized (loose) cargo and some rolling stock on military and civil reserve air fleet aircraft. During peacetime operations, most loaded pallets are unloaded (broken down) at the aerial port and the cargo is transferred to the user. Thus, the pallet remains within the airlift system and is reused on a continuous basis.*
- b. Pallet shortages occur during contingency operations for several reasons. Not all cargo is broken down at the aerial port of debarkation (APOD). Much is transshipped as a unit to the employing forces. During DESERT SHIELD/STORM pallets were consumed at an alarming rate. When users did not return them to the airlift system, this quickly depleted the 120,000 war reserve material (WRM) pallet stockpile and became a potential "Warstopper." Pallet manufacturing was surged, providing a short-term solution to the problem. Once pallets arrived at the forward areas, our plans called for them to be broken down and returned to the airlift system. However, in both Vietnam and DESERT SHIELD/STORM, 463L pallets were used for many different functions other than those for which they were designed.*
 - (1) Many pallets were withheld for legitimate uses. For example, the customer kept built-up pallets stored near the front for rapid movement forward. These proved*

critical during the DESERT STORM "end run" move in the final days before the ground offensive.

- (2) Many pallet uses were not legitimate. these included tent floors, bunker roofing, and sidewalk uses which removed these critical assets from the transportation system were used because they were handy and other construction materials were not available.*
 - (3) Other pallets were broken down at the APOD but not returned to the aerial ports of embarkation as retrograde cargo. This occurred for a number of reasons: lack of ramp space and storage of aircraft parking, short turnaround times, a shortage of aerial port personnel, and a shortage of material handling equipment.*
- c. Each of these three cases contributed to the pallet shortage problem in the early stages of the build-up. Shortages occurred due to both material and non material problems with the current transportation system.*
 - d. Multiple humanitarian relief operations, such as PROVIDE COMFORT, Kurdish PROVIDE HOPE, RESTORE HOPE (Somalia), and Bosnia have resulted in large pallet losses where it is impractical or uneconomical to recover the pallets.*

2. Non Material Alternatives to Recover Pallets

- a. Air Mobility Command (AMC) and Air Force Materiel Command (AFMC) worked on several nonmaterial solutions which partially meet the need. One is to get more pallets returned from the theater of operations through a combination of programs aimed at recovering tiedown assets and shipping them back to the CONUS. Procedures were worked through the JCS to require supported CINCs to plan for the return of pallets to the airlift system. The initial flow capability can only be maintained for a limited time until a shortage of pallets constrains operations. Therefore, at some point into the operation, the flow schedule must be adjusted and resources applied to accommodate the retrograde flow of empty pallets for recycling. This would require a conscious reprioritization of activities and resources to prevent a pallet shortage. Also, as stockpiles are depleted during a contingency, AMC will be required to source enough people and material handling equipment to handle the additional workload associated with preparing the recovered pallets for return shipment. Another alternative calls for the shipment of construction material to the front for use in bunkers, etc. These alternatives can help alleviate the situation, but are not considered stand alone solutions.*
- b. There is nothing new in these nonmaterial alternatives. Pallet recovery teams in the theater, stronger enforcement of accounting and inventory procedures, and increasing regulations have all been tried without success since the Vietnam era. The press of battle, the urgency of the contingency, and the desirability and availability of the pallets to meet nontransportation needs that have no other ready solutions have always resulted in the loss of pallets and degradation of the airlift system.*
- c. In view of the above discussions, there are no satisfactory stand alone nonmaterial alternatives. A combination of nonmaterial and material alternatives may provide a final solution.*

This MNS was drafted to explore the possible solution of a contingency air cargo pallet. Although this idea was later deemed unfeasible, the problems mentioned in the above dialogue have remained. The primary purpose of Battelle's study was to determine where further research by Armstrong Laboratory may help remedy the above-mentioned transportation issues. In order to get a comprehensive view of the complete 463L system, Battelle had to evaluate all components associated with the storage, movement, and tracking of cargo. The focus was on the pallet and dunnage as it affected the operations of the air cargo transportation system. Practical new processes, advanced hardware technologies, and materials that would improve the pallet system should be identified. The best solution was expected to be obtained by considering how these technologies can be integrated into a system level solution, which included technologies applicable to communications, handling, transportation, resource management, etc.

3. APPROACH

In order to gain a better understanding of the 463L pallet and its associated components, a review and study of relevant regulations, technical orders, mobility lessons learned, and operating procedures was performed. Additionally, commercial information about pallet design, construction, manufacturing, and delivery was obtained. A bibliography of some of the documents reviewed for this study is presented in Appendix A.

Samples of pallet availability, load performance, and purchase and repair costs were obtained for limited time spans. This data provided a basis for doing projected long term availability, performance, and cost analysis. An estimate of annual costs to repair damaged pallets is given.

Many groups of people have a great deal of experience with pallet systems. These groups include loadmasters, aerial port managers, logistics planners, item managers, commercial manufacturers, and packaging technologists. Interviews with these people at Wright-Patterson AFB, OH, Travis AFB, CA, Dover AFB, DE, and Ramstein AFB, Germany, identified the needs and problems of pallet users. The interviews included discussions of handling procedures under varying conditions, and those procedures most frequently neglected, deleted, or changed. In conjunction with the interviews, a detailed analysis of the use and control of the pallets, dunnage, and cargo was performed at the above-mentioned sites. In this way, actual operation processes were identified.

Battelle identified current methods used to track pallets and their associated cargo. Advanced tracking systems were assessed for their impact and applicability to the 463L pallet system.

As an associated task, Battelle evaluated the current usage, handling procedures, operating environment, costs, and resource usage of dunnage. A comparison was made between the current wooden pieces and commercially available recycled plastic lumber. The 463L pallet requires 3 pieces of wood (4"x4"x88") to be placed underneath it when sitting on the ground. Wood has been effective and the most appropriate material for many years, but is now becoming a scarce commodity with increasing costs. It also has operational problems with potential for insect infestation and deterioration by environmental elements.

As part of this study, an engineering and operational assessment of plastic dunnage was performed. The sample used in the study was manufactured by ReNew Plastics and furnished by HQ AMC/DOZ. The assessment of plastic lumber used in place of wood for dunnage addressed comparisons in three specific areas: material properties, operational usage, and costs.

The material properties of ReNew's lumber were compared to the presently used white pine. Environmental properties, burning characteristics, mechanical properties, fuel/lubricant resistance, and chemical warfare agent absorption and resistance were all evaluated. Most of the comparisons were obtained using manufacturer's published information. Laboratory testing was conducted to determine impact resistance for both the plastic and wooden lumber.

The operational effectiveness of the plastic lumber was demonstrated at Elmendorf AFB, Travis AFB, Dover AFB, and Howard AFB. Travis and Dover were selected based upon the volume of air cargo freight shipped through their aerial ports. Elmendorf allowed us to test in arctic conditions, while Howard provided a tropical climate. Each base was given three sticks of the plastic lumber and asked to use the plastic as they currently use their wooden dunnage. The aerial ports provided feedback throughout the two-month test period on the condition and effectiveness of the plastic samples.

Determining the associated cost difference between the use of plastic and wood was much more difficult. The difficulty arose from determining exactly how much the Air Force currently spends on wooden dunnage. Using the expected life cycle of both wood and plastics and averaging several bases' estimates for dunnage expenditures, it was possible to determine quantitative cost savings estimates.

4. RESULTS

4.1 463L Pallet System Description

The 463L Pallet System consists primarily of the 463L pallet, dunnage, cargo netting, plastic cover, forklift, k-loader, aircraft rail system, and manpower. A combination of these components make up the entire system. Although, the concentration is on the pallet and dunnage, an understanding of all functional parts of the system and how they interact is important.

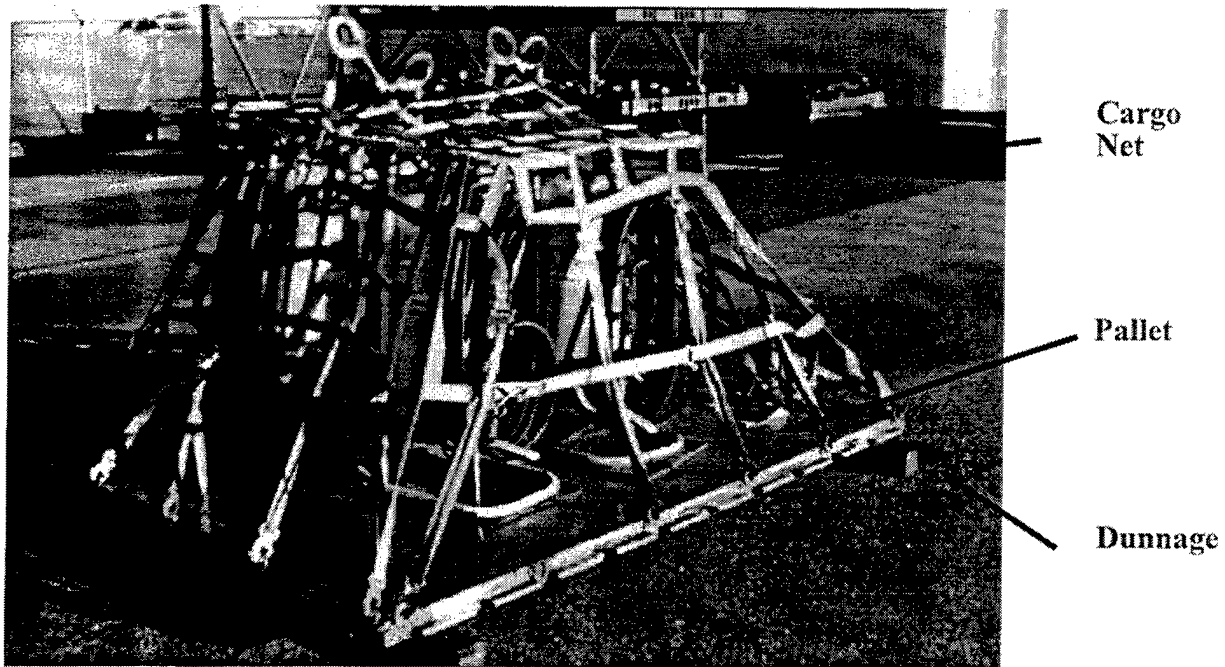


Figure 1: Loaded 463L Pallet

4.1.1 Pallet

The 463L pallet consists of a balsa wood core and two sheets of aluminum edge rail. The indentations along the outer perimeter of the pallet have dual functions; first, they match the aircraft rail system and, second, they allow the pallet to lock into the rail system. There are twenty-two (22) D-rings located along the pallet rails which are used to attach the cargo nets, chains, or other devices to the pallet. Each tie down ring has a restraint capacity of 7,500 lbs. The pallet's empty weight is 290 lbs and its dimensions are 88" X 108" X 2.25".

4.1.2 Cargo Net

The net system is designed to connect with the rings and retain an equally dispersed load on the 463L pallet. The cargo net assembly includes two side nets and a top net, which together weigh approximately 65 pounds. The straps, which are adjustable to allow for different side loads, are constructed with high strength nylon webbing. The net is capable of restraining loads in excess of 3.0 Gs forward, 1.5 Gs aft, 1.5 Gs lateral, and 2.0 Gs vertical.

4.1.3 Chains, Straps, and Devices

Not all cargo can be secured sufficiently with cargo nets. For outsized cargo or rolling stock, chains and straps are normally used for tie-down in lieu of the cargo net. Specially made devices are used to attach the chains to the D-rings of the pallet.

4.1.4 Dunnage

Dunnage is generally a wooden piece of 4"X4"X88" wood. Three pieces are required to be placed under pallets to allow forklift tines to fit under the pallet and lift it up. Dunnage also protects the pallet from debris and possible damage to the bottom of the pallet skin. If there is not an adequate supply of dunnage at the receiving location, three pieces of dunnage must accompany each pallet in addition to the cargo.

4.1.5 Forklift

The forklift is used to carry a pallet (loaded or unloaded) between two locations and also to carry loads to and from a pallet. These are typically used in the build-up and break-down areas. Dunnage is placed under the pallet to allow the tines of the forklift to fit under the loaded pallet.



Figure 2: Forklift

4.1.6 K-Loader

The K-loader is used to transport several pallets from the loading area to the aircraft. It contains a similar roller system to that of the aircraft's. The loader has the ability to carry the loaded pallets and lift them to the height required to push them into the aircraft.

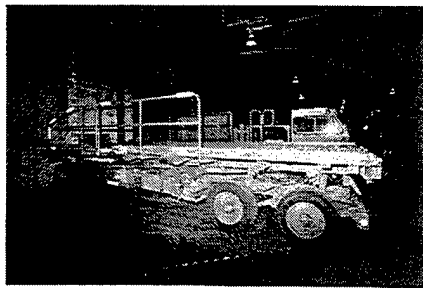


Figure 3: K-Loader

4.1.7 Aircraft Rail System

The aircraft rail system was specifically designed for the 463L pallet. The system contains rollers to ease the loading and removal of loaded pallets. Also, it contains a locking system to secure the loaded pallets during flight. The same rails are used on the k-loader.

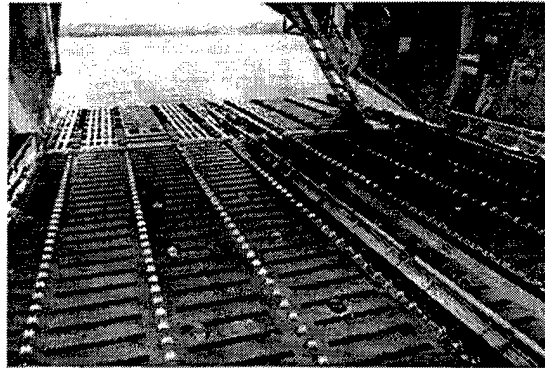


Figure 4: Aircraft Rail System

4.2 Pallet and Net Usage

Pallets and nets are crucial components of the airlift portion of the Defense Transportation System. During routine operations, they maximize available airlift capability and reduce aircraft ground time by allowing for buildup prior to aircraft arrival. In contingencies, their availability at the right place and time can be the determining factor in a mission's success or failure. The responsibility to maintain optimum readiness capability and cost efficiency requires that these critical assets be managed effectively at all levels.

The interaction between each component of the system sheds light on how and where each component fits into the pallet system flow. New or reconditioned pallets arrive at an aerial port either from another aerial port or Cadillac Manufacturing via truck or aircraft. Usually the pallets are placed in the warehouse (or hanger) to be built up with cargo. Overflow pallets may be stored in a semi-permanent area with dunnage laid on the ground, referred to as the staging yard. Here, pallets may be stacked up to 50 high spaced by dunnage between every tenth pallet. If stacking for storage, the pallets must be stacked at a slant to allow drainage. As pallets are needed, they are removed from the stack by forklift and moved to the usage point. Incoming loaded pallets are broken down in the warehouse as well and then stored for rebuilding.

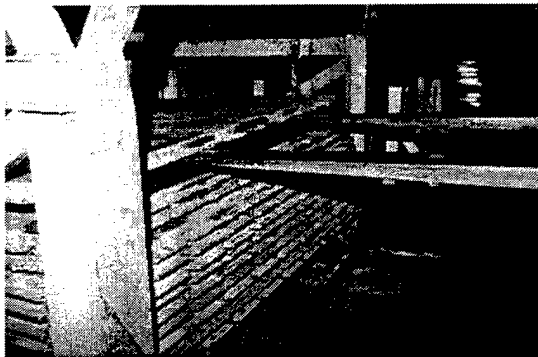


Figure 6: Pallet Removal From Stack

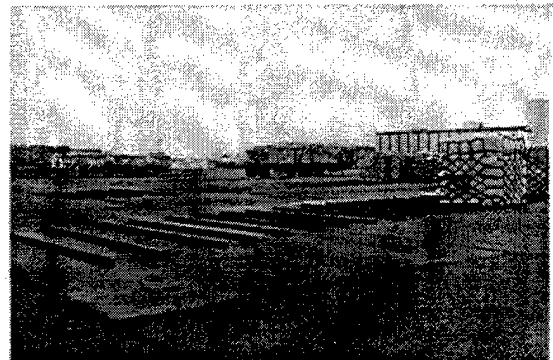


Figure 5: Staging Yard

A typical pallet use could be to support a load of household goods or boxed cargo that will be stacked on the pallet. In these applications, the pallet will be lightly to moderately loaded with relatively even loading across the surface. Other applications, such as armament or engines, place heavy loads on the pallet. In such instances, it is critical that the cargo does not exceed 250 pounds per square inch (PSI). In order to prevent such overloading, which will cause skin damage to occur, plywood shoring is usually used to distribute the weight evenly across the pallet surface. Once a pallet is built, the next step is to cover the contents with a plastic wrapper to protect the cargo from water in case of inclement weather. After inspecting the nets, chains, straps or other devices for serviceability, personnel attach the appropriate amount of tie down to secure the load. Attached to each pallet is a placard that gives the pallet's unit line number, unit type code, destination, height, weight, and several other pieces of information. A load list is also attached that specifies what cargo has been consolidated in a single shipment. If needed, a packing list is attached to provide an inventory of what has been packed inside a container. The built-up pallet is then transferred to storage areas where it awaits loading onto the aircraft via a K-loader. Appendix B provides a graphical life cycle model of the pallet. It describes in some detail the relationship of the 463L Pallet with the 463L Pallet System.

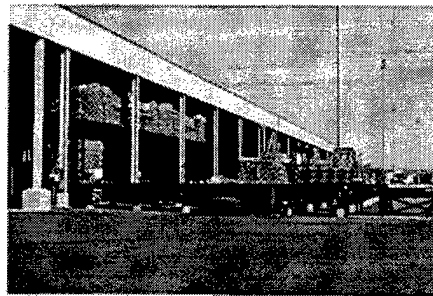


Figure 7: Storage Area

In addition to pallets being used to move cargo forward on the ground, they also get set aside at cargo forward-distribution sites because there is no mechanism for their return. This is usually true in humanitarian operations. Another condition is the unauthorized use of pallets as tent floors, bunker ceilings, building walls, walkways, etc. Pallets work well for these purposes and are generally used when other materials are not provided or lag behind the initial deployment. Many of these pallets are never returned to the air cargo system. This diversion of pallets will probably continue when there are no suitable building materials available. Since nets are attached to these pallets, they are often lost when the pallets are used in such non-traditional ways. As an example of the equipment losses associated with a contingency operation, Appendix C contains the losses for pallets, nets, and straps for certain time periods of the Bosnia effort.



Figure 8: Pallets as Wall Supports



Figure 9: Pallets as Walkways

4.3 Pallet Damage

Personnel must be trained to detect the various types of pallet damage. Before building cargo up on the pallet, the pallet top and bottom should be checked for serviceability. The most common types of damage to the pallet are skin separation, skin punctures, warping, and missing or damaged D-rings. Any time damage is found, the pallet cannot be used to ship cargo. Instead, it is tagged and moved to the damaged-pallet staging area. Whenever the aerial port accumulates at least 10 damaged pallets, they will ship the pallets back to their regional hub (Travis AFB, Dover AFB, etc.). When the hubs accumulate approximately 120 damaged pallets, they will ship them back to the manufacturer for repair.

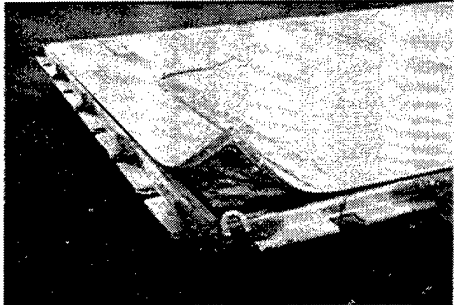


Figure 11: Pallet Skin Separation



Figure 10: Damaged D-rings

Loads that sit on a concentrated part of the pallet (especially when heavy) are tied down with chains and straps to prevent movement. This action pulls up on the side of the pallets and may permanently warp them. To a lesser extent, nets put consistent upward pull on all pallet rings. The upward pull on the pallet with cargo pushing down in the middle of the pallet can contribute to bowing. A warped pallet is likely to jam in the K-Loaders and in the aircraft rail systems. Jamming will cause loading delays and will often further damage the side flanges of the pallet.

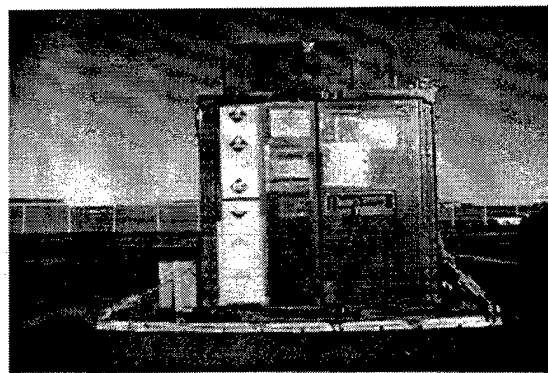


Figure 12: Heavily Loaded Pallet

Heavy loads may also damage the bottom surface of the pallet as it slides across the aircraft roller system. If a pallet is loaded so that the majority of weight rests in a particular area, the skin from that area may become indented or grooved due to the resistance from the rollers. This situation is more likely to occur if the aircraft rollers are damaged so they no longer roll smoothly. Extreme cases may puncture the skin of the pallet. Once the skin is punctured, the aircraft rollers will catch in the hole, further damaging the pallet.

Improper storage facilities, coupled with the pallet materials, account for a majority of pallet problems. The thin aluminum skin is glued to the side frames to keep the internal materials dry and give strength to the pallet. The glue bonding often separates under the normal stress of use. This separation allows water to seep into the balsa wood core, which expands with great force when wet. This expansion causes the skin to separate from the pallet frame (see Figures 13 and 14). Besides allowing water to seep in, outdoor storage near an ocean allows the salt air to corrode the pallet surfaces. Additionally, if nets are subjected to moisture, they must be thoroughly dried to prevent them from rotting.



Figure 13: Brand New Pallet



Figure 14: Pallet with Skin Separation

4.4 Pallet Repair Costs

Attempts were made to obtain the total number of pallets that are repaired each year at AAR Cadillac and the costs associated with these repairs. Unfortunately, the exact quantity and costs could not be identified for the entire Air Force. However, accurate information was obtained from Dover AFB and Travis AFB, the eastern and western regional hubs, respectively. Since bases within the Pacific Rim will always send their damaged pallets to Travis, it is possible to obtain a reasonable view of the damage occurring to pallets just by analyzing Travis' information. A similar situation exists for Dover AFB and the European theater. During calendar year 1996, Dover returned approximately 3700 damaged pallets to Cadillac for repair, while Travis returned 3600. These numbers do not appear to be out of the ordinary since a 1994 Report of Audit stated that in fiscal year 1993, Dover returned 3,780 pallets for repair. Also quoted in this audit, was the average repair price of \$708. The shipping costs to transport the pallets to Cadillac, MI are approximately \$900 per truckload from Dover and \$1600 per truckload from Travis. A truckload contains 120 pallets. Therefore, the following table details the cost of pallet repairs for calendar year 1996, assuming a modest average repair cost of \$500.

Table 1: Pallet Repairs

| | Travis AFB | Dover AFB |
|---|------------|-----------|
| # of pallets repaired | 3600 | 3700 |
| Estimated average cost (\$) | 500 | 500 |
| Cost of repair (\$) | 1,800,000 | 1,850,000 |
| Cost of shipping (\$) | 48,000 | 27,900 |
| Total cost (\$) | 1,848,000 | 1,877,900 |
| Life-cycle Cost of Repaired Pallet (cost of pallet \$838) | 1,351 | 1,345 |

Considering the damaged pallets not routed through Travis and Dover, it is a reasonable estimate that approximately \$5 M is spent on pallet repairs each year. The Life-cycle cost of a pallet for a one-time repair was calculated by adding the current cost of the pallet (\$838), the estimated repair cost (\$500), and the applicable shipping cost. These costs do not account for the additional labor required to handle the damaged pallets. It should also be noted that the

Department of Defense Transportation Budget pays for these repairs. The only cost incurred by the aerial port is for shipping. Since the aerial ports are not responsible for these repair costs, little concern is given to the amount of money spent to fix damaged pallets.

4.5 Dunnage Usage

The stated requirement for dunnage can be found in TO35D33-2-2-2 Change 6, dated 30 Jun 91:

Loaded pallets shall always be placed upon roller conveyors, palletized cargo trailers, slave pallets or suitable dunnage. Dunnage shall provide three rows of support to each loaded pallet, one row under the center line and one row along each side (88 inch dimension of the HCU-6/E) of the pallet. Dunnage shall be uniform in height, smooth and free of protrusions, and/or sharp corners. The preferred types of support and acceptable types of dunnage are wooden dunnage with a uniform thickness of at least 3 inches (88 inches long minimum for HCU-6/E) arranged to form three rows of support.

In the larger aerial ports, a large area will be semi-permanently set up for storage of transient pallets, referred to as the marshalling or staging area (Figure 15). These areas are often relatively flat blacktop lots where rows of dunnage (groups of 3 pieces appropriately spaced on the ground) are laid out on the ground. These pieces of dunnage are continually exposed to sun, rain, snow, heat, cold, etc., all of which deteriorates them. In addition, fork-lift trucks may run into the dunnage, splintering and breaking the wood (especially at night when the dunnage is hard to see.)



Figure 15: Marshalling Area



Figure 16: Wood Dunnage as Protective Flooring

Dunnage may also be used to distribute cargo weight, provide protective flooring, stabilize equipment, and build equipment ramps to aircraft. Wood used for these purposes is called "shoring". Dunnage is often diverted for shoring purposes and then not returned for dunnage use.

Wood is a wonderful material used for many purposes. It is especially useful for building structures and as a source of heating. When these materials are not supplied by other sources (especially in regions that do not have an abundance of wood) the wooden dunnage is often diverted for these additional uses.

4.6 Dunnage Problems

It is hypothesized that the 463L pallet was designed with the need for dunnage in order to:

- Raise the pallet off the ground to make room for fork lift tines
- Avoid setting the pallet on something that could damage the bottom skin
- Evenly distribute the weight of the loaded pallet on the ground

Wooden dunnage accomplishes these tasks, but requires that three similar pieces of wood be available whenever the pallet is set on anything other than rollers. This approach requires additional personnel and other resources to move, store, position, and attach the dunnage to a pallet. If less than three pieces of dunnage are used, or if any one of the pieces is different from the others, the pallet may warp due to uneven weight distribution. Dissimilar pieces of wood is a common problem at aerial ports, especially smaller ones. However, if personnel inspect for uniformity before using the dunnage, damage to the pallet can be prevented.

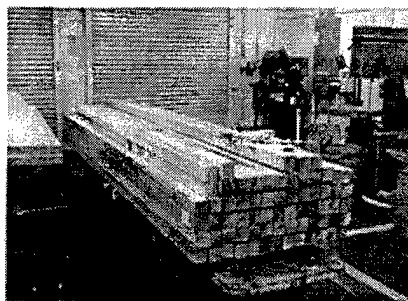


Figure 18: New Wooden Dunnage

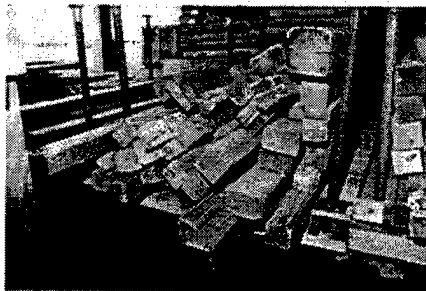


Figure 17: Used Wooden Dunnage

When wood was originally specified for dunnage in the late 1950's and early 1960's, it was plentiful and inexpensive. The original dunnage requirement specified the use of a hardwood. Hardwoods were strong, would not easily damage, and would hold up to environmental conditions well. As the years passed, the requirement for dunnage only specified that wood be used because hardwood became scarce and expensive. Soft woods (often a variant of pine) became the norm. This wood is easily damaged and will deteriorate relatively quickly in an open environment. It is also becoming scarce, and the cost is expected to substantially increase. In addition, wood cannot be transported across many national borders because of the potential of transporting insect infestations. This often means that dunnage must be obtained in the country where the pallet is being transported, and many of these countries do not have wood readily available or it is available only at an exorbitant cost.

4.7 Plastic Lumber

In recent years many products have been made from recycled plastics. Recycled plastic lumber is one product that was considered as a potential alternative for wooden dunnage. HQ AMC requested that one vendor's product, a 4"x4"x88" piece of plastic lumber by ReNew Plastics, Inc., be compared to wood for use as dunnage.

The ReNew pieces are made of a polyolefin-based plastic lumber called Perma-Poly™. A complete evaluation of Perma-Poly™ was carried out at Battelle Memorial Institute's

Industrial and Commercial Development Division, Polymer Product Center, in Columbus, Ohio. Appendix D contains the complete study plan, test procedures, and test results. The results are presented in a way that could be interpreted for application to other types of plastics suitable for dunnage. It should be noted that Black Rhino Recycling, Inc. currently has plastic lumber in various shapes and sizes available through government supply channels. Some aerial ports have already begun to use Black Rhino's 4"x4"s as dunnage.

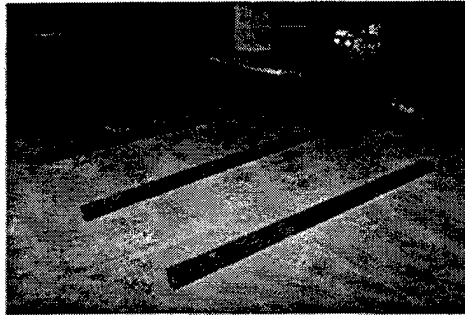


Figure 19: ReNew Plastic Dunnage

The material property analysis found the plastic lumber to be essentially the same as or better than the wood in all cases except two: agent decontamination and density. After exposure to chemical warfare agents, decontamination may be more difficult for plastic than for wood. This scenario would be true if the contaminated dunnage needs to be disposed of. Wood is easily disposed of by burning. The polyolefin will also burn, but takes much longer. The plastic's higher density makes each piece significantly heavier than wood. A 4"x4"x88" piece of wood weighs around 15-20 lbs, compared to 25-30 lbs for the Perma-Poly™. However, Black Rhino also makes a hollow core dunnage which weighs only 13 lbs. Unfortunately, due to the limited scope of this task, the hollow piece was not analyzed for this study.

The functional testing at the aerial ports provided valuable user feedback. All four sites were very pleased with the plastic's operational effectiveness. After its two-month use, no visible deterioration could be seen at any of the bases except for a few roughed-up edges. Elmendorf AFB reported that the plastic held up perfectly in cold weather testing. Likewise, Howard AFB reported no deterioration from the severe rain storms and high humidity of Panama. Travis AFB performed extensive testing by running over the plastic pieces with 10K forklifts and spearing them with the tines. No splintering or other damage occurred due to these tests. They also jammed the lumber into a wall to see how far it would bend. After bending nearly in half, the plastic snapped back to its original shape without any splintering. Dover AFB effectively used the pieces to build ten pallets a day on average in their main warehouse. The major complaint was the heaviness of the plastic pieces. Several bases suggested improvements in the design to decrease the weight, without affecting the structural integrity. Other complaints were the slickness, especially when wet, and the brown color, which made it hard to see at night. Overall, the test bases were very pleased and recommended the plastic pieces be substituted for the wooden dunnage.

To determine the cost savings associated with using plastic instead of wooden dunnage, several inputs were considered. First, the purchase cost for commercially available plastics is on average three times higher than wood. Since there are no repair costs associated with dunnage, the usage costs for wood and plastic are the same. Therefore, assuming disposal costs are negligible since most of the time it will be given away, burned, or recycled, the life cycle cost depends solely on the purchase price and lifetime of the dunnage. The plastic pieces are expected to last forty (40) years based on material analyses by several plastic manufacturers. The lifetime of wooden dunnage appeared to vary substantially from base to base. These variations are due to climactic conditions, facilities available, and operational mission. For instance, bases that support Army units tend to replace their dunnage supply more frequently

since their dunnage is rarely returned. Also, bases that have outdoor staging yards must replace dunnage every one to three years due to the constant exposure to the elements. It appears that bases are extremely lucky if they can obtain five years of good use from their wooden dunnage. The following table calculates the percent savings obtained by using plastic dunnage (compared to wooden dunnage) for various wood lifetimes. It also assumes plastic is three times more expensive than wood.

Table 2: Wooden vs. Plastic Dunnage

| If wood only lasts | % saved by using plastic 40-years |
|--------------------|-----------------------------------|
| 1 year | 92.5% |
| 3 years | 77.5% |
| 5 years | 62.5% |
| 10 years | 25.0% |
| 13.3 years | 0.0% |

Therefore, if the Air Force spends a million dollars a year on dunnage and the average wooden piece currently lasts only 5 years, the Air Force could save 62.5% or \$625,000 a year by using recycled plastic. Also, this table shows that organizations will save money by using plastic instead of wood, as long as their current wooden pieces last less than 13.3 years. Unfortunately, this study was unable to determine the exact amount that is actually spent by the Air Force each year on dunnage. Many times dunnage is purchased with the IMPAC card in small quantities that are not tracked. Also, other base organization may either purchase lumber that ends up at the aerial port or borrow dunnage that the aerial port purchased. Additionally, the aerial ports do not distinguish between lumber purchased for dunnage and lumber purchased for other uses.

Some valuable information was obtained at Ramstein AB, where the 623rd Air Mobility Support Squadron has been using plastic dunnage in their staging yard and pallet build-up areas since 1994. Since this initial purchase, not a single piece has been damaged to an unusable status. The following chart details how many plastic 4"x4"s Ramstein AB has purchased and the dollar amount saved from this purchase. It is assumed that the plastic will last 40 years (based on manufacturer's analyses), that wood only lasts 3 years (based on previous experience at Ramstein), and that the average cost for wood is half the price Ramstein paid for the plastic pieces. It should be noted that Ramstein bought bulk quantities of the plastic dunnage from a local manufacturer. Most plastic manufacturers in the United States quote higher prices, but many are willing to discount bulk orders.

Table 3: Ramstein AFB Cost Comparison (4"X4" wood vs plastic dunnage)

| | Wooden Dunnage | Plastic Dunnage |
|---------------------------|----------------|-----------------|
| Board Feet | 203,200 | 203,200 |
| Cost/Board Foot (Avg.) | \$0.26 | \$0.53 |
| Total Cost | \$52,832 | \$108,176 |
| Estimated Life Cycle | 3 years | 40 years |
| Life Cycle Cost for 40yrs | \$704,426 | \$108,176 |
| Savings after 40 years: | | \$596,250 |

5. RECOMMENDATIONS

5.1 Updated Pallet Design

This study identified the need to improve the current pallet materials in order to remedy several of the problems associated with the 463L system. By substituting different materials for the balsa wood core and aluminum skin, a more rigid pallet could be produced to prevent warping, punctures, corrosion, and skin separation. A significant amount of research would be needed to identify the proper materials to be used and the anticipated cost savings produced by such a change. Besides the cost benefit, a material design change will make loading and unloading aircraft more effective and efficient, and a reduction of labor effort could be experienced.

A modified design could also eliminate the need for dunnage, which is a labor and cost intensive resource. At the time the pallet was designed and deployed, there were more personnel resources available to handle dunnage. Today there are substantially fewer personnel resources available while the demand remains. One such design would be to build fork lift tines into the pallet. Figure 20 shows an example of this concept, the Air Cargo pallet, HCU-10/C. This modified pallet is manufactured by Cadillac and is 88"X54"X4-1/2". It has a maximum capacity of 5,000 lbs. This does not meet the requirements of the 463L, HCU-6/E, pallets, but the concept is functional.

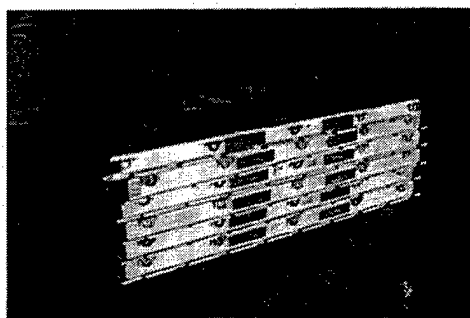


Figure 20: HCU-10/C Air Cargo Pallet

Several issues arise with this recommendation. First, the bottom of the current 463L pallet is not durable enough to be placed directly on the ground. Therefore, punctures would occur and render the pallet unusable. Replacing the bottom skin with a harder material should eliminate this problem. Also, the forklift holes would raise the height of the pallet, thus limiting the height of the cargo that can be placed on it. Several aerial port personnel stated that such a height limitation would be unacceptable due to its adverse mission impact. Another concern is the addition of a time constraint to properly position the fork lift tines into the pallet slots.

5.2 Pallet Availability Plan

Lack of pallet availability is often a major problem in a time of military and humanitarian contingency operations. This is due to: pallets being permanently taken out of the airlift system when used for other purposes, pallets being retained for subsequent ground transportation, pallets being damaged, and pallets not being collected and returned for use. Currently, with few high-volume contingency operations, the War Material Reserve and operational supply is close to allotment. But the issue of how to prevent shortages from occurring in high operations tempo contingency operations has not been answered. A process needs to be developed to ensure that an adequate number of pallets will be available for these demanding situations.

5.3 Updated Technical Orders

Technical Orders were extremely helpful since they covered the use and repair of the pallets. Most of this information is current and appropriate except for the sections dealing with field repair and determining when a pallet is no longer serviceable. Once damaged in any way (even something as minor as a broken tie-down ring rivet), pallets are sent back to the manufacturer for repair. The cost of repairing damaged pallets is borne by the DOD, while local repair would come out of the aerial ports operations budget. This situation, coupled with a manpower shortage, environmental issues, and lack of equipment for field repair, results in all damaged pallets being sent to AAR Cadillac for repair. The Technical Orders should be rewritten to reflect this change in operations for the repair of pallets.

The technical orders also need simple, clear procedures for determining if a pallet is serviceable. Obvious damage like broken side rails, tie down rings, and torn skin is straightforward to detect, but checking for warpage (amount and type) and damage to the skin on the bottom of the pallet should be addressed.

5.4 Pallet Damage Detection

Every damaged pallet not detected during inspection will likely cause operational problems. Most of the interviewed workers used their personal experience as a gage for what constituted a damaged pallet. None knew of any specific guidelines. A written guide to help personnel identify damaged pallets before they are built-up will prevent unnecessary loading delays, thus saving time and money.

5.5 Tools for Pallet Build-up

Cargo coming into the aerial ports by truck has a great deal of information associated with it. The attached information is scanned when it is received to tell the aerial port tracking system all the pertinent information about each piece of cargo. At the same time, the person scanning the label marks on the cargo its destination (pallet build-up area) with a wax pencil. A fork-lift operator then moves the cargo to the appropriate pallet build-up area. A person will begin building a pallet from the cargo that has been identified for a specific destination. This person selects and arranges cargo on the pallet in a manner that will meet regulations and best practices. It is based on skill and trial-and-error. The result may be a well built pallet or one out of balance, over/underloaded, etc. Currently there are no tools that help the builder determine what should go on a pallet based on volume, shape, and weight.

The technology exists (information systems and visual modeling) to use the cargo weight, shape, and volume information to designate a specific pallet and location for each piece of cargo. This tool could facilitate quick and effective building of pallets that are well balanced, properly weighed, and correctly routed. Such a system would substantially reduce cargo-handling in the Aerial Port and, thus, greatly reduce data processing errors because of fewer manual data recording and processing tasks in cargo handling. It is suggested that a more automated process of cargo handling and pallet building be evaluated.

5.6 Pallet Accountability and Tracking

Currently, pallets are not tracked in real-time. Therefore, there is no way for the Air Force to know where each pallet is (location or state of transport) all the time. Material and non-material solutions need to be explored in order to reduce the number of pallets lost from the system during both peacetime and combat situations. One possible solution is to embed Radio Frequency (RF) tags into the pallet in order to keep constant track of their whereabouts. Such tracking would require additional manpower to monitor and manage the effort. It might be reasonable to only monitor the pallets during contingency situations or on an "as needed" basis.

This approach and others need to be analyzed to determine if the benefits associated with such a program will outweigh the cost.

The US Army has a pilot program using SAVI technology that allows for the tracking of the pallet and its cargo. The Air Force is monitoring this program to determine its effectiveness. Other tracking methods currently used should be researched to determine their applicability to Air Force cargo transportation needs and the Total Asset Visibility concept.

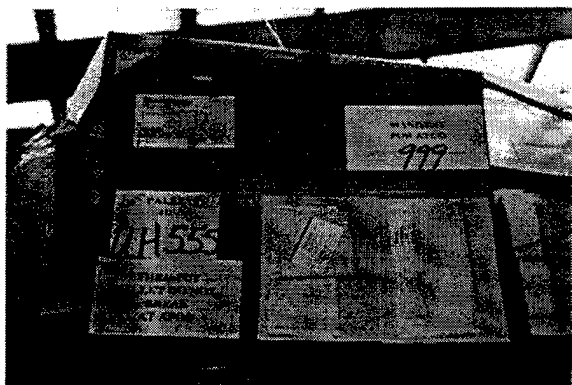


Figure 22: Identification Board with Laser Card



Figure 21: SAVI RF Tag for Tracking

5.7 Proper Maintenance of Aircraft Roller Systems

The 463L Pallets spend much of their time on roller systems. These systems are in the aerial ports, on material handling equipment, and on the aircraft. Roller systems that have few contact points and little surface-area-contact with the pallet can cause grooves to be worn in the bottom of the pallets. Stuck or jammed rollers will severely damage a pallet as the pallet is dragged across them. Missing rollers are less of a problem, but they put stress and more load on surrounding rollers, increasing the likelihood of damage to the pallet bottom. Stuck rollers may also cause pallet jamming in the rail system. If roller systems are better maintained, less damage is likely to occur and the mission will be positively affected.

5.8 Proper Storage Facilities

Many of the pallet problems are caused by excessive exposure to the elements. If aerial ports had adequate facilities to keep pallets and dunnage dry, much of the damage would be diminished. Also, proper drying facilities for nets and straps will keep them from rotting, thus allowing for a longer life. However, field conditions may not allow for such facilities to exist. An ideal solution would be to replace the material with one that could withstand the weathering conditions of contingency operations.

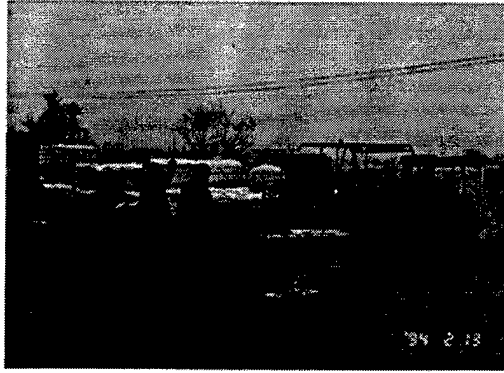


Figure 23: Weathering Conditions: A Contingency Operation

5.9 Replace Wooden Dunnage with Plastic Lumber

Plastic lumber is currently in the Air Force supply system and can now be ordered through the GSA catalogue. The recommendation to buy is based on the cost savings associated with using plastic lumber instead of wood and on the fact that its use does not negatively impact the mission. Currently, the benefits associated with its use may be limited to intermediate air freight storage at the aerial ports. The reason behind this limitation is that aerial ports will be leery of shipping out their more expensive plastic with no guarantee that they will not receive the less favorable wood in return. The cost benefits of plastic only occur if the plastic remains in the aerial port's possession.

Another issue could arise if aerial ports send plastic pieces to one another. Currently, the plastic dunnage at Ramstein AB, Germany is 4.5" x 4.5", while the plastic pieces being used at Travis and Dover are 3.5" x 3.5". Additionally, Howard AFB uses a plastic truck block that is not the same shape as any piece of plastic lumber. If different sizes and shapes of plastic dunnage are used, uneven support will be given to the pallet and warping will occur. If aerial ports begin shipping plastic dunnage to one another, a specification should be written to ensure everyone is using the same size and shape of plastic dunnage.

5.10 Plastic Lumber Design Improvements

New designs, like Black Rhino's hollow pieces, should be researched to cut out some of the weight from the dunnage currently available in the Air Force supply system. Also, a non-slip surface will allow personnel to pick up the dunnage easier and keep pallets from sliding around. The plastic dunnage used at Ramstein AB, Germany was specifically designed for the pallet. The ends contain grips for ease of grabbing, and there are grooves along all sides to allow air flow, thus preventing the dunnage from freezing to the pallet.

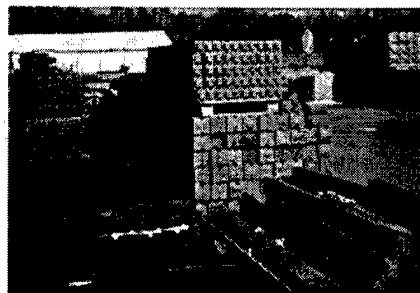


Figure 24: Plastic Dunnage at Ramstein AB

6. CONCLUSIONS

This report discussed several issues associated with the 463L Pallet System. Aerial port personnel are generally very pleased with the system and see very little reason to change something that has worked so well for the past 35 years. There were, however, a number of minor problems that users identified with the pallet system. These problems are so commonplace and have been accepted for so long as "inevitable" that aerial port personnel have learned to overcome them. In many instances, they do not realize the added burden placed upon their organization and the cargo system in general. Obviously, since the Air Force's complete traffic management system, as well as the major weapon systems (C-130, C-141, C-5, C-17), are centered on the 463L system, only very minor changes will be cost effective. The objective of this report was to highlight areas where further research may lead to beneficial improvements in the air cargo transportation system.

Many commercial vendors perform material research that may be applicable to pallet design. This research should be analyzed thoroughly for potential implementation. Although many organizations feel pallet effectiveness and costs are at appropriate levels, possible improvements, even minor ones, should be considered. During this generally peaceful global environment it is just as important to improve upon our war-fighting capability, as well as improving our affordability, as it is during times of conflict.

Appendix A: Literature Review

The following documents were obtained and reviewed in support of the project. A literature review was conducted that identified a large volume of information available about pallets in general. Another body of information focused on the functional application of the 463L pallet for tasks such as air dropping and automatic handling of the pallet. No information was obtained that identified the original functional and design requirements for the 463L Pallet System.

In order to record the findings about dunnage, pallets, and the pallet system over 280 photographs were taken of all aspects of the 463L Pallet System. These photographs illustrate most of the warpage and dunnage issues.

Document Name: 463L AIR CARGO PALLETS Types HCU-6/E & HCU-12/E

Document #: TO 35D33-2-2-2 *Date:* 9/19/94 *Type of Document:* Technical Manual
Description: Instructions and pertinent information necessary to inspect, maintain, repair, and replace the HCU-6/E and HCU-12/E aircraft cargo pallets.

Document Name: AIR CARGO PALLET NETS - Maintenance and Repair Instructions for HCU-7/E-I Side; HCU-15/C-II Top; HCU-11/C-III Side; HCU-16/C- IV TOP

Document #: TO35D33-2-3-1 *Date:* 6/3/93 *Type of Document:* Technical Manual
Description: Provides instruction and illustrates various repair methods and materials which shall be used to keep the four different types of nets in operational status.

Document Name: CLEANING, REPAIR, AND TEST INSTRUCTIONS FOR AIR CARGO TIE - DOWN EQUIPMENT

Document #: TO 13C2-1-1 *Date:* 2/29/96 *Responsible Organization:* WRALC *Type of Document:* Technical Manual
Description: To provide cleaning, repair, and test instructions for cargo tie down equipment as listed.

Document Name: CONTINGENCY PALLET ISSUE, HQ AMC MNS

Responsible Organization: AMC *Type of Document:* Point Paper with comments
Description: Purpose is to answer customer questions relating to acquisition of contingency pallets, if the decision is made to buy.

Document Name: 463L PALLET AND NET INSPECTION REPAIR REGULATIONS per WR-ALC

Document #: WR-ALC-RAFB Regulation 65-11 *Responsible Organization:* WR-ALC and FMCA
Type of Document: Regulation
Description: Regulation sets forth procedures used in the condition check of 463: pallets and nets to determine the disposition according to technical order TO 35D33-2-2-2 and TO 35D33-2-3-1. There is an attached letter to WR-ALC requesting a review of the regulations to determine if they were needed and/or updated.

Document Name: 463L PALLETS, NETS, AND TIE DOWN EQUIPMENT SENT TO AND RECOVERED FROM BOSNIA RELIEF EFFORTS

Responsible Organization: WR-ALC/LVV *Type of Document:* Letter
Description: Per AMC/DOZ the numbers of the pallets and nets sent to Bosnia.

Document Name: AMENDMENTS TO PALLET AND NETS PURCHASE DESCRIPTION # WR-ALC/IRA-1670-6133 DTD 9 JUL 92.

Document #: NSN 1670-00-820-4896CT *Date:* 3/29/95 *Responsible Organization:* PD
WR-ALC/RA *Description:* See title

Document Name: AFAA DRAFT REPORT OF AUDIT, PALLET AND NET REQUIREMENTS MANAGEMENT (PROJECT 94061021)

Responsible Organization: AFAA/QLS *Description:* Notification to AFAA/QLS that HQ USAF/LGS had reduced the potential monetary savings (PMS) claimed by the auditor from \$ 11.6M to \$0.600 M. HQ AFMC validated their FY95 pallet and net data independently from the auditor before providing the information to the item manager at Warner-Robins ALC as part of the computation process.

Document Name: PROCUREMENT OF EXPENDABLE 463L PALLETS (response to Letter of 11 Apr 91 from HQ AFLC/XRC)

Responsible Organization: WR-ALC/LVV *Type of Document:* Letter
Description: Response to a request to evaluate the possibility of acquiring an "expendable" WRM emergency use only 463L pallet.

Document Name: GAO FACT SHEETS ABOUT THE NEED TO PURCHASE AIR CARGO PALLETS AND ASSEMBLY NETS FOR FISCAL YEAR 1996

Responsible Organization: WR-ALC/LVDV *Type of Document:* Letter/Technical Report
Description: This was a fax to WR-ALC/LVDV requesting comments on the proposal that the GAO assembled related to the need to purchase pallets in fiscal 1996.

Document Name: DISPOSABLE PALLET FEASIBILITY/COST INFORMATION AND ANALYSIS COMMENTS

Type of Document: Technical Report *Description:* Request an evaluation/testing plan including safety, 463L compatibility, restrictions on load and air/surface transportability and implementation costs be considered. The attached document has identified numerous issues identified about a contingency pallet.

Document Name: TECHNICAL DISCUSSION ON CONTINGENCY PALLET FOR THE 463L CARGO SYSTEMS

Document #: BID # 617313-1 *Responsible Organization:* WR-ALC
Type of Document: Technical Report/PROPOSAL BID. *Description:* Presents the qualifications and capabilities of Brunswick to manufacture the Contingency Pallet. Set for the proposed design concept for the Contingency Pallet.

Document Name: REPORT OF AUDIT 26595050, REVIEW OF PALLET AND NET REQUIREMENTS, HQ AIR MOBILITY COMMAND (PROJECT 94265130)

Responsible Organization: AMC/CV *Type of Document:* Financial Report/Audit
Description: The overall objective was to evaluate the effectiveness of management internal controls over pallet and net requirements. Specifically, we determined whether: (a) requirements were correctly computed and validated; (b) pallet recovery programs were effective; and (c) contingency pallets were economical and required.

Document Name: CONTINGENCY PALLET, HCU-6E PLASTIC PROPOSAL

Responsible Organization: WR-ALC *Type of Document:* Letter/Proposal
Description: Proposes a plastic pallet that Plastics Research Corporation believes could meet contingency pallet requirements.

Document Name: PALLETS, CARGO, AIRCRAFT, TYPE HCU-6/E AND HCU-12/E
Document #: WR-ALC/IRA 1670-013B *Date:* 7/9/92 *Responsible Organization:* WR-ALC
Type of Document: Purchase Description *Description:* The purchase description for the HCU-6/E, and HCU-12/E.

Document Name: 463L PLASTIC PALLET DUNNAGE
Type of Document: Letter *Description:* Official request for Armstrong Laboratories to conduct an operational assessment on the plastic dunnage. Once again, we feel plastic dunnage has great potential and ask for assistance in evaluating it.

Document Name: PLASTIC DUNNAGE TEST AND EVALUATION PLAN
Type of Document: Technical Report-Test Outline *Responsible Organization:* Battelle Polymer Center *Description:* Outline of a testing plan for plastic dunnage

Document Name: CARGO MOVEMENT (Preparation and Movement of Air Force Material) OLD
Document #: Air Force Instruction 24-201 *Date:* 6/29/94 *Responsible Organization:* Air Force
Type of Document: Instruction Manual *Description:* Implements AFPD 24-2 Preparation and Movement of Air Force Material. It assigns responsibilities and provides guidance and procedure on the planning, documentation, funding, and other actions associated with the movement of Air Force cargo in both peace and wartime.

Document Name: AFAA DRAFT REPORT OF AUDIT, PALLET AND NET REQUIREMENTS MANAGEMENT (Project 94061021)
Responsible Organization: WA-ALC/LW *Description:* Recommendations: (1) Revise Pallet and net requirements as plans and missions change. (2) Calculate war reserve requirements using only the most stringent operation plan. (3) Calculate the annual pallet and net requirements based on operations plans rather than estimating or setting the requirements equal to on-hand or recorded inventories.

Document Name: "CONTINGENCY" PALLET FOR THE 463L CARGO SYSTEM
Responsible Organization: WR-ALC/LVKA *Description:* Production estimates of cost, dates, etc. Provides information on manufacturing schedules, costs, etc. for contingency pallets.

Document Name: REPORT OF AUDIT, PALLET AND NET REQUIREMENTS MANAGEMENT (Project 94061021)
Type of Document: Financial Report-Audit *Description:* Air Force managers did not accurately compute pallet and net requirements because of internal control deficiencies over the computation process. Further pallet and net recovery rates need improvement, and the proposed contingency pallet, at its current price, is not cost effective.

Document Name: MISSION NEEDS STATEMENT FOR 463L AIR CARGO PALLET
Type of Document: Cover Letter Only *Description:* Draft is designed to initiate acquisition efforts to solve the 463L air cargo pallet shortage.

Document Name: CARGO MOVEMENT (Preparation and Movement of Air Force Material) NEW
Document #: Air Force Instruction 24-201 *Date:* 8/1/96 *Type of Document:* Instruction Manual *Description:* Implements AFPD 24-2 Preparation and Movement of Air Force Material. It assigns responsibilities and provides guidance and procedure on the planning, documentation, funding, and other actions associated with the movement of Air Force cargo in both peace and wartime.

Document Name: RECYCLED PLASTICS LUMBER

Type of Document: Sales Brochure from WEB site *Description:* Provides general dimensional and product specs for plastic lumber.

Document Name: BASE RESOURCE AND CAPACITY ESTIMATOR (BRACE) 1.0

Responsible Organization: HQAMC/XPY *Type of Document:* Technical Report
Description: Describes a software simulation tool used by planners to estimate the capabilities of airfields to support the strategic airlift of passengers and cargo.

Document Name: BARGO TRUCK BLOCK SUGGESTION AND SPECIFICATIONS

Type of Document: Change Suggestion Package *Description:* A recommendation to use plastic truck stops for dunnage.

Document Name: RAMSTEIN REDEPLOYMENT ANALYSIS FOR OPERATION JOIN ENDEAVOR

Responsible Organization: HQAMC/XPY *Type of Document:* Technical Report
Description: Use of the BRACE simulation tool to evaluate the number of aircraft that effectively could use the air base and the support system needed.

Document Name: ARMY AIR LIFT OPERATIONS MANUAL (DUNNAGE, LOAF SHORING, PALLETS, WHEELED VEHICLES)

Responsible Organization: US Army *Technical Type of Document:* Manual
Description: Planning for loading aircraft, unloading aircraft, and deploying.

Document Name: CHANNEL PERFORMANCE AND ANALYSIS REPORT AUGUST 1996. TANKER AIRLIFT CONTROL CENTER (TACC) TRAVIS, AFB

Responsible Organization: HQ AMC TACC/TRKP; 402 Scott Drive; Scott, AFB IL 62225-5303
Type of Document: Performance Report *Description:* 1996 performance and work cargo moved description.

Document Name: TECHNOLOGIES FOR AIRLIFT CARGO HANDLING (TACH) - [BOEING]

Document #: WL-TR-93-3057 (Boeing) *Responsible Organization:* Flight Dynamics Directorate; Wright Laboratory; WPAFB, OH 45433-6503
Type of Document: Technical Report
Description: Results of a study to develop and evaluate concepts for autonomous cargo handling that can be used on current and future military aircraft with minimal dependence on both manpower and material handling equipment. It includes weight analysis, life cycle cost analysis, and recommended development plan.

Document Name: TECHNOLOGIES FOR AIRLIFT CARGO HANDLING (TACH) - [LOCKHEED AERONAUTICAL SYSTEMS]

Document #: WL-TR-93-3032 *Type of Document:* Final Report [Lockheed Aeronautical Systems] Flight Dynamics Directorate; Wright Laboratory; WPAFB, OH 45433-6503
Type of Report: Technical Report
Description: Defines a cargo compartment concept for the transfer of cargo to and from non-rollerized vehicles and to the ground. The operations are accomplished by one loadmaster and one vehicle driver without ground based material handling equipment. Automated cargo unit positioning minimizes human workload. The technology application and availability to accomplish these tasks is described. An evaluation of the concept develops operational load and unload time lines for six representative missions. The value engineering analysis compares the life cycle costs of a baseline Future Theater Airlift Studies (FTAS) configuration with a configuration which incorporated the advanced cargo compartment equipment. Full scale, mobile concept demonstrator configurations are defined and costs are estimated.

Document Name: TECHNOLOGIES FOR AIRLIFT CARGO HANDLING (TACH) - [MCDONNELL DOUGLAS]

Document #: WL-TR-93-3056 *Type of Document:* Final Report (McDonnell Douglas) Flight Dynamics Directorate; Wright Laboratory; WPAFB, OH 45433-6503 Technical Manual *Description:* Defined need, and developed and evaluated concepts for autonomous cargo handling that can be used on current and future military aircraft with minimal dependence on both manpower and material handling equipment, and which take advantage of available and emerging technologies. The overall goal of the TACH program was to develop the capability to deliver more ton-miles per day at longer operation and cost. Includes life cycle cost analysis and a proposed technology development plan.

Document Name: AIR TRANSPORTATION SPECIALIST: AIRCRAFT SERVICES [CDC 60555]

Document #: CDC 50555 Vol. 2 Date: 4/1/93 *Type of Document:* Training *Description:* Sections: 1. Cargo Documentation; 2. Hazardous and special cargo; 3. Inspecting shipments and processing; 4. Palletization of cargo for movement; 5. Actual loading of the aircraft; 6. Airdrop; 7. Fleet service requirements.

Document Name: 436TH AERIAL PORT SQUADRON TELEPHONE LISTING

Document #: 436th Aerial Port Squadron *Type of Document:* Telephone Number Listing

Document Name: SITE FURNISHINGS AND SIGNS - PLASTIC LUMBER CO.

Description: The Plastic Lumber Company

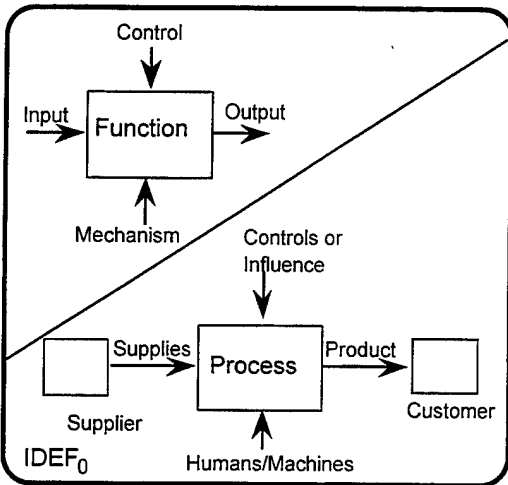
Document Name: IMPORT/EXPORT CARGO FUNCTIONAL FLOW CHART FOR DOVER 436TH AERIAL PORT OPERATIONS

Responsible Organization: 436th Aerial Port Squadron *Description:* A detailed functional flow chart of cargo import and export within the building is being used to determine how to merge the two functions/organizations into one operation. MSgt. Seeberger will expand the model to the whole aerial port if he has time.

Appendix B: Pallet Life Cycle Functional Model

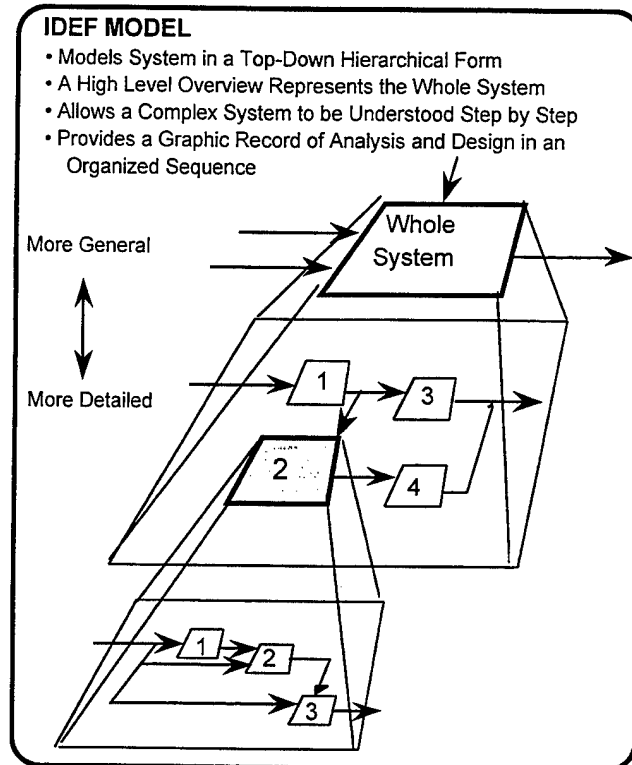
At the start of this task a clear visualization of the life cycle of a 463L pallet did not exist. The following model was created to help identify all phases and functions that a pallet experiences. This model could be extended to provide more detail as needed. The model could also be the basis for a cargo system operation focused on pallet functions. Other documents reviewed for this project gave task performance times for many tasks associated with cargo movement via the 463L pallet. These times would also be directly usable via a simulation.

The following figures provide a short description of how to interpret the Integrated Definition Methodology (IDEF) used to develop the model.



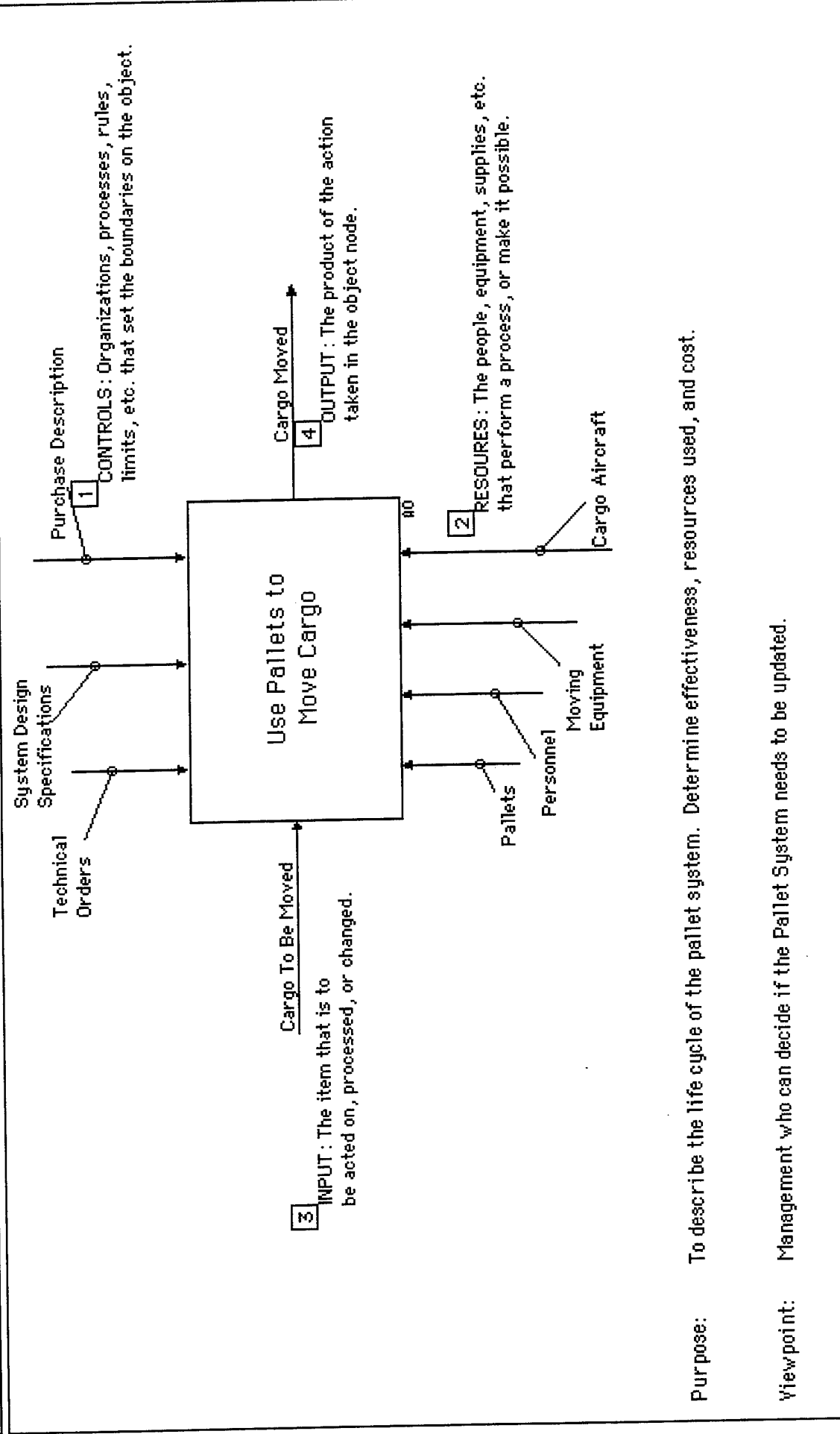
Basic model of an enterprise using the IDEF process.

Visual Description Of IDEF Task/
Functional Analysis Structure



The Pallet System Model is presented on the following seven pages.

| | | | | | | |
|-----------------------------|--------------------------|----------------|---------|----------|------|----------|
| USED AT: | AUTHOR: Glen R. Gallaway | DATE: 01/15/97 | WORKING | READER | DATE | CONTEXT: |
| | PROJECT: Pallet System | REV: 06/03/97 | DRAFT | | | |
| NOTES: 1 2 3 4 5 6 7 8 9 10 | X RECOMMENDED | | GG | 05/23/97 | | NONE |
| | PUBLICATION | | | | | |

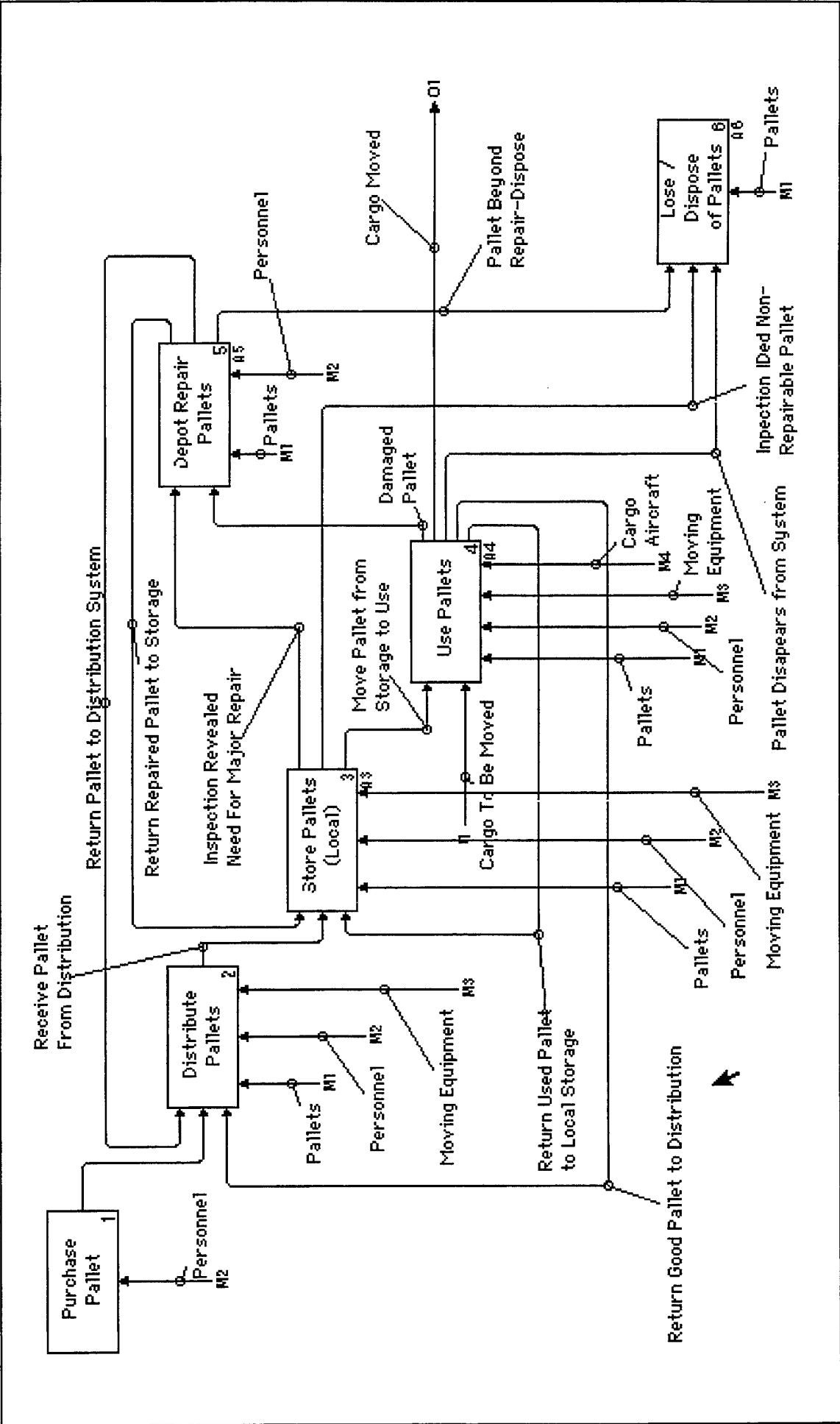


Purpose: To describe the life cycle of the pallet system. Determine effectiveness, resources used, and cost.

Viewpoint: Management who can decide if the Pallet System needs to be updated.

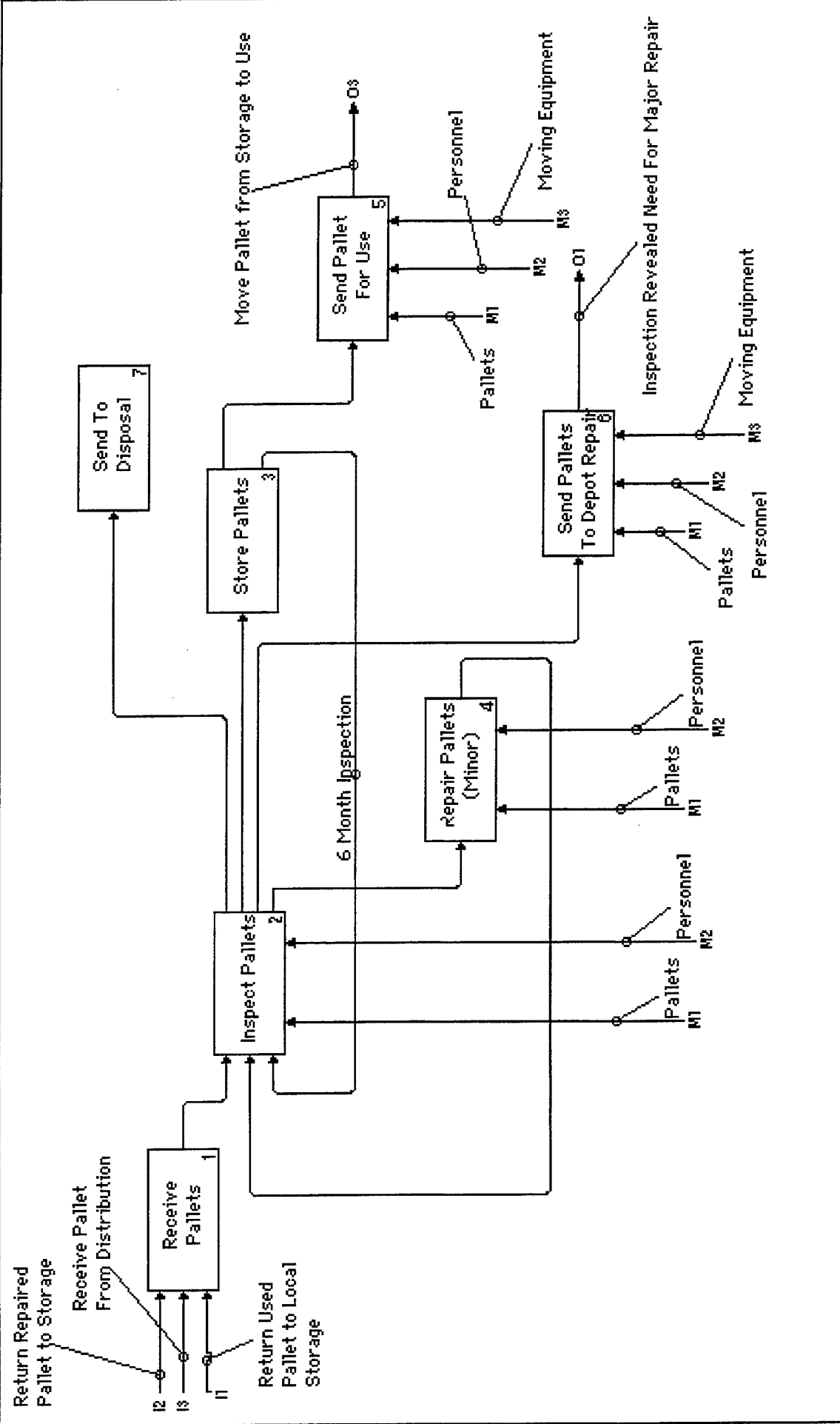
| | | |
|------------------|----------------------------------|---------|
| MODE: Pallet/A-0 | TITLE: Use Pallets to Move Cargo | NUMBER: |
|------------------|----------------------------------|---------|

| | | | | | | |
|----------|-----------------------------|----------------|---------------------------|--------|----------|----------|
| USED AT: | AUTHOR: Glen R. Callaway | DATE: 01/15/97 | WORKING | READER | DATE | CONTEXT: |
| | PROJECT: Pallet System | REV: 05/23/97 | DRAFT | | | |
| | NOTES: 1 2 3 4 5 6 7 8 9 10 | | X RECOMMENDED PUBLICATION | GG | 05/23/97 | TOP |



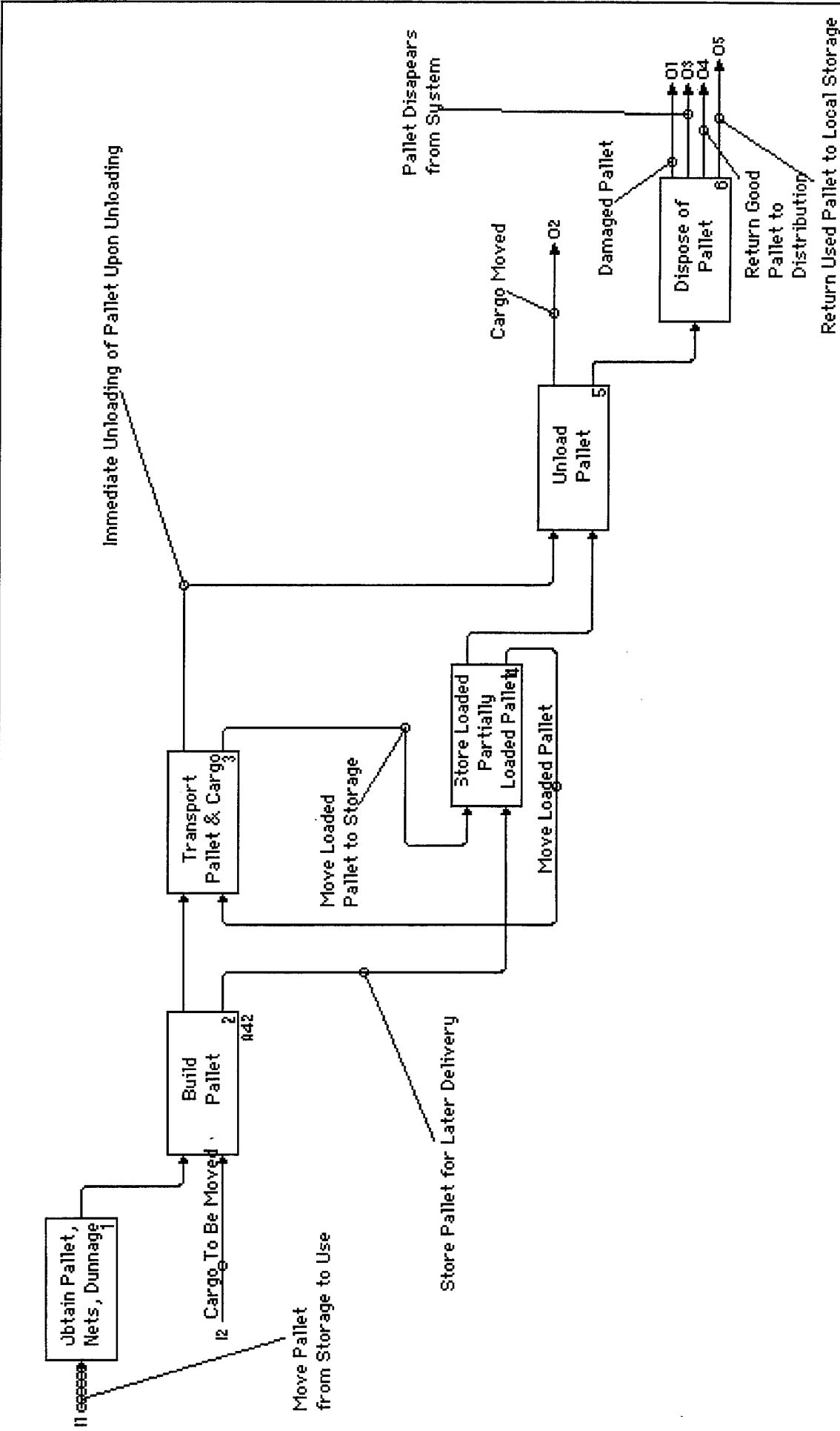
| | | |
|-----------------|----------------------------------|---------|
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|-----------------|----------------------------------|---------|

| | | | | | | |
|-----------------------------|--------------------------|----------------|---|--------|----------|----------|
| USED AT: | AUTHOR: Glen R. Galloway | DATE: 01/27/97 | WORKING | READER | DATE | CONTEXT: |
| | PROJECT: Pallet System | REV: 05/23/97 | <input checked="" type="checkbox"/> DRAFT | GG | 05/23/97 | |
| NOTES: 1 2 3 4 5 6 7 8 9 10 | | | <input type="checkbox"/> RECOMMENDED | | | |
| | | | <input type="checkbox"/> PUBLICATION | | | |



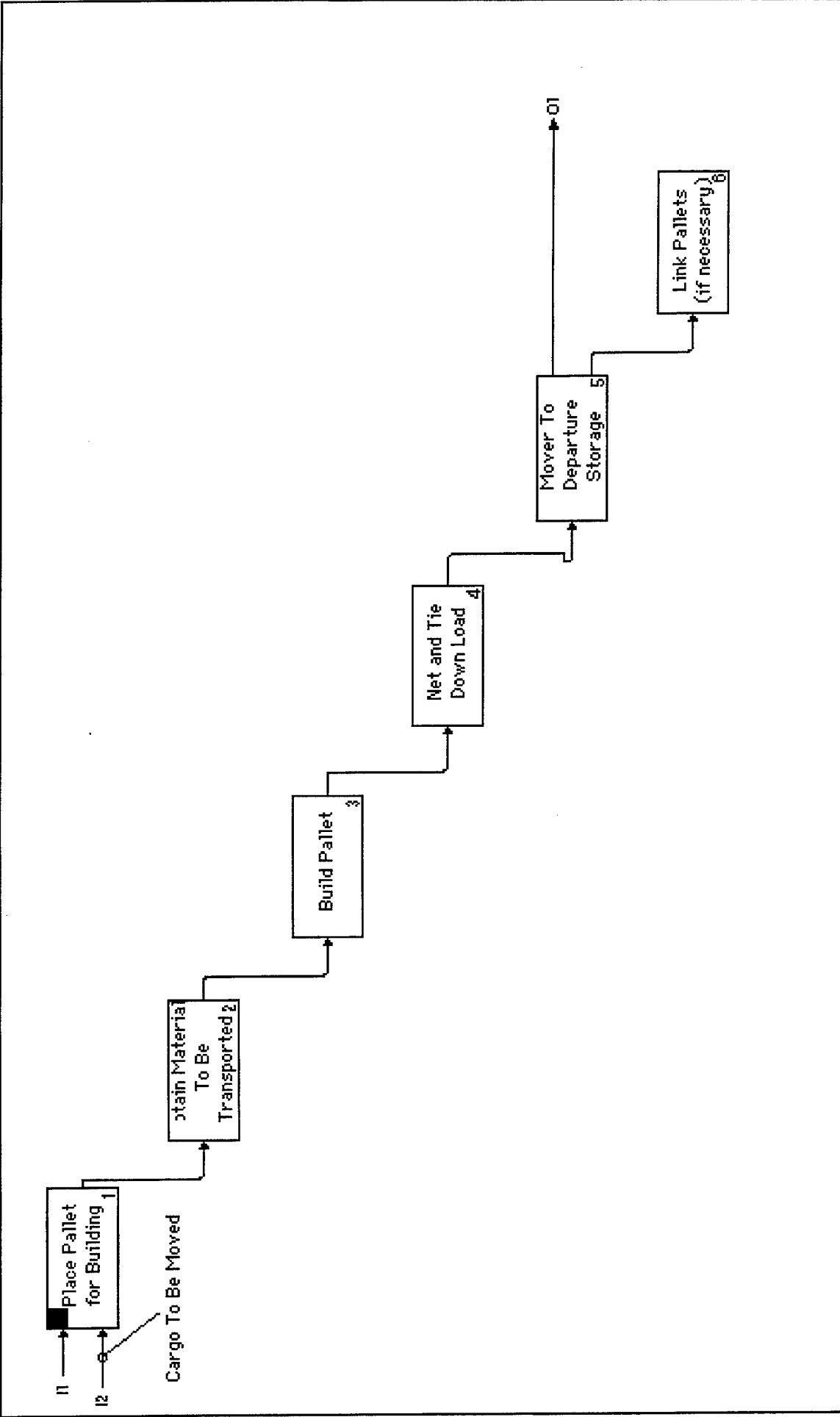
| | | |
|-----------------|------------------------------|---------|
| NODE: Pallet/A3 | TITLE: Store Pallets (Local) | NUMBER: |
|-----------------|------------------------------|---------|

| | | | | | | |
|----------|-----------------------------|----------------|---------------|--------|----------|----------|
| USED AT: | AUTHOR: Glen R. Galloway | DATE: 01/15/97 | WORKING | READER | DATE | CONTEXT: |
| | PROJECT: Pallet System | REV: 05/23/97 | DRAFT | | | |
| | NOTES: 1 2 3 4 5 6 7 8 9 10 | | X RECOMMENDED | GG | 05/23/97 | |
| | | | PUBLICATION | | | |



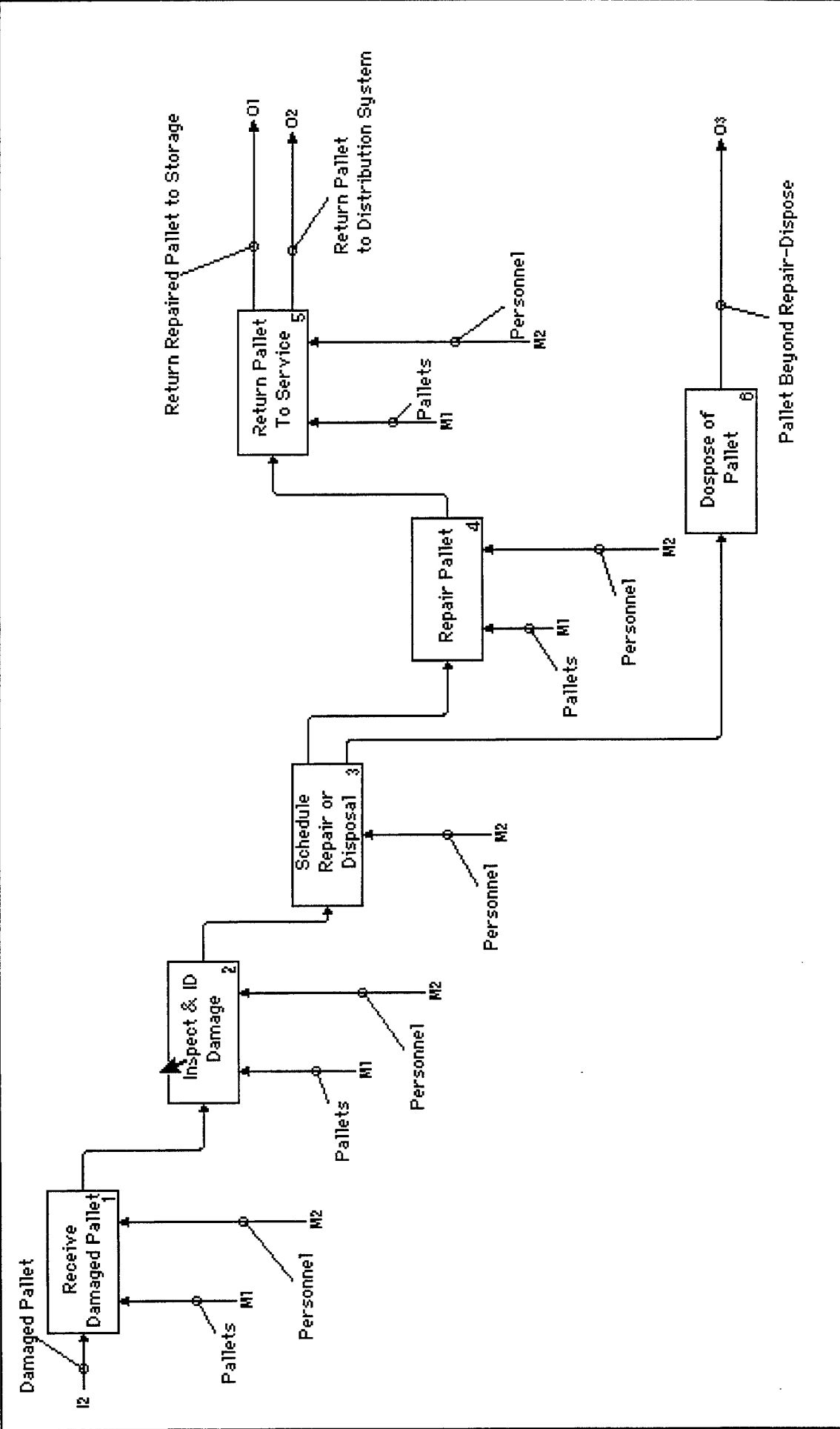
| | | |
|-----------------|--------------------|---------|
| NODE: Pallet/A4 | TITLE: Use Pallets | NUMBER: |
|-----------------|--------------------|---------|

| | | | | | | |
|----------|-----------------------------|----------------|---------------|--------|----------|----------|
| USED AT: | AUTHOR: Glen R. Galloway | DATE: 01/16/97 | WORKING | READER | DATE | CONTEXT: |
| | PROJECT: Pallet System | REV: 05/23/97 | DRAFT | | | |
| | NOTES: 1 2 3 4 5 6 7 8 9 10 | | X RECOMMENDED | GG | 05/23/97 | |
| | | | PUBLICATION | | | |



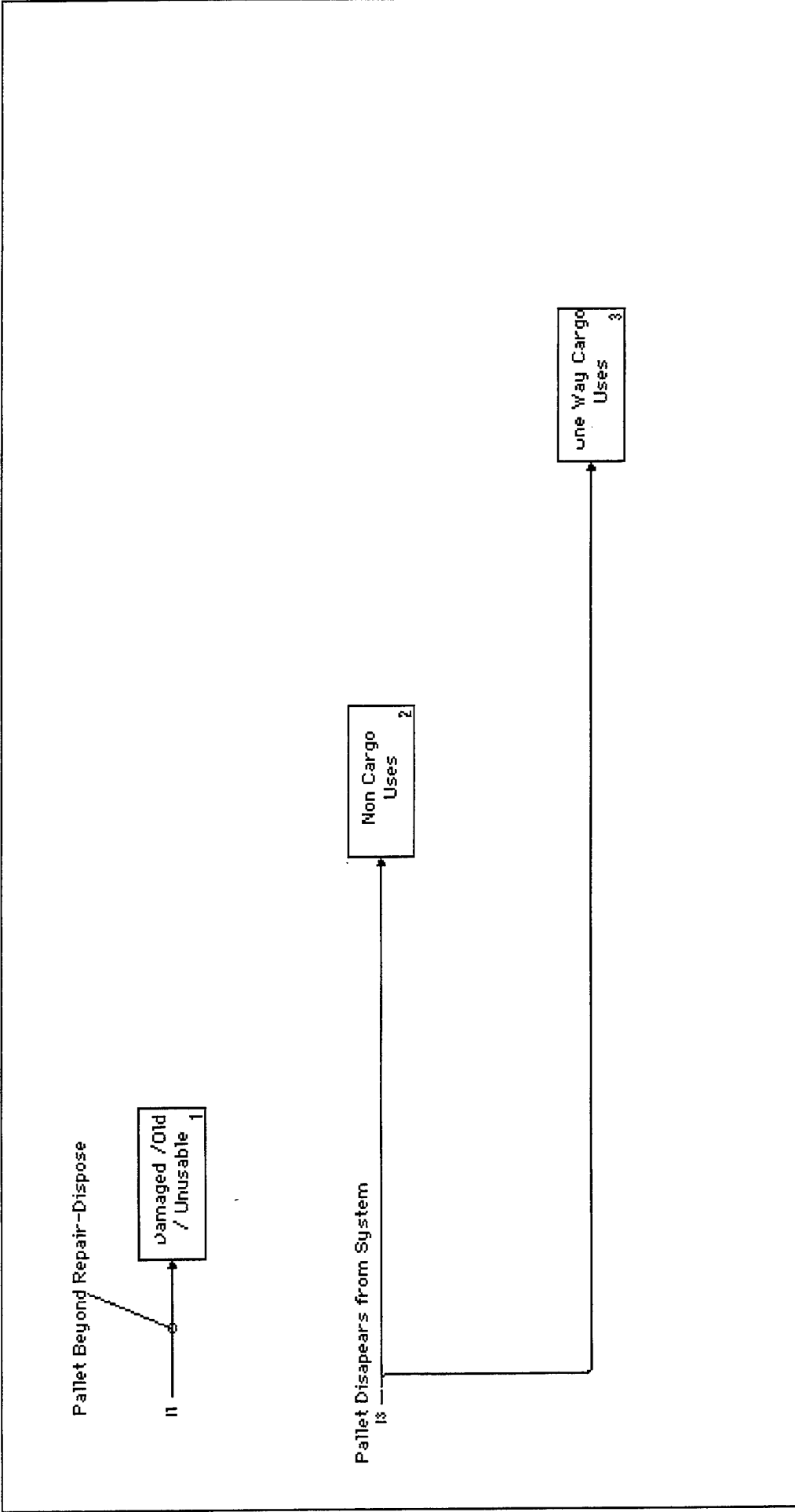
| | | |
|------------------|---------------------|---------|
| NODE: Pallet/A42 | TITLE: Build Pallet | NUMBER: |
|------------------|---------------------|---------|

| | | | | | | |
|----------|-----------------------------|----------------|---------------|--------|----------|----------|
| USED AT: | AUTHOR: Glen R. Gallaway | DATE: 01/24/97 | WORKING | READER | DATE | CONTEXT: |
| | PROJECT: Pallet System | REV: 05/23/97 | DRAFT | | | |
| | NOTES: 1 2 3 4 5 6 7 8 9 10 | | X RECOMMENDED | GG | 05/23/97 | |
| | | | PUBLICATION | | | |



| | | |
|-----------------|-----------------------------|---------|
| NODE: Pallet/A5 | TITLE: Depot Repair Pallets | NUMBER: |
|-----------------|-----------------------------|---------|

| | | | | | | |
|----------|-----------------------------|----------------|---------------|--------|----------|----------|
| USED AT: | AUTHOR: Glen R. Galloway | DATE: 01/15/97 | WORKING | READER | DATE | CONTEXT: |
| | PROJECT: Pallet System | REY: 05/23/97 | DRAFT | | | |
| | NOTES: 1 2 3 4 5 6 7 8 9 10 | | X RECOMMENDED | GG | 05/23/97 | |
| | | | PUBLICATION | | | |



| | | |
|-----------------|----------------------------------|---------|
| NODE: Pallet/A6 | TITLE: Lose / Dispose of Pallets | NUMBER: |
|-----------------|----------------------------------|---------|

Appendix C: Equipment Recovery Charts From Bosnia

This data shows the loss rate of pallets, nets, and straps during the contingency operation in Bosnia. The last column has been added to indicate the cost of pallet repair based on a \$500 average repair cost. The cost for pallet loss and repair was \$ 3,690,297 for this operation alone. This data indicates that about 55% of the pallets are lost in a contingency operation (at an average cost of \$900 each). Additionally, 10% of the pallets used are returned for repair (at an average cost of \$500 each).

| | Shipped | Returned Unserviceable | Returned Serviceable / Unserviceable | Total Assets Returned | % of Assets Returned | \$ Profit or Loss of Assets | Cost of Pallet Repair (Ave. \$500 each) |
|---|---------|------------------------|--------------------------------------|-----------------------|----------------------|-----------------------------|---|
| July 92-December 93 | | | | | | | |
| 463L Pallets | 3903 | 632 | 0 | 632 | 16.20% | \$ (2,771,808) | \$0 |
| 463L Top Nets | 1516 | 185 | 0 | 185 | 13.20% | (135,481) | |
| 463L Side Nets | 7806 | 1294 | 0 | 1294 | 16.60% | (561,204) | |
| 5K Straps | 16870 | 1085 | 0 | 1085 | 6.40% | (193,051) | |
| January 94 - March 94 | | | | | | | |
| 463L Pallets | 681 | 431 | 421 | 852 | 125.20% | \$ 153,900 | \$210,500 |
| 463L Top Nets | 739 | 422 | 75 | 492 | 67.50% | (32,505) | |
| 463L Side Nets | 1358 | 555 | 290 | 855 | 63.00% | (68,125) | |
| 5K Straps | 674 | 202 | 150 | 352 | 52.20% | (5,683) | |
| April 94 - June 94 | | | | | | | |
| 463L Pallets | 790 | 756 | 108 | 866 | 115.50% | \$ 68,400 | \$54,000 |
| 463L Top Nets | 190 | 150 | 75 | 232 | 120.20% | 4,393 | |
| 463L Side Nets | 1436 | 880 | 100 | 1380 | 96.10% | (47,917) | |
| 5K Straps | 3640 | 917 | 110 | 1327 | 28.7 | (32,784) | |
| July 94 - November 94 | | | | | | | |
| 463L Pallets | 941 | 220 | 129 | 349 | 37.10% | \$ (611,468) | \$64,500 |
| 463L Top Nets | 384 | 43 | 7 | 50 | 12.90% | (34,966) | |
| 463L Side Nets | 1884 | 358 | 122 | 480 | 25.50% | (131,308) | |
| 5K Straps | 3927 | 291 | 25 | 314 | 8.10% | (43,777) | |
| Totals | | | | | | | |
| 463L Pallets | 6275 | 2649 | 650 | 2599 | 43.00% | \$ (3,361,297) | \$329,000 |
| 463L Top Nets | 2832 | 810 | 154 | 964 | 34.00% | (202,944) | |
| 463L Side Nets | 12482 | 3097 | 913 | 4309 | 33.10% | (808,674) | |
| 5K Straps | 25111 | 2495 | 283 | 2780 | 11.10% | (272,256) | |
| Total \$ Lost from Lost Pallets and Repairs to Damaged Pallets | | | | | | | \$3,690,297 |

Appendix D: Evaluation and Testing of Plastic Dunnage

Background

The Air Force is considering replacing wooden dunnage with recycled plastic dunnage. Before committing to this change, the Air Force would like to assure that the plastic dunnage will offer at least equivalent service to that now obtained with wood dunnage. It is important that this evaluation take into account the many factors that affect the overall life cycle of the dunnage.

Plastic lumber has been around for many years. Most products are made from scrap or waste plastics in order to keep the cost as low as possible. At present, the Air Force is evaluating a specific product, Perma-Poly™, a polyolefin-based plastic lumber made by ReNew™ Plastics, Luxemburg, WI.

This report describes the evaluation carried out by a team at Battelle Memorial Institute's Polymer Product Center in Columbus, Ohio.

Objective

The objective of this evaluation is to determine on the short term if plastic lumber, in this case Perma-Poly™, is a suitable replacement for the presently used wood dunnage. It should be noted that each of the several commercially available plastic lumber products may have its own profile of properties and characteristics that are influenced by the materials used and the manufacturing process. For example, some products use no filler and are foamed during formation to lower cost and weight. Other materials have added fillers ranging from wood flour to glass fibers and other inorganic fillers. Thus, care should be taken in selecting the properties and characteristics that are specified for this application.

Service Environment

The dunnage is used throughout the world. In most cases, the dunnage remains at the loading station. However, there are also cases in which the dunnage remains with the load until its destination. As a result, the dunnage will be in service in a wide range of environmental conditions from hot to cold and dry to wet and all combinations in-between. Temperatures from about -10°F to about 120°F will not be uncommon. In some very hot and sunny climates, dunnage resting on an asphalt runway may be heated to as high as 160°F. In the arctic, dunnage left on the runway for several hours can encounter temperatures as low as -60°F.

The maximum load specified for the pallets is 10,000 pounds, which is supported by three pieces of dunnage. The load is usually distributed uniformly over the three pieces because the pallet is very stiff. However, occasionally the dunnage may experience a higher localized load due to uneven packing of the pallet or unevenness of the ground under the pallet. In addition, in extreme circumstances it is possible to have loads up to three times the specified limit, for a total of 30,000 pounds.

One piece of dunnage provides a pallet-contact area of nominal 3 1/2 in. x 88 in. (308 sq. in.). Using three pieces of dunnage as support, the total area supporting the load of 10,000 lbs., maximum, would be 924 sq. in. Thus, assuming a uniform load, the pressure on the dunnage would be only 10.8 pounds per square inch (psi). Even if the pallet is loaded to its safety limit of 30,000 lbs., the pressure would only be 32.5 psi.

The dunnage may be dropped from the ramp of an aircraft, as high as 20 ft, and will also be thrown onto stacks after use. The impact from these actions will have an effect both from chipping and from breakage of the dunnage. Forklift tines will be driven against the dunnage whenever an operator misguides the forks. The dunnage may also be run over by trucks and soak up excess fuels or lubricants.

On some bases where the wood dunnage will be used in unloading the cargo, the environment is conducive to insect infestation. Not only does this infestation shorten the life of

the wood dunnage, but also the dunnage cannot be taken from one country to another when infestation is a possibility.

The dunnage may also be exposed to chemical warfare agents. It is important to understand what will happen to the dunnage in the presence of the agents as well as how to decontaminate the dunnage after exposure.

Technical Analysis

For this evaluation, a recycled plastic lumber, Perma-Poly™ by Renew, was compared to the presently used white pine. Perma-Poly™ is a polyolefin product extruded from recycled plastics. The product is apparently based on polyethylene, although the type of polyethylene—low-, medium-, or high-density—has not been specified. White pine is currently the most commonly used material for dunnage.

Most material characteristics that need to be compared between the wood and plastic dunnage were evaluated without incurring the cost of testing. Only one material property, impact resistance at low temperature, was tested. In all other cases, the properties of the two materials were compared using manufacturer's published information, accepted knowledge about the materials, and known responses to the selected factors. In these cases, a textual description is given.

A brief discussion of the possible use of other polymeric materials will be included but this work will specifically address the suitability of the Perma-Poly product from ReNew.

Environmental Properties

Temperature and Moisture Resistance

Temperature. Wood dunnage will have very little response to temperature extremes from -60°F to 160°F. If the higher temperatures lead to drying, the wood may become slightly more brittle. No effect is anticipated at temperatures as low as -60°F.

Polyolefins, such as the materials used in PermaPoly™, are semi-crystalline materials that have a melting point above which the material has very little structural integrity. Since PermaPoly™ is based on polyethylenes, this melting temperature will be about 250°F to 260°F. However, as the temperature of the PermaPoly™ increases from room temperature, the stiffness of the polyolefin boards will decrease. At the melting point, the board will have hardly any structural strength.

The highest temperatures that the plastic dunnage will encounter will be on the order of 160°F. Although the dunnage will be more easily bent at this temperature, deforming the dunnage beyond serviceability will require stress well above that expected in normal usage.

Temperatures below freezing may cause more problems for plastic dunnage than temperatures above 100°F. Most plastics will become brittle at a low temperature when the amorphous part of the plastic goes through a transition from a rubbery state to a glassy state. The result of this transition is a change in the material's response to stress. A crack can be initiated and propagated at a much lower stress at temperatures below the glass transition temperature.

Precautions against dropping the dunnage from heights over four to five feet at temperatures below -10°F should be implemented.

Moisture. Prolonged exposure to moisture often has a detrimental effect on wood. The softer woods, such as pine, are more susceptible. Wood absorbs water and becomes heavier, but more importantly, the wood will soften and become more likely to rot. Due to this softness, it is also more likely to become bug-infested.

Perma-Poly™, on the other hand, will show very little effect from moisture. Polyethylene will absorb only a few tenths of a percent of its weight in moisture and that moisture does not in any way interact chemically with the polyolefin base. Perma-Poly™ appears to have some porosity in the center. This may be an artifact of the manufacturing process in which the core of the board will cool more slowly than the outer volume and thus will shrink more, leaving voids. Some plastic lumber uses a foaming agent in the basic formulation, which will result in a porous material. If the voids in either case are open, moisture may absorb into the space. However, the only detrimental effect expected would be a slight increase in weight.

Based on the above analysis, it is expected that PermaPoly™ will provide better service than wood in a moist environment.

Sunlight Resistance

Both wood and polyethylene will experience some changes when exposed to sunlight and heat over long periods. The effects of outdoor exposure were considered in light of the geometric shape and size of the dunnage. Because of the thickness of the dunnage, even severe damage of the surface may not have a significant effect on its serviceability.

Both wood and plastic dunnage are relatively opaque to ultraviolet radiation, which is the most damaging component of weathering. The UV radiation will then affect the outer surface by causing chemical changes in the material. However, the damage will take place at a depth of 1/8 to 1/4 inch. The remainder of the dunnage, well over 90% of the total thickness, will not be affected.

The weathering of the wood may, however, cause some embrittlement that leads to chipping and splintering. This situation is not expected in the plastic dunnage, making it superior to wood in terms of weather resistance.

Resistance to Insects

Wood is susceptible to insects that eat it and thus significantly weaken the dunnage. There are no known insects that will have an effect on polyethylene. Some countries prohibit importing used wood articles. Some countries do not allow wood to be imported without some testing and/or certification that it is insect free. Plastic dunnage will not be damaged by insects and can be imported to any country.

The resistance of the polyolefin plastic dunnage to insect infestation gives the PermaPoly™ an important advantage over wood dunnage.

Burning Characteristics

There are many plastics, each having its own burning characteristics. Some are more flammable than others. Some will continue to burn, once ignited, while others are self-extinguishing when the source of flame has been removed. The National Fire Protection Association (NFPA) has a system of rating materials in regard to fire hazards. This system is used in most fire codes throughout the country.

Both wood and polyolefin will sustain a flame after being lit. The major difference in the two is that the wood will remain stiff and will burn away, whereas the plastic will burn and melt. In many construction applications, the melting is a problem because it may be the source of fire-spreading as the dripping, burning plastic falls on other areas and propagates the flame. This situation is not a consideration, however, with the dunnage because the plastic pieces should not be stored in an area where there is a danger of the fire spreading.

There is no significant difference between the plastic and the wood dunnage in its resistance to burning.

Mechanical Properties

Compressive Properties

The pallets are normally loaded to no more than 10,000 pounds. Even if an extreme circumstance required a load of 30,000 pounds, the maximum compressive load in this situation will be no more than 33.9 psi.

The compressive strength of PermaPoly™ is about 3900 psi. The expected compressive stress placed on the dunnage is, therefore, well below the point at which any physical effect is expected. Likewise, pine has a compressive strength near 5000 psi.

Creep Resistance

If a continuing load is applied to the plastic dunnage, creep may occur. Creep is the relaxation of the material under load so that the material deforms. Creep is not normally exhibited by wood even at very high loads. However, creep is a common phenomenon with polyolefins. Creep becomes more important as the load approaches the compressive strength of the material. The 33.9 psi that might be applied to the dunnage in its proper use, however, is well below the compressive strength. Significant creep is not expected under such a load on polyolefins.

Since the potential for creep with the wood and the plastic dunnage is negligible, it is judged that there is no significant difference between the two.

Tensile Properties

Since the dunnage will rarely be placed in a tensile load during service or even in storage, no comparison of the tensile properties of the materials was necessary. Any differences in the tensile properties of the wood and plastic materials will not have a significant effect on the serviceability of the dunnage.

Shear Properties

A shear load results when forces acting in opposite directions but parallel to one another are applied to an object. A preliminary analysis indicated that there are no significant shear forces applied to the dunnage.

No comparison of the effects of shear forces on wood and plastic dunnage was necessary. Any difference in the resistance to shear forces of the wood and plastic materials will not have a significant effect on the serviceability of the dunnage.

Impact Resistance

Impact will be a common force applied to the dunnage. The dunnage may be dropped from a plane or thrown from place to place on the ground as the cargo is loaded and unloaded. Temperature can make a significant difference in the impact resistance of materials. Lower temperatures may result in a significantly lower impact resistance.

Wood is not known to become significantly more brittle at high or low temperatures. At temperatures above freezing, i.e., above 32°F, the plastic will remain relatively ductile and dropping the dunnage from heights of as much as 20 feet should not damage the PermaPoly™. However, polyethylene has a temperature, called the glass transition temperature, below which the material becomes significantly easier to break through impact. It is expected that this transition will occur in the range of -20°F to -60°F for recycled polyethylene in the plastic

dunnage. In order to test this hypothesis, the impact resistance of the PermaPoly™ dunnage was evaluated experimentally.

PermaPoly™ boards were dynamically tested in a pendulum drop-weight-testing machine to simulate the effects of impact on the dunnage. In order to completely understand the safety factors involved in the service loads, it is necessary to determine how near to failure the dunnage is when it is subjected to a typical impact force. A worst case for the dunnage impact was chosen to be a 20 foot fall from an airplane cargo hold.

The relationship between failure and service loads can only be determined by obtaining failures under known conditions and comparing them to the project impact load in service. In Battelle's approach, the energy available from dropping the dunnage 20 feet was compared to the energy required to break the PermaPoly™ dunnage at various temperatures under controlled conditions. If the drop energy is higher than the energy required to fracture the plastic lumber in the laboratory, then it is possible that the plastic lumber will fail when thrown from the cargo bay of an airplane. Failure is expected to occur at lower energy at lower temperatures.

The drop-weight tester used for this testing drops a 1720-pound head attached to a 5.15-foot pendulum. The machine is capable of generating 15,000 foot pounds of energy at its maximum height. An energy of 5,000 foot pounds was used for this testing by decreasing the drop height. The energy required to fracture a specimen is determined by measuring the initial drop height of the weight and comparing it with the return height after the weight has fractured the test specimen. The energy required to fracture the specimen is given by:

Where: $E = \text{energy in foot pounds,}$ $E = W \times \langle h_{init.} - h_{final} \rangle$

$W = \text{weight of drop weight head in pounds,}$

$h_{init.} = \text{initial height of weight in feet,}$

$h_{final} = \text{final height of weight in feet.}$

The test specimens were 20-inch lengths of 3½ in. X 3½ in. PermaPoly™. The thickness and width were left in the as-received condition. The specimens were tested at 4 temperatures: 70°F, -20°F, -40°F and -60°F. Each specimen was soaked for at least 2 hours at the test temperature in a cold furnace. The specimens were taken out of the furnace and tested within 1 minute of their removal. A minimum of 3 specimens was tested at each temperature.

As a point of comparison to the results of the drop-weight tests on the PermaPoly™, specimens of yellow pine dunnage were tested. The three specimens were cut from the same piece of dunnage but were slightly different. One specimen had no knot, one had a knot in the center of the specimen, and the third had knots at the ends of the specimen. The results were correspondingly different.

The drop-weight test machine provides an impact at a relatively high strain rate. The fracture surfaces of the failures at all temperatures were quite similar and indicated a brittle fracture mode. As a check against the reality of this observation, one piece of PermaPoly™ was fractured in a four-point bend test at 70°F. The strain rate in this test is significantly lower than in the impact test. There was no significant difference in the appearance of the fracture surface.

Overall, the results are quite interesting and provide some guidance about potential for breakage of the dunnage in cold weather service. All of the wood specimens failed at energy above that of the PermaPoly™, indicating that the wood has higher impact resistance than the PermaPoly™. The presence and position of the knots are definitely important. It is interesting that there is no significant difference in the energy required to break the specimen at temperatures ranging from 70°F to -60°F. The glass transition temperature is expected to occur somewhere in that range and should have caused a decrease in the energy required to break the specimen at temperatures below that transition.

Based on these results, it appears that wood will be preferred over the PermaPoly™ in situations involving impact. However, it was not possible to determine if the PermaPoly™ will

break if thrown from 20 ft. at low temperatures. It is believed that breakage would not occur in the usual case in which the impact is not placed at an exact point to maximize the transfer of energy from the drop to a single site on the dunnage.

The data indicate that limiting the drop height to no more than 12 feet during low temperature service will likely give a safety factor of 2, which will be adequate.

Another issue is involved in the impact resistance of dunnage. The pieces of dunnage may chip and splinter upon impact. In the drop-weight tests, the wood specimens chipped and splintered whereas the plastic had only a few specimens for which small pieces of plastic were broken *from the fracture surface*. There should be no chipping or splintering with the plastic dunnage upon impact.

Elasticity

Elasticity is the property through which a deformed object returns to its original shape. This property has an important influence on the impact, tensile, and compressive properties.

No comparison of the elasticity of the two materials was necessary. Any difference in the elasticity of the wood and plastic in dunnage will not result in a significant difference in the serviceability of the two materials in use as dunnage.

Specific Gravity

The specific gravity of PermaPoly™ is in the range of 0.94 g/cc to 0.96 g/cc according to ReNew's literature. The specific gravity of wood will vary according to the type of pine and to how well it was dried before use. Some wood is pressure-treated with a preservative. This treatment generally raises the density of the wood, so that this type of wood will be heavier than the untreated wood. The specific gravity of untreated yellow pine is in the range of 0.61 to 0.75.

Using samples of PermaPoly™ and a wood provided by the Air Force, the approximate weight of one piece of dunnage from each material was determined. The weights of one piece of dunnage approximately 3½ in. by 3½ in. by 7 ft. are:

| | |
|-------------|-----------|
| Yellow pine | 17.9 lbs. |
| PermaPoly™ | 24.9 lbs. |

Thus, the PermaPoly™ plastic dunnage is about 39% more dense than the wood dunnage supplied by the Air Force. Note that the plastic dunnage from this manufacturer will not likely vary from piece to piece. However, the wood dunnage may vary if the wood is a different type of wood, e.g., pine versus ash, or if the wood has been impregnated with a preservative.

The 39% difference in weight of an equivalent piece of dunnage may be a significant factor to the crew. However, the real effect must be determined by comparing the actual use of the two materials by the ground crews on the flight line. It should also be noted that Black Rhino Recycling currently has developed a hollow 4"x4" that weighs only 13 lbs. The structural integrity and operational effectiveness for this piece of plastic lumber still needs to be determined by the field.

The only effect of specific gravity (density) on serviceability of the dunnage will be the difference in weight of the dunnage. This property difference may be significant in the serviceability of the plastic dunnage as compared to the serviceability of the wood dunnage and in the lifetime costs of the plastic dunnage.

Hardness

The hardness of the dunnage will have an effect on its resistance to denting and scuffing. The hardness of the polyethylene will be more uniform from piece to piece than wood. The wood will be more likely to chip under some loads than the polyethylene.

The chipping exhibited by the wood will eventually result in splintering. Splintering may cause some safety problems, as the crew must move the dunnage around by hand in many cases, risking cuts and penetrations by the splinters for those not wearing the required leather gloves.

The PermaPoly™ will not splinter. However, it can be dented and the edges can be deformed by impact. The dents and rough edges will not affect the serviceability of the plastic dunnage.

Because of the wood's potential for splintering, the plastic dunnage will have an advantage in this particular area of evaluation.

Torsion Load

Torsion loads occur when a twisting action is applied to an object. There do not appear to be situations in which significant torsional loads would be applied to the dunnage.

Infrared Absorption Spectrum

Although wood and polyethylene have distinctly different absorptions of infrared (IR) radiation, there is no known detrimental effect on the properties of these materials from exposure to IR.

Fuel/Lubricant Resistance

Dunnage will be exposed to certain fuels and lubricants used around the flightline. Wood is affected, but not drastically, by this exposure. Plastic dunnage, particularly if fabricated from polyethylene-based plastics, is susceptible to hydrocarbon-based fluids. Thus, some fuels and oils may affect the material in the PermaPoly™. The interaction may result in some "swelling" of the plastic. Swelling is caused by the absorption of the fluid into the plastic, increasing its volume. This swelling generally reduces the physical strength of the plastic.

The major question is whether or not swelling will occur under the conditions of exposure in service and whether or not the swelling will be sufficient to reduce the serviceability of the dunnage.

The higher the molecular weight of the hydrocarbon, the less likely that the fluid will absorb into the plastic. Automobile fuels are relatively low molecular weights and may cause some swelling. Unless the dunnage is soaked for many hours, even days, there will be very little swelling. As soon as the plastic is removed from the gasoline, the gasoline will begin to evaporate and the swelling is reversed, usually with no permanent effect on the plastic.

Higher molecular weight hydrocarbons, such as might be used in lubricants, will not easily absorb and should not be considered a problem.

The swelling is not likely to extend very far into the bulk of the dunnage, probably no more than 1/4 inch under normal service. This is not likely to cause any change in the ability of the plastic dunnage to support the load of the pallets.

Non-hydrocarbon fuels and lubricants are polar materials that are not likely to absorb into the non-polar polyethylene-based materials. No effect on the serviceability of PermaPoly™ as dunnage is expected from exposure to these types of fuels and lubricants.

Exposure to fuels and lubricants should not significantly affect the serviceability of either the wood or the plastic dunnage. There is a slight possibility that these materials may reduce the life of the wood dunnage. Thus, the plastic dunnage is slightly preferable to the wood dunnage in situations of exposure to fuels and lubricants.

Chemical Warfare Agent Absorption and Resistance

Dunnage will be used in tactical situations in which it may be exposed to chemical warfare agents. It is important that the dunnage have no detrimental effects from exposure to the agents. If the dunnage absorbs agents, which most materials do, there must be a practical means of decontaminating the dunnage or disposing of the dunnage so that the usual activities can continue after the agent attack. The response of the materials to decontaminates commonly used in the Air Force is also important.

Both the wood and the plastic will absorb a measurable amount chemical warfare agents presently in use. Decontamination will be necessary. In both cases, desorption rates will be important in determining the amount of time required to reduce the amount of remaining agent to a less than dangerous level.

Since both the wood and the plastic dunnage are not expensive items, they will likely be considered disposable and will not be decontaminated for reuse. However, in some cases, even contaminated disposable items must be treated to remove the potential for later contamination. One approach commonly used with disposable material is burning. Wood burns faster than polyolefins. It is expected that the PermaPoly™ will be slightly more difficult to burn in a practical period of time.

The wood dunnage will be more desirable in tactical situations where exposure to chemical warfare agents is possible, particularly if the dunnage must be burned after exposure. However, the ability of the wood and of the plastic dunnage to act as supports for pallets will not be compromised during or after an agent attack or after decontamination.

Toxicity of Fumes

Since the PermaPoly now being considered for plastic dunnage is based on polyethylene, the fumes from burning the dunnage should be no more toxic than ordinary trash, which usually has some polyethylene included. The smoke may be more dense than non-plastic trash but it is a breakdown product of a saturated hydrocarbon so the organic chemicals that remain should not have exceptional toxicity. As with any smoke, however, prolonged breathing may be hazardous.

Method of Manufacturing

The method of manufacturing of plastic articles can have an effect on the properties of the article. Plastic dunnage is extruded in lengths that can later be cut to specified lengths. The materials used in PermaPoly™ are recycled polyolefins. Although there is some variation in some recyclates due to the methods of collection and of cleaning, the manufacturer of the material has good control over the raw materials. In addition, an analysis of the key properties that were discussed above indicates that the likely variations in the raw materials, the extrusion process, and the properties of the lumber will not be significant in the application of the PermaPoly™ as dunnage.

In considering the manufacturing method of wood, one must include the condition under which the tree grew. There can be differences due to soil and climatic conditions. These are usually accounted for when the wood is graded before selecting the application for which the wood is cut. Assuming that the dimensions of the board are properly maintained, the sawing of the wood should not have a detrimental effect on its use as dunnage.

There is no significant difference between the wood and plastic dunnage due to the distinctly different manufacturing methods. Table D-1 on the next page summarizes the results from the analysis conducted at Battelle's Polymer Test Center.

Table D-1. Summary of Comparisons of Plastic and Wood Dunnage

| Property/Characteristic | Comparison |
|--------------------------------|--|
| Burning Characteristics | No significant resistance |
| Chemical Agent Exposure | Wood is slightly preferred |
| Compressive Strength | No significant difference |
| Creep | No significant difference |
| Density | Wood is preferred. |
| Elasticity | Comparison is irrelevant |
| Fuel/Lubricant Resistance | Plastic is slightly preferred |
| Hardness | Plastic is preferred |
| Impact Resistance | Plastic may require limitations to use in low temperatures |
| Infrared Absorption | No significant difference |
| Insect Resistance | Plastic is clearly preferred |
| Manufacturing Method | No significant difference |
| Moisture Resistance | Plastic is clearly preferred |
| Property/Characteristic | Comparison |
| Shear Properties | Comparison is irrelevant |
| Temperature Resistance | Plastic may require limitations to use in low temperatures |
| Tensile Properties | Comparison is irrelevant |
| Torsion Load | Comparison is irrelevant |
| Water Absorption | Plastic is clearly preferred |
| Sunlight Resistance | Plastic slightly preferred |

Discussion of Use of other Plastics in Dunnage

PermaPoly™ is fabricated from a recycled polyolefin and is expected to be mostly polyethylene. Polyethylene has several interesting advantages. It is one of the cheapest polymeric materials. Its recyclate is even lower in cost, in the range of 40% to 60% of the price of virgin polyethylenes. It is recycled in a high enough volume to offer a sustained source of raw materials. It is one of the least dense of the plastics and it can be easily converted into profiles such as the 4" X 4" boards used in dunnage.

Other plastics may offer some, but not all, of these advantages. For example, polyvinyl chloride (PVC) is cheaper by the pound than any other plastic. However, it is also denser by more than 30% and it is not recycled in sufficiently high volumes as of the writing of this report to sustain a source of recycled raw materials. PVC is also more difficult to process; it requires more energy due to the higher softening points of PVC versus polyolefins, and it requires that special alloys be used in the processing equipment to minimize the effects of the HCl released during the processing of PVC at elevated temperatures.

Polypropylene offers similar advantages to polyethylene. Although the virgin polypropylene is still less expensive than most other plastics except polyethylenes and PVC, it is still more costly. The recycling of polypropylene has not been taken to the extent of polyethylene, so that the price and the sustainability of the source of recycled polypropylene is not sufficient for a continuing supply for plastic lumber.

Other plastics such as nylon, acrylic, and polycarbonate are significantly more costly than polyethylene and the price can not be adequately lowered by using recyclate because there is very little of these plastics recycled at present.

Thus, one must conclude that recycled polyethylene is the preferred basic plastic for dunnage.

Other products can be added to the plastic lumber to change some of its properties. Wood flour has been shown to provide some advantages in properties over the unfilled plastics,

but they would not make the plastic dunnage more serviceable or longer-lasting than the present PermaPoly™. The cost would be higher than the present product, as well.

The addition of glass fibers will add some strength but they will also add weight. No advantages in the dunnage application are perceived.

Other fillers will yield similar results with no definable advantage other than a potential lowering of cost for very cheap fillers such as calcium carbonate and talc. However, they will render the plastic lumber more dense.

The most appealing additive would be a foaming agent that could be judiciously used to lower the weight and the cost of the lumber while maintaining strength. This benefit may be a very important factor in the acceptance of the plastic dunnage by the ground crews.