TALPS
The T-AVB Automated Load Planning System

Paul S. Cerkez
DCS Corporation
46641 Corporate Drive
Lexington Park MD 20653
(301)-862-2390 ext 317
FAX: (301) 863-0324
pcerkez@dcscorp.com
pcerkez@acm.org
Affiliations:
AAAI, ACM: (SIGART and SIGRAPH), IEEE Computer Society

Abstract

Due to military drawdowns and the need for additional transportation lift requirements, the US MARINE CORPS developed a concept wherein they had modified a commercial container ship to support deployed aviation units. However, a problem soon emerged in that there were too few people who were expert enough to do the unique type of planning required for this ship. Additionally, once someone did develop some expertise, it was time for him or her to move on, retire or leave the active duty forces. There needed to be a way to capture this knowledge. This condition was the impetus for the TALPS effort. TALPS is now a fielded, certified application for Marine Corps Aviation.

T-AVB Background Information

Background:
Historically, one of the most difficult problems facing Marine Aviation Logistics planners was finding an affordable, flexible, and rapid means of providing intermediate maintenance capability for forward-deployed aircraft. To overcome these challenges, in the mid 1980's, the Department of the Navy purchased the T-AVBs and the Marine Corps introduced the Marine Aviation Logistics Support Program (MALSP).

MALSP incorporates a flexible "building-block concept," known as Contingency Support Packages (CSPs) that follows a pre-arranged deployment and employment scenario for assembling the right mix of Marines, support equipment, Mobile Facilities (MF), and spare parts within a Marine Aviation Logistics Squadron (MALS) to support deployed aircraft. The key word is "flexible." Contingency Support Packages can be rapidly configured to support the contingency aircraft mix and marshaled for movement. CSPs are comprised of either the fixed-wing or rotary-wing common support, and/or the peculiar IMA and Supply support for the various deploying aircraft. Initial support packages (30 days of spare parts) are flown in to the operational theater as part of the Fly-In Echelon (FIE); the balance of the Marine Air Ground Task Force (MAGTF) commander's tailored aviation logistics support arrives in theater aboard the T-AVB. Without the T-AVB, it would require more than 140 C-141 cargo aircraft flights to deploy a MALS with an IMA level capability to a crisis area.

The T-AVB ships were acquired as a result of a Marine Corps "Feasibility Study of the Aviation Logistics Support Ship" (USMC 1983). Two ships have been modified for use by USMC I-Level aviation maintenance and supply organizations. The Department of Transportation Maritime Administration (MARAD) maintains the ships in a 5 day reduced readiness status using a civilian, commercial U.S. Merchant Marine retention crew stationed aboard each ship to monitor equipment conditions and conduct vessel maintenance and repair.

The Mobile Facility (MFs) work centers used by the Marine Corps conform to the standard commercial International Standardization Organization (ISO) container dimensions, which are 8'x 8'x 20'. Figure 1

Figure 1: MF being prepared for loading

shows a typical work center MF being prepared for loading. Figure 2 shows a special doublewide arrangement. Access modules are used to access 2nd and 3rd tier MFs that are 'complex'd' for IMA Level repair capability. Figure 3 shows a typical access module.

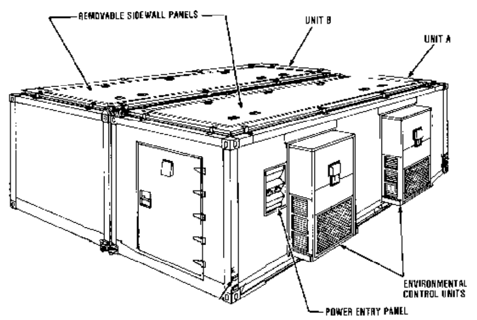

Figure 2: MF Double wide configuration

The modifications to the ships to support an MF setup allows a MALS to operate fully functional work centers on board a ship or in an expeditionary mode ashore, or both. Two basic load out configurations exist for each ship: TRANSPORT mode and OPERATIONAL mode.

In the TRANSPORT configuration, the ship is loaded for maximum capacity. In this mode, MFs are not accessible nor can the equipment contained therein be operated. In this configuration, more than 650 Twenty-foot Equivalent Unit (TEU) containers can be loaded. In this mode, the ship is a standard container ship and

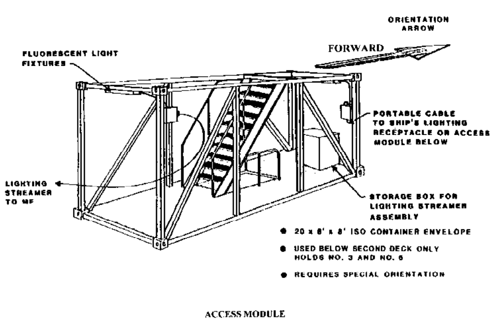

Figure 3: Access Module

supports re-supply operations and missions. The function of re-supply is the secondary mission of the T-AVB.

In the OPERATIONAL configuration, the ship is loaded such that MFs can be placed in a functional, operating condition. What you have in effect is a tailorable, floating, aviation repair facility. Officially, in this configuration, 300 MFs and 42 Access Modules can be loaded, or 342 TEUs. This configuration allows the embarked work centers to process and repair defective or broken aircraft components while en route to an operational theater, or should the concept of operations in theater dictate, continue operating until finally moved ashore (referred to as operating "in stream"). This describes the primary mission of the T-AVB and the most difficult area of load planning.

Load Planning Overview:

The embarking Marines responsible for a particular ship must develop the load plan for that ship. The civilians manning and loading the T-AVB will load the ship any way the Marines tell them, as long as it does not put the ship in an unsafe condition. Unsafe is defined as any condition that would 'hazard' the vessel. For example, if the ship were loaded so that is was top heavy or too heavy on one side, it would put the ship at risk of capsizing. (La Dage and Van Germert 1990)

T-AVB load planning is a time consuming, inflexible process made more so by the high tempo of operations and pressure to execute operational orders in the time allotted in a time of war. The manual system of load planning is not responsive (in a timely manner) to modifications in the force structure, concept of employment or both. There is no formal training, and On-The-Job Training (OJT) opportunities for implementing and exercising load planning considerations are scarce. The lack of this experience and training was abundantly evident when the T-AVBs had to be loaded for Desert Shield/Storm. At that time, the T-AVB concept was still new and there were no experts. It took 5 full 24-hour days to load one of the ships for the desert. With all of the changes, the actual manifest and inventory had to be manually validated after the ship set sail. Changes were being made right up until the very end.

The following facts exist:

- Load planning is complex and tedious.
- No formal training is available.
- Attrition of experienced personnel occurs regularly, (orders, retirement, force reductions, etc.).
- If the load plan is found unstable or modified after being presented to the ship's First Mate/Master, it must be redone.
- For a variety of reasons, T-AVB will not be exercised often enough to maintain a knowledge base readily available to plan loads and deploy.

To develop a load plan, the planner must have a listing of all MFs and cargo to be loaded. MFs embarked include not only maintenance work centers, but also supply department MFs, bulk cargo and rolling stock. That list must identify:

- MF/container power requirements
- MFs needing air and/or water hookups
- MFs/containers needing access
- MF interconnection requirements (shop integrity)
- Ownership of the MFs (Rotary Wing, Fixed Wing, Work Center, etc.).
- Type of MF.

- Projected off-load priority.
- The availability and locations of facility assets on the ship (air, power, etc.).
- Special limitations on locations or MFs.
- Types of additional cargo, (rotor blades, nose cones, rolling stock (MMGs (Mobile Motor Generators), mobilizers, etc.), POLs (Petroleum, Oils, Lubricants), etc.).
- Pier side facilities at both departure and destination ports.
- Status of the Ship's cargo handling equipment, MF support systems, and ship access points (hatches, ramps and doors).

Once the load planner has all the requisite data in hand, he must compare what is needed against the ship's facilities and develop a proposed load plan. After the load plan is completed it must be presented to the ship's First Mate/Master for approval. If the load plan is found to be unsafe, (i.e., "…the ship floats upside down"), the load plan must be redone. Any modifications to an approved plan require resubmission.

Taking into account the above listed conditions, if it takes the load planner only 1 minute per item of cargo to identify where to place it in the ship, with over 350 MFs and access modules, it will take over 5 hours to develop a load plan. Now, add to that rolling stock and other bulk stores/cargos that may take two minutes per item due to irregular shapes, sizes and ability to stack (or lack of). Assuming NO CHANGES in what is to be loaded, an experienced, seasoned load planner can develop a load plan to present to the ship's First Mate/Master in about 8 to 10 hours. In reality, it takes anywhere from 1.5 to 2.5 days to develop the initial load plan.

Prior to TALPS, T-AVB load planning had always been done manually, (the "stubby pencil" method). The particular problems presented by this unique situation made it an ideal candidate for automation.

Solution

Automation Of the Load Planning Process

The purpose of the T-AVB Automated Load Planning System (TALPS) is to automate the T-AVB load planning process. The TALPS program uses artificial intelligence (AI) to follow the same logical steps that an expert uses in completing complex tasks associated with load planning.

The ability to develop load plans with a prolog-based expert system was proven in the early 1980's when SRI International developed the Automated Airload Planning System (AALPS) for the military (U.S. Air Force) using Quintus Prolog. AALPS was constraint based, but like a number of other load planning programs, it requires the user to place the item of cargo. The aircraft cargo loading system then validated the load against all constraints. Stanley & Associates developed a ship loading program called CAEMS (Computer Aided Embarkation Management System) using a Paradox Database driving an AutoCad user interface, interfaced using the C Language, for the United States Marine Corps in the late 1980's. CAEMS was used to help load the ships coming back from Desert Storm and a much improved, updated version is still in use by the Marine Corps embarkation community today. "AutoShip" (Autoship Systems Corporation) is another software tool available to commercial shipping companies that supports loading containerized cargo. AutoShip, is a ship type/class specific tool and is configured at purchase time for the vessel(s) it will support. The US Army Military Traffic Management Command had an application called CODES that is in the process of being upgraded, modernized and renamed to ICODES (Integrated Computerized Deployment System). ICODES is being developed by the CAD Research Center, California Polytechnical Institute in San Luis Obispo and has seen limited fielding.

CAEMS, ICODES, and AutoShip operate primarily the same way for ships that AALPS does for aircraft loads; the user loads the cargo and the system validates the load against constraints. These programs are designed to be extremely flexible in that they never know what kind of ship or load they may have to develop. All three are 'template' based. CAEMS does have an AI module that does 'auto-pro-ration' (a term used to describe how the module computes the flow of cargo into a location) while ICODES is an AI 'Agent' based application (originally built using CLIPS and now being developed in C++) that will automatically place cargo items in a template developed by the user. These routines analyze the cargo to ensure it can get to it's designated cargo storage location, (i.e., can it fit through the hatch, make the turn onto a vehicle ramp, etc) and assigns specific cargo items to the template locations. The templates act as 'greedy attractors' (locations trying to pull certain types of cargo to them) to specific cargo types and individual serialized items are then stowed. For example, if the template shows a position for a M1A1 tank for Unit A, any one of Unit A's tanks could end up there unless the user designates a specific one. Developing these templates is the most time consuming operation of load planning, it is in effect, manual load planning.

While TALPS will support this manual cargo placement method of operation also, the significant difference with TALPS is that it can also place the cargo automatically. With most of the other systems, a domain expert is doing the template and load plan development. Due to the unique mission of the T-AVB, all of the 'template' knowledge for any type of load the ship is capable of carrying is in the TALPS fact and rule bases. Because of the unique functionality provided by the ship, there are extremely few people with T-AVB load planning expertise. The problem is that there are domain experts for the ship, there are domain experts for the cargo, and there are experts in ship loading, but there are extremely few experts in all three domain areas. TALPS combines the expertise from all three domains for this application. The prolog development environment for this expert system is "PDC Visual Prolog".

The Advantages of TALPS

One important feature of TALPS is it automatically considers the ship's load and stabilization requirements. As such, the ship's First Mate/Master will not reject a load plan as being unsafe. CAEMS and ICODES must export the load to another application for Trim, Stress and Stability (TSS) verification. This represents the single most significant benefit of TALPS: TIME SAVINGS. With a manual load planning time of 8 to 10 hours per session (that could be rejected as unsafe, thus restarting the 10 hour clock), the time to develop a load plan can be significant. In actual planning exercises, the time to complete a load plan with TALPS from start to finish, has been under 1 hour.

Additionally, TALPS provides cargo preparation schedules, load team assignments, and cargo flow schedules. These additional items are by-products of the load planning process within TALPS that normally would have to be prepared manually after the plan is approved. Each of these products would normally take hours by themselves to produce. All of these products increase the efficiency of the loading evolution. CAEMS and ICODES do not provide these additional capabilities.

The Evolution of TALPS

The TALPS efforts began in 1992 with a proposal from the Naval Aviation Maintenance Office to Headquarters Marine Corps, Department of Aviation. From 1992 through 1997, the TALPS development team participated in every T-AVB training exercise as observers, interviewed all load planners involved with each exercise and extracted knowledge from the few load planning manuals that existed for the ships. From that effort, a T-AVB load-planning manual was written and the TALPS software was produced.

During the initial development efforts, the load plan generation routines went through a couple of revisions. The most notable being the attempt to use a Genetic Algorithm (GA) (Goldberg 1989) to generate a load plan and then have it evaluated against the fact bases for fitness. This effort was attempted however the GA would never advance beyond 50% fitness. After 6 months, the effort was abandoned due to product delivery requirements and budgetary limitations. The lessons learned from developing the fitness function for the GA were then applied to the rule and fact bases.

In May 1997, TALPS, version 1.03c, was certified by American Bureau of Shipping (ABS) as a Safe Loading Instrument and the software was distributed to Marine Corps Aviation Logistics Squadrons (MALS). In 1999, DCS Corporation was contracted to update the software, update the user interface, and update the rules and fact bases to account for additional modifications made to the ships after the initial release of TALPS. TALPS will be reviewed after the annual T-AVB exercise and updated or modified as required. TALPS version 2.1 was fielded in Nov 2000 and is currently being used to plan the 2001 T-AVB exercise. What follows is a discussion of the underlying methodologies of how TALPS works.

The Technology of TALPS

TALPS is primarily a constraint based, expert scheduling system. TALPS is configured to recursively process all cargo items and assigns them to cargo locations. After each complete iteration of cargo assignments, the ship's TSS characteristics are evaluated. If any safety parameters are exceeded, the plan is rejected, the system backtracks (via the internal prolog backtracking mechanism) and the system recalculates the load. By incorporating domain knowledge into the rules that process the cargo data, many of the conditions that would cause a plan to fail are avoided. By avoiding the known unsafe conditions, safe load plans are almost always generated correctly the first time.

As a result of the interviews during the initial TALPS development efforts, certain patterns emerged that later became 'iron clad'. Certain MFs will always be combined and co-located with particular other MFs and these 'blocks' will almost always go into a select few ship locations. A 'block' is normally made up of 2, 3 or 4 MFs. As a result, rules and facts were incorporated to take advantage of these heuristics. By building up a fact base of these 'standardized' blocks, their possible locations, and adding rules to process them, 'blocks' of MFs can be assigned in seconds, leaving only the unattached MFs to be dealt with by the system. One of the biggest challenges was to represent the knowledge and data so the prolog engines could process it. In TALPS, the block's data is represented as facts, each containing a single paired list that represents a block.

An example of the data representation of a single predefined block and three of the legal cell block sets is shown below.

The top level clause (`autoLoad`) controls the sequence of events and cargos are assigned in an order that prunes the search space rapidly. Access Modules are almost always placed in 42 specific locations on the ship. The `autoLoad` clause calls the sub-clauses that handle access modules very early in the process. This removes 42 cargo items from the search space. Dry stores and crew Reefers (refrigeration containers) are handled the

```
mf_blocks(["MV01B","2F32","MV02A","2F34","MV03","2A34","NA01","2A32"])
mf_blocks(["MV01B","2F33","MV02A","2F35","MV03","2A35","NA01","2A33"])
mf_blocks(["MV01B","3F32","MV02A","3F34","MV03","3A34","NA01","3A32"])
```

```
cargo_item(1,"NONE","DRY006","TAVB","000","TAVB00","Z","0","DRY006","000",ds,"AC","NA","TA
VB only")
cargo_params("DRY006",w(2500,2500,2500,2500,5000,5000,10000,"LBS"),d(240,"INCHES1",96,"INC
HES2",98,"INCHES",1306.67,37),b(120,58.8,48))
cargo_info("DRY006","Embark1","Debark1",0,0,0,0,0)
```

same way removing another 10. Next come deep stow cargos. They require no access and are always put into the same 54 cargo locations thus reducing the count. The system then searches for predefined blocks, potentially removing another 50 to 60 MFs from the search space. The previous steps are an application of the heuristics learned during the initial TALPS development efforts; the load planners always got these items out of the way first. By the time the system has to place individual cargo items, the search space has been reduced typically from 350 items to about 180, or about one half the search space.

Another example of the heuristics involved is predefined blocks. The system reads in a predefined block, determines if all of the necessary MFs are available and awaiting location assignment (i.e., not already assigned), and verifies that the cargo locations are available. If both are true, the block is then loaded and system stored parameters are updated to reflect the loaded cargo. If not, the system checks the next available set of preferred cargo locations. Once all of the locations are exhausted, the current block is rejected, the system backtracks and retrieves the next predefined block starting the process all over.

Structuring of the rules and data in this format allows the system to adapt for exceptions to the rules should there ever be a MF block in excess of 4 MFs. The exception is then handled in data without having to change any code.

Once all of the predefined types are assigned, the system then starts assigning cargo items individually based on the parameters listed earlier. If any cargo item is placed that has a 'user designated' partner, they are then treated similarly as a predefined block. If both cannot be placed, then a new set of locations is searched for.

The three facts at the top of the page represent the internal representation of a single cargo item. The serial number ("DRY006") is the link. The data represented carries all of the data needed not just by the system, but also by the user before and after loading.

Ship cargo locations are defined internally as shown below. The cell number ("6F13") is the unique identifier. The two lists at the end of the fact contain constraint data and preference data. By expressing a preference for a particular set of cargo types ["DS","SEAC"] into a specific location, the cell becomes 'greedy' and tries to attract those types of cargo. The limitations list, ["TEU","ISO"] prevents 'un-wanted' cargos. Various other data about the ship that affects load planning are also stored.

In all cases of cargo-to-location assignment, cargo item and cell location characteristics are evaluated. By structuring the facts and rules to account for cargo needs that matched cells facilities, we created a knowledge mapping that allowed for direct pattern matches. The only thing we had to do 'extra' was to create a set of rules that handles the 'don't care' situations. (Example: a cell provides 400Hz power, but the cargo item does not need it.) The five positions at the end of `cargo_info` (all zeros in this case), map directly to the five positions after the "G" in the cell location shown below. This particular cargo item is a dry store container (`cargo_item` fact, 4th field from the end: **`ds`**). This maps directly to the preferred cargo type in cell 6F13, **"DS".** In this case, the cargo item and cell location would be a match.

Overall, the planning process allows the user to define the general concept of the ship's load. This is accomplished by setting a hold's parameters. A schema was developed to maintain the knowledge of the hold's capabilities as well as attributes of the hold in various configurations.

In addition to the holds themselves, a separate schema was developed to maintain data about the cargo handling equipment, access ports and hatches, and location usability based on the status of same. The user sets these parameters at anytime during the planning evolution to reflect the current condition of the ship. Rules within the system act on these conditions and subsequently modify as necessary the cell location parameters.

TALPS rules process all of the facts, within constraints set by the user and imposed by the system, and rapidly produces a certified safe load plan. Figure 5 is a highly simplified drawing of the Load Planning process. All of the Cargo data is entered or updated, all of the ship data is updated, and then the cargo is scheduled into cargo locations. After the scheduling of the cargo, the load is validated for TSS. At any point of failure, the system backtracks and starts the process again. The output is shown as a 'proposed load plan' only because the one constant in T-AVB load planning is change!

```
define cell("6F13",6,"FWD",1,3,"G",0,0,0,0,0,"DSW",1,["TEU","ISO"],["DS","SEAC"])
```

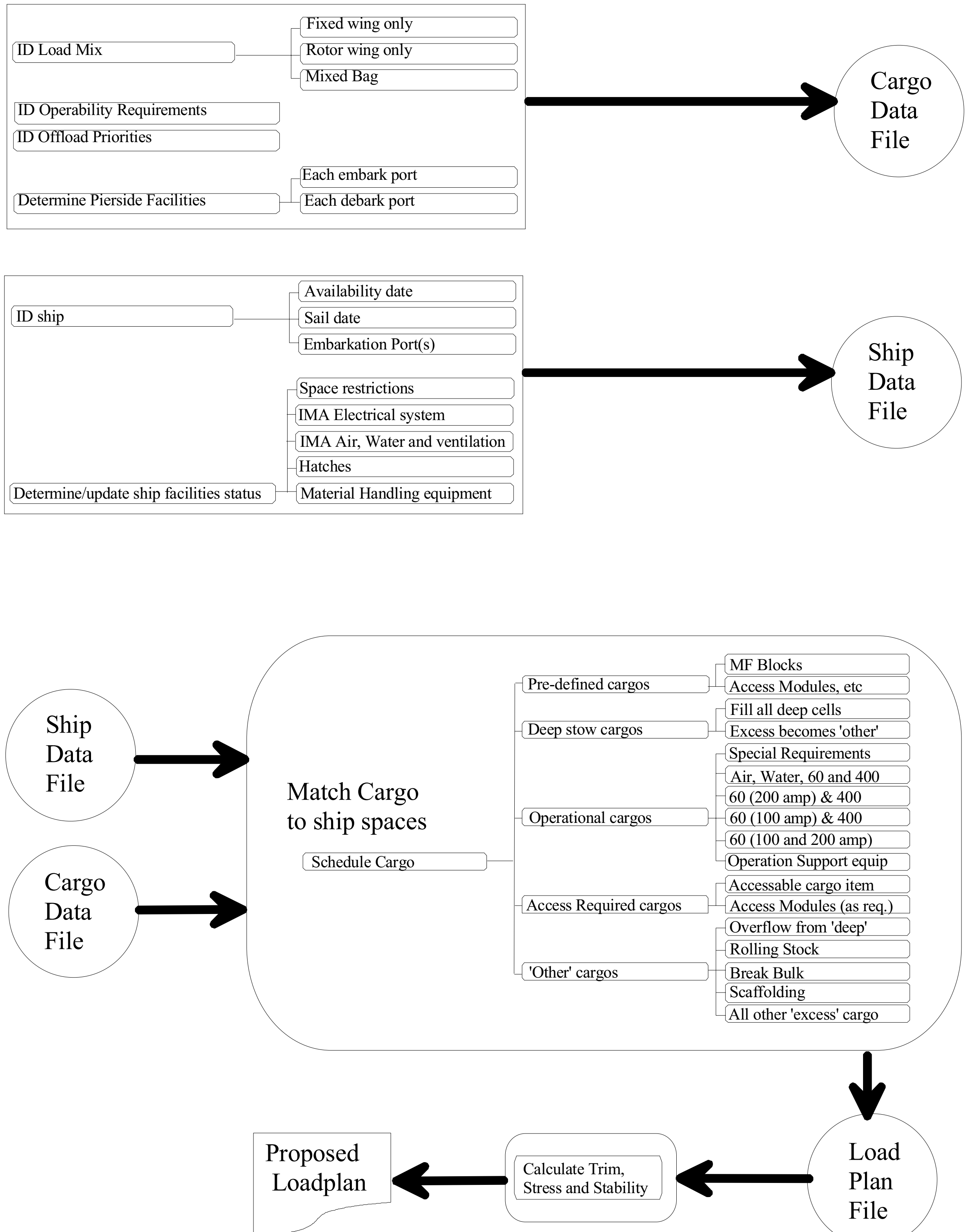

Figure 5: Simplified TALPS flow

The future of TALPS

TALPS was originally conceived as a tool to help the harried planner develop load plans for the T-AVB class of vessels. Over time, it evolved into a repository to maintain the volatile corporate knowledge of the T-AVB load planning process. TALPS has currently planned existence until 2005 at which time a Department of Defense ship-loading tool (ICODES) will be fielded. This new tool is designed to incorporate the knowledge and expertise that currently resides in TALPS as well as other ship loading applications.

Project Sponsor:

Department of Aviation, Logistics Support (ASL-34)
Headquarters, United States Marine Corps

References:

Carrico, M.A., Girard, J.E., & Jones, J.P., 1989. *Building Knowledge Systems: Developing & Managing Rule-Based Applications*, New York,: McGraw-Hill.

Cerkez, P. 1995. Knowledge Representation: An Explanation for 'Buddy', Technical Report, CS5374, Department of Computer Science, Florida Institute Of Technology, Patuxent River Campus.

Covington, M.A., Nute, D. & Vellino A., 1988. *Prolog Programming In Depth*, Glenview, Ill.: Scott Foresman and Company.

Goldberg, David E., 1989. *Genetic Algorithms in Search, Optimization & Machine Learning*, Reading MA. Addison Wesley

La Dage, John and Van Germert, Lee: 1990. *Stability and Trim for the Ship's Officer, Third Edition*, Centerville MD., Cornell Maritime Press,

Luger, G.F., & W.A. Stubblefield, 1993, *Artificial Intelligence: Structures and Strategies for Complex Problem Solving*, 2nd Ed. Redwood City Ca.: Benjamin/Cummings Publishing Co., Inc.

Rich, E., 1983, *Artificial Intelligence*, New York, McGraw-Hill.

Richards, T., 1989. *Clausal Form Logic: An Introduction to the Logic of Computer Reasoning*, Reading Mass., Addison-Wesley Publishing Co.

USMC, 1998. *Aviation Logistic Support Ship (T-AVB) Logistic Planning Manual*, *Revision A*, Lexington Park MD, DCS Corporation.

USMC, 1983. Feasibility, Study of the Aviation Logistics Support Ship, Washington DC: United States Marine Corps.