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Future Seabasing Technology Analysis: Logistics Systems

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Executive summary

The Center for Naval Analyses (CNA) was tasked by the Office of Naval Research (ONR) to review the Navy's seabasing concept, identify potential operational problems, and propose science and technology (S&T) investments to produce new technologies or significantly improve existing ones. We examined the composition of the sea base as a function of the type and scope of the contingencies, which were addressed by the seabased forces and determined that all seabasing operations, large or small, required a common set of operational capabilities. The needed capabilities can be grouped into three categories:

- Logistics systems
- Connectors
- Logistics Command and Control (C2)

We report on each of these categories separately in a three-document series that addresses the future logistics technologies required by the sea base in the 2020-decade; an additional summary report [1] ties the individual reports together. This document addresses logistics systems. Logistics systems allow for efficient tracking and handling of materials as they pass through the logistics pipeline and until they are delivered in support of the forces ashore. The connectors document [2] discusses the Maritime Prepositioning Force (Future) (MPF(F)) squadron of ships as well as the surface and air inter-theater and intra-theater platforms that connect the advanced base to the sea base and the sea base to the shore. The logistics C2 document [3] concentrates on the need for a new type of C2 system, drawing on the principles of Sense and Respond Logistics (S&RL) and information processing technologies, to manage the logistics flow to and through the sea base.

The seabasing concept places a demand on replenishment ships to supply the entire sea base. Providing this level of sustainment to the different customers in the sea base requires advances in logistics systems—in particular, in the cargo handling systems. These systems handle material and ordnance from their delivery point onto the ship, during storage in the ship, to their transfer point off of the ship to a customer.

The Fleet and Military Sealift Command (MSC) are able to keep supplies flowing with current systems, but they have:

- Limited visibility of material, ordnance, and personnel, both in the ship and throughout the supply chain
- Logistics systems that are manpower intensive and slow
- Disjointed logistics operations that lack a seamless flow between processes.

Improvements to these current systems are needed for the seabasing components and, particularly, the replenishment ships to support the warfighter in a timely manner. This document concentrates on the intra-ship logistics capabilities needed to fulfill the seabasing concept, the logistics products currently in development, and far-future technology areas that could improve seabasing logistics.

We have found that the right technologies are being developed to fill the near-term gaps in the sea-based logistics system. However, maturation of these technologies coincides with the purchase of the MPF(F) ships. This overlap means that implementing these technologies in the MPF(F) and, thus, the sea base will be through backfit. The lack of backfit plans and engineering-level designs has created doubts that these technologies can be backfit and that if they are, they will still achieve their maximum (and intended) performance. In addition to the challenge of backfitting, there are no current plans for funding the backfitting of logistics technologies on the MPF(F) ships. In the absence of these technologies, the MPF(F) squadron will reach full operational capability (FOC) in 2020 without the capabilities required by the seabasing concept.

Because of the overlap between the near-term technology development and the shipbuilding schedule, ONR and the Navy need to plan for incorporating the technology during ship construction or, the more likely scenario, for backfitting the technology. The Navy needs to think about how these technologies, which contribute to its ability to support the seabasing concept, will be fielded in the ships for which they were intended and will have the greatest impact. Having the technology transition agreements (TTAs), which ONR establishes with the acquisition community, in place is not enough to ensure full development and fielding of these technologies.

The future technologies result from performance gaps between the capabilities needed by the sea base and the capabilities of legacy and developmental logistics systems. The future technologies ONR should consider funding for sea basing logistics are:

- Sense and Respond Logistics
- Artificial Intelligence, which includes fuzzy logic and neural networks.

S&RL would address performance gaps in total asset visibility, material handling systems, and selective offload. Artificial intelligence affects the performance of material handling systems, selective offload, and logistics C2. While both of these areas are past the S&T phase, they are still developmental and have not been applied to marinized logistics systems.

Throughout this study, we have observed the disjointed development of seabasing. The Defense Science Board (DSB) Task Force [4], in its cornerstone report on seabasing, cited management as the number one issue that had to be addressed and suggested the establishment of a joint sea base program office. In other words, there must be overarching management of seabasing with the authority and funding to plan and coordinate developments in platforms, logistics systems, C2, and the seabasing concept.

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Introduction

In the sea base, the MPF(F) and Combat Logistics Force (CLF) will conduct the majority of the replenishment/sustainment operations[1]. As the seabasing concept stresses the ability of these ships to throughput more logistics material, we focus primarily on the logistics technology needs of these ships.

We define several terms below that we use throughout this document for brevity:

- Logistics resupply: primarily pertains to Class I (subsistence), III (fuel), and V (ammunition), but includes all classes of supply [see appendix A]
- Hold: dry cargo storerooms, reefers (refrigerated units), magazines, and cargo fuel tanks
- Transfer station: Standard Tensioned Replenishment Alongside Method (STREAM) rig, flight deck, and well-deck
- Underway replenishment (UNREP): includes both connected replenishment (CONREP) and vertical replenishment (VERTREP).

Naval logistics and the MPF(F)

Replenishment ships function much like wholesalers in the commercial world. They carry large quantities of supplies and transfer them to customer ships via underway replenishment. Today their primary customer is the Navy. In the future, their customers may include Marine Corps, Army, Air Force, and coalition forces, as well as the Navy. They will be the primary vehicle for throughputting the logistics resupply for the sea base.

[1] We use replenishment and sustainment to mean resupplying other ships in the sea base or forces ashore.

The logistics tasks of a replenishment ship center around receiving cargo, storing it in holds, and transporting it to transfer stations for onward delivery to the customer. Each ship maintains a log of all its cargo and receives resupply requests from customer ships. The subtleties of executing these activities, however, vary across the various ship classes and often within a class. These variations depend heavily on manpower, mission tasking, ship configuration, and logistics technologies.

The ability to conduct logistics functions smoothly and efficiently becomes critical for the MPF(F), which must sustain forces ashore in accordance with the seabasing concept and the Seabasing Joint Integrated Concept (JIC). The MPF(F) must have visibility of assets (e.g., logistics resupply and personnel) from the supplier to the end user and be able to deliver a timely response to the warfighter ashore. A key enabler of the timely response is the ability to move cargo within the ship at rates compatible with cargo moving onto or off of the replenishment ship during an UNREP.

While the seabasing concept demands greater visibility and responsiveness than today's logistics systems can provide, the MPF(F) requirements as part of the sea base continue to evolve—particularly in terms of the amount of cargo, the throughput rates, the degree of selectivity, and the extent to which packages will be tailored for the warfighter.

Although the Office of the Secretary of the Navy selected the MPF(F) squadron design in May 2005 [5], the ship designs and modifications are still uncertain. The three mobile landing platforms (MLPs) will be new designs and new builds. The two maritime prepositioning squadron (MPS) legacy ships and one LHD are the only ships that will be neither new builds nor new designs; they may receive modifications, however. The remaining ships—two LHA(R)s, three Large, Medium-Speed Roll-on/Roll-off ships (LMSRs), and three T-AKEs—will be new builds, but not totally new designs, which means they may receive ship design modifications. Even though most of these ships are based on existing designs, they will still be new builds. The logistics systems are most easily and efficiently installed when they are included while the ship is being built. Once the ship is built without the systems, they have to be backfit, which introduces new engineering, system, performance, funding, and scheduling issues.

Shipboard considerations

The maritime environment poses a unique set of challenges for logistics systems. These challenges prevent land-based commercial systems from being easily installed in ships. Many of the logistics systems discussed in this document are either already in use or well on their way to being adopted by the commercial sector. In some cases, these systems can be modified for the maritime environment, or marinized. In other cases, new systems must be developed from scratch.

Shipboard-specific considerations include the ship configuration, environmental conditions, fail-safe operation, and system design considerations. Compound hull curvature and watertight hull integrity pertain to the ship configuration. Watertight bulkheads separate individual holds and impede horizontal movement [6]. Environmental conditions on a ship include shock, vibration, ship's motion, high sea states, corrosion, and thermal extremes. Electromagnetic interference (EMI) exists due to other shipboard electronic systems and the metal hull, bulkheads, and structures. EMI is undesirable in electronic systems, and it also creates safety concerns in connection with some types of ordnance. Fail-safe operation encompasses redundancy and automated safeties. In the case of a malfunction, the system must remain under positive control, and automated safeties must ensure that there is no damage or uncontrolled movement of the system, load, or personnel. Shipboard systems must be designed to minimize their impact on the overall space, power, and maintenance constraints of a ship.

We previously mentioned the importance of being able to backfit these systems because they must operate with legacy as well as future ships and systems.

ONR's FNC and INP process

The ONR currently funds several of the key logistics technologies under development. Below we briefly explain ONR's Future Naval Capability (FNC) and Innovative Naval Prototype (INP) programs.

- The FNC program identifies "mature and evolving logistics technologies that, through focused investment, guidance and management, can be demonstrated to provide the required enabling capability".[2] ONR must identify the acquisition community to which the technology will transition early in the development process, culminating in a TTA. A TTA defines the project deliverables and exit criteria. The products associated with an enabling capability (EC) transition to acquisition once the exit criteria are met.
- INPs focus on high-risk, "game-changing" technologies. They concentrate on prototype development and do not necessarily have an acquisition program associated with them [9].

[2] [7] and [8] pp 5–1.

Analysis approach

We focus on intra-ship cargo movement, vice a broad treatment of seabasing logistics, because the seabasing concept taxes the cargo movement portion of the logistics chain most heavily. The logistics chain up to the sea base will continue very much as it is today; however, the seabasing concept takes the *iron mountain*[3] off the shore and places it on the sea base. This shift will strain the present logistics systems on the ships in terms of visibility, throughput, and space.

For the logistics systems, we took an approach typical of gap analysis. We began by examining current logistics systems used by replenishment ships. We identified capabilities called for in the seabasing concept. We determined current capability gaps by comparing the capabilities of the current logistics systems and the needed capabilities of the sea base. We then examined the technology products under development, primarily by ONR. By mapping these products against the current capability gaps, we determined the extent to which they close the gaps. This approach was repeated to identify the future performance gaps. These gaps arose because technology products under development either did not completely fill the current capability gaps or filled some of the gaps but opened new ones. Finally, we propose future technologies to close the future performance gaps.

We present quantitative data where possible. However, the assessments are primarily qualitative because of the lack of sufficient quantitative data. Several factors contribute to this situation. Seabasing requirements are defined at a high-level—close, assemble, employ, sustain, reconstitute, and redeploy—with their associated metrics of performance (MOP). The MPF(F) requirements con-

[3] When forces move ashore, a large mass of logistics resupply accompanies them. The forces rely on this stockpile because it reduces their wait for supplies.

tinue to evolve, which means that the needs and requirements of the technologies are not always clear. Another major factor is that the gap-closing technologies are still under development, and their capabilities and specifications are not expressed in quantitative detail. Some of ONR's products have exit criteria. However, where such statements about these technologies or exit criteria were available, we have taken them to be the actual capabilities and specifications of the product. We did not evaluate the progress of the individual projects toward meeting their requirements or exit criteria.

In addition to the technologies, we examine how the sequence of the Research and Development (R&D) programs and the ship construction schedules align and note the problems in integrating R&D results into new ships.

Intra-ship cargo movement

Intra-ship cargo movement incorporates all aspects of cargo handling for a ship. This section outlines how cargo now moves within a ship and how it should move in the future.

Legacy

Internal cargo movement currently demands excessive amounts of space, manpower, and equipment to complete the time-intensive process of striking logistics resupply up and down. Strike-up is the process of locating cargo in storage, retrieving it, reconfiguring the load (if necessary), and transporting it to a transfer station on the ship. Strike-down is the reverse of this process: when material arrives on board ship, it is reconfigured, if necessary, and transported to the appropriate hold and secured. Together, strike-up/strike-down (SUSD) encompasses the entire intra-ship cargo movement system.

Since strike-up and transfer rates are not equal, replenishment ships pre-stage much of the cargo they will transfer to the customer ship. Although pre-staging consumes a lot of space within the replenishment ship, particularly on the weather deck, it ensures that neither the replenishment stations nor the flight deck are starved for cargo. Frozen and refrigerated items are struck-up last and passed to the customer ship first for immediate storage in reefers.

While replenishment ships have pre-staging areas to mitigate the unequal strike-up and transfer rates, customer ships use “holding” areas in large part because current transfer rates exceed strike-down rates; in other words, the replenishment ship can transfer material faster than the customer ship can strike-down the goods into storage. A common scenario is for the customer ship to have pallets and ordnance containers on the deck and in the hangar bay (in the case of a carrier) after the UNREP is complete.

Striking the logistics resupply down into holds where they "can be properly identified and located may take days."[4] In addition to time, it requires significant manpower. Specifically, clearing the hangar deck of a CV/CVN of 530 ST of ordnance and 684 ST of dry stores after a typical UNREP takes 600+ personnel between 6 and 10 hours.[5]

During the strike-down process, pallets and containers often have to be broken out into packages that can be hand carried or transported through the ship. Securing the loads is "labor intensive, result[s] in inefficient utilization of storage space, and utilize[s] waste material for dunnage."[6]

Future

Future systems must exploit automation in order to meet the demands of the sea base with less manpower. The future systems should equalize the rates for SUSD and UNREP, thereby reducing the need to pre-stage cargo. Material should move through the system seamlessly without human intervention.

Both Naval Surface Warfare Center–Panama City (NSWC–PC) [10] and Naval Stowage and Retrieval System (NAVSTORS) [12] describe similar concepts for the desired operation of future intra-ship cargo handling systems. Within a hold, cargo is located, accessed, and reconfigured automatically. The load is then placed on an omni-directional vehicle (ODV), which self-loads onto the elevator. It transports the load to the STREAM rig. A top-lifting device (attached to the STREAM rig) locks onto the packaging interface.[7] The load is transferred to the customer ship, where it is trapped at

[4] [10] pp. 3–21.

[5] [11] pp. 10 and 33.

[6] [10] pp 3–21.

[7] Interlocking devices on the packaging enable individual units to be (un)locked together to maximize efficiency, particularly in terms of elevator and UNREP evolutions.

the attachment point. The load is stabilized, aligned to, and loaded onto an ODV. The ODV then transports the load to the elevator for movement to the appropriate hold where the automated warehousing system will store and secure it.

Automated shipboard handling systems require technologies to move cargo about the ship, to enable high-density storage and selective offload, to identify and track cargo (e.g., Automated Information Technology (AIT)/Source Data Automation), and to integrate the computers, sensors, interfaces, etc. that compose the material handling system (e.g., Shipboard Warehouse Management System (SWMS)). The integration of these technologies must handle a variety of packaging configurations and both weapons and general cargo. Automating cargo handling seeks to increase throughput and safety, while decreasing manpower.

In short, the horizontal and vertical movement of cargo on board must be automated and integrated seamlessly to minimize delays. Therefore, elevator designs must have large capacity to provide increased throughput and be easily maintained, highly reliable, and safer (alleviate the need for watch standers/multiple operators). A high storage density must be achieved in the cargo holds, and selective offload must still be permitted.

Automating cargo and ordnance handling, storage, and retrieval could reduce manpower requirements and improve the operational flow. Automation has the potential to eliminate manual inventory tracking and manipulation through logistics resupply management systems. Moving, manipulating, storing, and retrieving logics resupply would no longer involve large work parties. The labor-intensive process of manually bracing and blocking is eliminated as well.

More direct paths to the holds should be considered for future new logistics ship designs. Today (and for the foreseeable future), cargo travels long horizontal distances in order to move vertically, which means the cargo zigzags through the ship on the way to the hold. Furthermore, there are no dedicated cargo handling paths—cargo must maneuver around obstacles and share floor space with personnel, equipment, etc. Future designs should consider more direct and dedicated material handling paths.

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Overview of logistics systems

This section defines each of the four technology areas that we have identified under the seabasing capabilities for logistics systems:

- Total asset visibility (TAV)
- Standardized packaging
- Material handling systems
- Selective offload.

Total asset visibility

TAV refers to the ability to track assets as they move from the supplier to the end user. It answers two fundamental questions:

1. What assets are available?
2. Where are they located?

Automation of the logistics system on board ship requires asset visibility within the ship. Fulfilling the seabasing concept, however, requires that the visibility extend across the joint services and encompass the entire pipeline from "factory to foxhole"—*total asset visibility.*

Manual documentation and barcode technology are currently used to track assets. In the future, radio frequency identification (RFID) technology will replace these methods. However, simply improving the technologies used to track assets does not deliver total asset visibility; these data have to be available in a universal format to all the Services.

Standardized packaging

Packaging applies to the entire logistics cycle: from the supplier to the warfighter and back, in the form of retrograde, as shown in figure 1. At every stage in this cycle, packaging plays a role in how logistics resupply is handled, stored, and transported. Cargo may be packaged and repackaged several times along the way. Therefore packaging can have a significant impact on how smoothly material flows through the logistics pipeline.

Figure 1. Logistics lifecycle[a]

a. From [13] p. 6.

Legacy packaging options tend to impede the continuous flow of material. As packaging evolves to address the needs of the sea base, the options move toward standardized containers compatible with automation systems and independent of manpower for packaging, repackaging, and securing.

According to the Naval Packaging, Handling, Storage, and Transportation (PHST) Center [14], standardized packaging means that the envelope size is an agreed-upon standard or a multiple thereof;

the handling features and the spacing between such features are also standard. The definition for *standardization* applicable to military applications is also relevant:

> The development and implementation of concepts, doctrines, procedures and designs to achieve and maintain the required levels of *compatibility*, *interchangeability* or *commonality* in the operational, procedural, materiel, technical and administrative fields to attain interoperability [15].

Material handling systems

Material handling systems are integral to intra-ship cargo movement. These systems currently assist humans with the strike-up and strike-down of material. In the future they will replace manpower by assuming control of material from the time it is delivered to the ship until it is transferred off the ship. Thus the integration of material handling technologies is key to delivering a fully automated material handling system.

Current systems do not have the at-sea material handling capability needed for the logistics support functions of the sea base. Near-term systems move in the direction of automation and reducing manpower. Future systems must be fully automated, eliminate the need for manpower, and address the bottleneck caused by traditional mechanical elevators.

Selective offload

Selective offload incorporates the three foregoing logistics systems. Total asset visibility identifies what cargo is on board and pinpoints its exact location. Standardized packaging allows seamless interfacing with material handling systems and enables the (re-)packaging of tailored loads suitable for use by the warfighter. Material handling systems move cargo throughout the ship and store it in holds for later use. Pulling these systems together enables selective offload—the ability to pull a particular item out of storage, package it in a suitable manner, and deliver it to the end user via an UNREP system.

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Current logistics systems

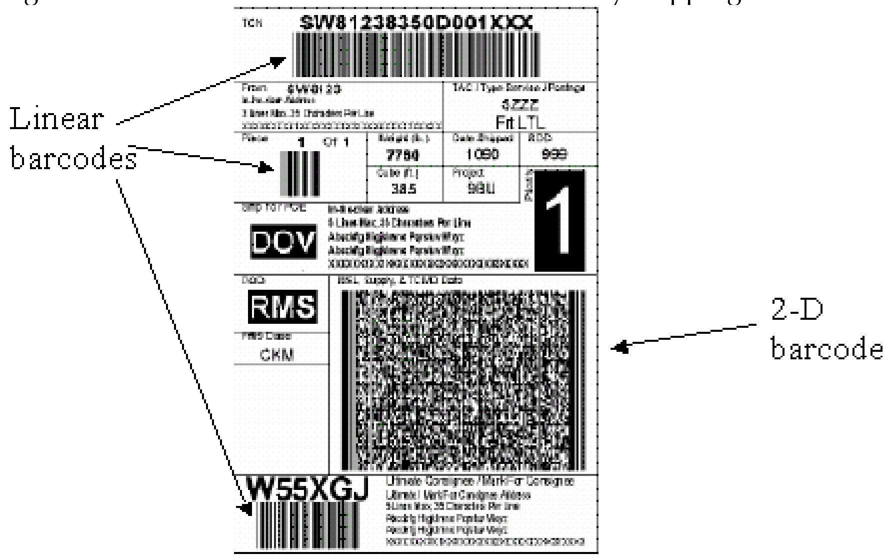
In this section we discuss the logistics systems currently used in replenishment ships. The capabilities of these legacy systems together with the needed capabilities for the sea base will identify the current technology gaps.

Total asset visibility

Currently TAV does not exist within the U.S. military. Cargo cannot be tracked from its point of origin at a supplier, through the transportation system, to the ship, and finally to the end user. Current warehousing methods are time consuming, manual intensive, and stove-piped across and within the military Services. Items are often unaccounted for or unlocate-able. Orders often take a long time to fill and may be either lost or duplicated.

Although shipments from Department of Defense (DoD) contractors to the U.S. Government must have RFID tags, most inventory, logging, and material reporting is done manually. Personnel check deliveries against a shipment list. Sometimes, barcode technology, a type of AIT, is used (see figure 2). While barcodes facilitate the logging of cargo, they are a line-of-sight technology; in other words, the barcode scanner must have a direct, unobstructed view of the barcode in order to read it. The data are fed into Service- and product-specific management and processing systems.

Figure 2. Linear and 2-D barcodes on a military shipping label[8]



DoD's RFID policy

The DoD RFID policy [16] mandates that its suppliers place RFID tags on all solicitations issued on or after October 1, 2004 for delivery of material on or after January 1, 2005. Freight containers must have active RFID tags, and the four lower layers of packaging must have passive RFID tags.

Per this mandate, material is arriving from the supplier with RFID tags. The Services now need to follow up with installing the technology to read and use the tags. Because of this mandate, we confine our discussion of AIT to RFID technology.

Standardized packaging

Currently the assortment of packaging sizes and shapes clog the military logistics pipeline and create packaging, handling, transpor-

8. From [13] p. 16.

tation, and storage inefficiencies. The packages and their internal packaging create significant retrograde. Furthermore, packaging is often content specific and, in many cases, Service specific. These packaging options often require specific, dedicated material handling equipment (MHE) along the distribution system. The lack of interoperability between the various types of MHE and packaging consumes time and manpower. In short, incompatibilities in packaging create significant retrograde, require excessive an excessive amount of MHE along with space to store them, and place an unnecessary demand on manpower.

The following example illustrates the challenges of non-standardized packaging. Conventional ammunition, missiles, and missile boosters normally are transferred on pallets, in their containers, or on dollies. These pallets are moved using pallet/handlift trucks, which the customer ship often does not have. Therefore the replenishment ship often cross-decks such special MHE to the customer ship for use in moving pallets from the landing area to the elevators. At the end of the replenishment, the MHE is returned to the replenishment ship. Common packaging would reduce the cross-decking of MHE.

NSWC–PC's report[9] lists 20-foot equivalent units (TEUs), Quadcons and pallets as the existing forms of standardized packaging. The standard container for rail, truck, and sea transport is the International Organization for Standardization (ISO) container, which comes in several standard sizes, starting with a 20-foot container. The volume occupied by a 20-foot ISO container is referred to as a TEU and measures 20′ x 8′ x 8.5′. A 20-foot ISO container weighs a maximum of 53,000 pounds.[10] They are efficient for bulk transport and are used only on dense stow ships that have access to port facilities. They do not collapse, or break down, for efficient retrograde.

The Quadcon is specially developed for military use; it has a maximum weight of 12,000 pounds, which is compatible with VERTREP

[9] [10] pp. 3–27

[10] [10] pp. 3–27

but exceeds the weight limit for CONREP with a STREAM rig.[11] Its size also makes it impractical for delivering tailored sustainment packages ashore for the warfighter. Additionally, the Quadcon requires internal wood dunnage and is not collapsible, making it inefficient for retrograde.[12] Quadcons have side connectors that allow them to be secured together; four connected Quadcons occupies the same footprint as an ISO TEU. Figure 3 shows both the single-unit Quadcon with its external dimensions and the four-unit TEU equivalent.

Figure 3. Individual Quadcon (left) and TEU equivalent with 4-interlocked Quadcons (right)[13]

Since TEUs and Quadcons are too large for most customer ships (e.g., carriers and surface combatants) to handle, cargo is palletized for delivery on board all customer ships. Currently pallets are the most practical option for transferring logistics resupply during replenishment. They have a maximum weight limit of 6,000 pounds,[14] which makes them efficient for replenishment, yet they are small enough for the customer ship to handle. In the case of ordnance,

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[11] The future Heavy Underway Replenishment system developed by Naval Surface Warfare Center (NSWC) Port Hueneme Division, however, is rated for 12,000 lb. Discussions are ongoing as to whether it will be adopted and by which ships.

[12] [10] pp. 3–27

[13] [17] slide 3. Not to scale.

[14] [10] pp. 3–27

however, packaging may be based on volume versus weight considerations (e.g., two AIM-9s are packaged in a 55-cubic foot container that weighs 2500 lb).[15] Specific ordnance containers (e.g., "coffins") are used for out-sized missiles.

Retrograde

Once items reach their destination, they are unpacked and made available for use. The discarded packaging (e.g., pallets, containers, and filler) is termed retrograde and must be disposed of, which often entails transport back to the continental United States (CONUS). Discarded packaging accounts for more than 50 percent of shipboard solid waste.[16] In addition to discarded packaging, other items such as aircraft engines, broken vehicles and other high-value, expensive, and reparable components are also retrograde. In short, retrograde is any item moving in the opposite direction of the normal logistics flow.

The assortment of packages makes retrograde difficult. For example, during CONREP, the customer ship sends back retrograde material after every three to four loads received; each retrograde load is limited to 150 pounds.[17]

Material handling systems

Cargo zigzags through the ship in a series of horizontal and vertical transitions as it moves between the transfer deck and the hold. Watertight bulkheads separating individual holds impede horizontal movement below deck [6]. Therefore most of the horizontal movement takes place on the main or transfer decks. Once the cargo arrives at the elevator servicing the appropriate hold, it moves vertically to the hold. Once in the cargo hold, it moves horizontally

15 [18] slide 10

16 [13] p. 14.

17 [19] pp. 6–48. The cargo drop reel (CDR) cannot hoist more than 150 pounds clear of the deck. For heavier loads, one of the other methods described in Sections 6.15.7 and 6.15.8 must be used.

within the hold. The indirect logistics paths and the assortment of MHE result in uncoordinated, disjointed cargo movement.

Manual pallet jacks, dollies, and weapons carts and diesel or electric fork trucks move palletized or heavy cargo horizontally. Non-palletized loads move horizontally by means of roller or package conveyors. Crewmembers often carry individual carton loads.

Mechanical elevators, dumb waiters, and package conveyors move cargo vertically. Elevators are the primary means of vertical transport, however. The *Achilles heel* of intra-ship cargo movement is the elevator cycle time, with one cycle taking from 5 to 12 minutes [20, 21].

Within the holds/magazines, sailors or civilian mariners (CIVMARs) manually block and brace the cargo to prevent it from shifting due to ship's motion. This is done with metal stanchions and wood dunnage. The stanchions are inserted into "peg" holes in the floor and ceiling to provide vertical support. Securing cargo requires significant manpower and time. If the holds/magazines are being loaded to give selective access, then it also consumes additional space (broken stow as opposed to pallets) and lowers the storage density.

Inventory systems consist of logs, barcodes, and barcode readers [20]. Manual logs involve personnel checking items off against a list and writing out inventory lists/requests. Barcodes are a form of AIT, but they require line-of-sight scanning. Therefore, personnel must scan each barcode using a hand-held barcode reader. The data in the barcode reader are then uploaded to an inventory control system.

Handing off between material handling systems

Current material movement has been described as "a series of cargo staging sites linked by manpower chains and cumbersome conveyance methods to move items slowly, from a growing load staging area to the eventual storage location" [6]. The need to pass cargo from one type of MHE to another causes this disjointed movement. This passing off of cargo is referred to as a hand-off, or a touch. For example, when a fork truck loads pallets onto an elevator, there is a hand-off between the fork truck—one type of MHE—and the elevator—another type of MHE.

The use of separate MHE for horizontal and vertical movement, along with the zigzagging horizontal and vertical paths required to move between holds and the transfer deck, requires multiple hand-offs. We step through the strike-up process to explain the role of material handling systems and the extent of human involvement and to count the number of hand-offs involved.

To achieve strike-up, cargo is unsecured manually (i.e., removing tie-downs or a combination of portable stanchions and dunnage) from its storage location. The cargo is then either hand-carried or transported via MHE (fork trucks, hand trucks, dollies, etc.) to the elevator. If the elevator is available, cargo is loaded directly onto the elevator platform (hand-off = 1). Otherwise cargo is deposited at a staging area next to the elevator, where it waits until it can be moved onto the elevator (additional hand-off = 1).

Thus once the elevator arrives in the hold, an elevator operator removes the safety features, and the cargo is moved onto the elevator platform and, depending on sea conditions, secured with tie-down chains. Safety features are re-established, and the elevator operators coordinate moving it to another deck. Once the cargo arrives at an upper deck for offload, the safety measures are once again disengaged, and MHE (fork trucks, hand trucks, dollies, etc.) removes cargo from the elevator platform and transports it to an UNREP station (hand-off = 2). More often, however, the MHE unloads the elevator and moves the cargo to a staging area (additional hand-off = 2). From the staging area, the cargo is moved finally to an UNREP station (additional hand-off = 3).

The best-case scenario for striking up general cargo in a CLF-type ship involves about two hand-offs, which happens only when MHE and the elevator are immediately available. Otherwise the number of hand-offs can increase to as many as five.

The number of hand-offs increases when we look at the strike-down operation for a carrier, as described in the National Shipbuilding Research Program (NSRP) Technology Roadmap [8]. During a VERTREP, the helicopter positions the cargo on the flight deck. A fork truck picks up the cargo and transports it to the elevator (hand-off = 1). If the elevator is not available, the cargo is deposited at the elevator staging area (additional hand-off = 1) and later loaded onto the elevator (additional hand-off = 2). The elevator takes the loads to the main deck, where fork trucks offload the cargo to an inspection, or staging, queue (hand-off = 2). At this point, the VERTREP and CONREP cargo are merged and transported by MHE to the elevator servicing the appropriate hold/magazine. If the elevator is available, the MHE loads the cargo directly onto the elevator (hand-off = 3); otherwise the cargo goes to the elevator staging area (additional hand-off = 3) until it can be loaded (additional hand-off = 4). The elevator moves the cargo to the hold, where MHE unloads it and either moves it directly into a storage location (hand-off = 4) or to the staging area (additional hand-off = 5) for later transport to its storage location (additional hand-off = 6). This process yields a best case scenario of about four hand-offs and a more typical scenario of about 10 hand-offs.

In addition to the hand offs, the transition points create queuing delays. Such delays inhibit the balancing of the UNREP and SUSD rates; for the CVN68 class, the strike-down rate is three times slower than the UNREP rate [22].

Achilles heel, the elevator

Each of the additional hand-offs listed in the previous section occurs because the elevator is unavailable. The major reasons for the bottleneck are the long cycle times, an elevator servicing multiple holds, and the lack of dedicated MHE standing by to unload the elevator immediately. While the elevator waits for MHE to unload it, all further vertical movement to the decks and the holds it services is suspended.

Elevator operations have a cumulative impact. When the elevator can no longer keep up with demand, the elevator staging areas can become full with cargo waiting to be loaded, and operations in the holds are suspended. Cargo delivery to the customer slows down.

A solution to the elevator bottleneck employed by some ships is to dedicate MHE to offloading the elevators. In this case, the MHE unloads the elevator and moves the cargo to an elevator staging area, where another group of MHE picks it up and transport it to a VERTREP staging area or UNREP station. The same issues that apply to the staging area in the holds apply here: another hand-off occurs and strike-up ceases if the holding area fills up.

A solution to the strike-up problem is to pre-stage. Cargo is brought to a pre-staging area in advance of an UNREP, and then transferred to the UNREP stations once the UNREP begins. This option ensures that the UNREP stations always have cargo to transfer, but it takes up space and increases the number of hand-offs.

Selective offload

Replenishment and prepositioned ships, as well as combatants, share a common approach to loading: the first cargo loaded is the last cargo unloaded—or first on, last off. Prepositioned ships, in particular, are densely packed. Both the loading order and the confined space make locating and accessing cargo difficult.

To selectively offload cargo, personnel must know what material is needed and precisely where it is located and also be able to extract it from where it is stowed, repackage it for shipment, and deliver it to a transfer station. Therefore, selective offload entails warehouse management software and AIT (e.g., RFID tags and readers) for asset visibility, material handling systems, an automated storage and retrieval system, and packaging. Currently selective offload is limited. The process of locating, extracting, and delivering specific items is laborious[18] and time consuming. In many cases, the item simply cannot be accessed.

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[18] [10] pp 3–21.

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Needed capabilities

This section describes the capabilities the sea base will require in the 2020 decade.

Total asset visibility

Total asset visibility will be needed to answer two important questions:

1. What assets are available?
2. Where are they?

AIT must answer these questions at the lowest level (e.g., in the hold or warehouse). AIT must have a real-time data feed into the supply chain management system, the future Enterprise Resource Planning (ERP), automated material handling systems, and the common operational picture (COP).[19] The data must be shared across the forces; this sharing is what differentiates asset visibility from total asset visibility.

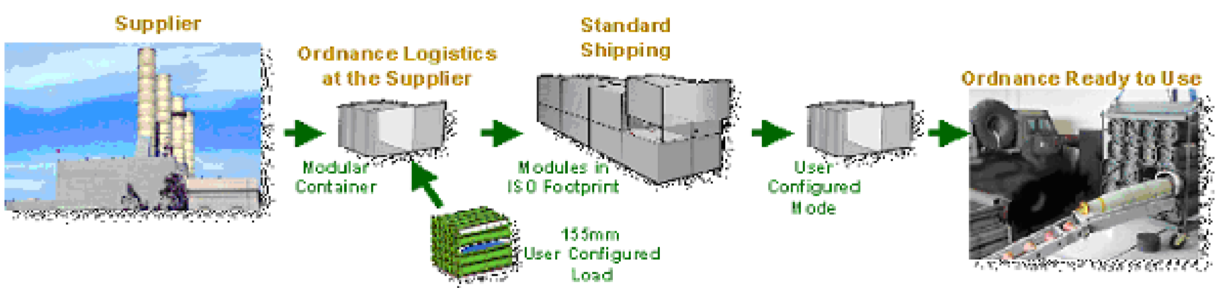
The enabling AIT must be capable of tracking packages throughout the entire supply chain: from the supplier, through the various means of transportation and warehousing, to the end user. The AIT device must be durable and adhere to the packaging despite handling (e.g., rubbing against other packages and equipment) and harsh environmental conditions.

[19] [17] ERP will replace the legacy system Naval Tactical Command Support System.

Standardized packaging

NSWC's Material Handling and Transfer (MHAT) team maintains that legacy break bulk operations cannot meet the throughput requirements of the sea base and that packaging must be standardized to improve the logistics pipeline [17]. The assortment of size, shape and weight packaging options should be replaced with a modular design that enables rapid breakout of contents and combat or user configured loads. A collapsible design and an internal dunnage system (packaging) integral to the container also reduce retrograde waste. Figure 4 illustrates the modular system design for ordnance packaging proposed by NSWC's MHAT team; this packaging system applies to general cargo as well.

Figure 4. Modular packaging enables factory-to-foxhole logistics[20]



The US Transportation Command (USTRANSCOM) is leading the effort to standardize packaging across DoD. The Naval Logistics Integration Initiative for Common Naval Packaging seeks a packaging solution for implementation by the joint forces across all classes of supply. A common packaging solution will improve handling, transportation, and storage efficiency, while potentially reducing retrograde and waste. Common packaging helps material to move seamlessly through the distribution system, as well as to achieve the throughput and automation required for the sea base.

[20] [17] slide 20 with minor modifications

Naval Surface Warfare Center–Panama City's report stresses the need for a modular packaging capability as follows:

> Standardized, modular packaging is essential to ASRS and SUSD to perform selective offload at the high throughput rates required by the sea base. Standardized ammunition containers must incorporate blast mitigation. Integral securing without dependence on dunnage for maximum sea state is needed by all types of containers.[21]

A major problem is packaging non-standard shapes and still maintaining compatibility—in terms of space, weight, and interfaces—with warehousing (or automated storage and retrieval) and material handling systems. Maintaining this compatibility maximizes the storage density. A feasible solution is to provide the Services with an assortment of standardized unit loads. The effect would be to eliminate the need for package-specific MHE, optimize the distribution system, and provide a less manpower-intensive process. The unit loads and the material handling systems supporting them would create interoperability across the joint forces.

The NSWC-PC report also lists the needed capabilities as:

> Modularity, legacy compatibility, System Interoperability (with ISO containers, 463L Pallet, ISO flatrack, Army CROP[22], future Joint Modular Intermodal Platform (JMIP), current and future military and commercial material handling equipment MHE and transportation platforms to include air, sea, and ground assets), Service interoperability, sturdiness, lightweight, storability, blast mitigation, retrograde friendly, minimal waste material, trackable, interlocking and securable.[23]

Standardized, modular packaging should have standardized interfaces that allow them to interlock to form larger units for commercial transport and UNREP. For commercial transport, the resulting unit must be compatible with a TEU footprint. For UNREP, the resulting unit can have maximum lift capacity and potentially reduce

[21] [10] pp. 3–21.

[22] Container roll out platform (CROP)

[23] [10] pp. 3–27.

the need for cargo nets. The flexibility to interlock modular packages to form loads from individual unit loads suitable for delivery to the warfighter all the way up to TEU-sized containers[24] maximizes the weight and volume transferred during each lift. This flexibility not only increases throughput, it also helps ensure the package configurations are compatible with commercial systems, tactical distribution systems, and shipboard storage, securing, and transport systems. The ability to collapse and interlock the packages minimizes the lifts required for retrograde.

Not only do standardized interfaces secure packages to each other, they also allow packages to secure to mobile or stationary platforms (e.g., MHE and decks). They give automated systems the ability to release and re-secure loads; this ways the system maintains control of the load at all times.

Lastly, the packaging must be compatible with the labeling or tagging technology used for total asset visibility. The packaging must not interfere with the AIT's ability to read and receive data from the labels or tags.

Material handling systems

According to the NSRP Technology Roadmap,[25] a shipboard material handling system must move cargo (with minimal hand-offs and queuing delays) from the ship delivery station to storage, enable high-density storage, and provide selective offload through automation of the cargo holds and magazines. It must also handle the wide variety of existing and future naval packaging and munitions.[26]

An automated material handling system should have control of the cargo from the time it arrives on board to the time it leaves the ship. Humans should not have to handle the cargo at any point in the

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24. Discussions are ongoing as to whether TEUs will be transferred, unpacked, and repacked on the sea base and, if so, which ships will have this capability.

25. [8] pp. 3-1 and 4-2.

26. [8] pp. 3-1 and 4-2.

process. In the previous section, "Intra-ship Cargo Movement, Future," we outlined how the material should flow through the ship.

Automation and standardization are two key considerations. Standardization applies to the automated systems, to the logistics resupply packaging, and to the system's ability to handle standardized, modular packaging. Their integration should achieve a balance between storage density and the need for selective access. Together they should also minimize the required manpower, time, and assortment of MHE required to conduct intra-ship logistics.

The SUSD rate should equal the supply/receipt rate of material during an UNREP. Equalizing these rates will eliminate the need to pre-stage cargo and the pile up of cargo waiting to be received into storage. To achieve this balance, cargo must flow in a seamless, coordinated manner, which primarily entails reducing the number of hand-offs and eliminating the queuing delays. Queuing delays are frequently found at the transitions point, that is, at the location of a hand-off.

The longest queuing delays occur at the transition between horizontally and vertically moving forms of MHE. We have already identified the elevator as the Achilles heel. Therefore, the future vertical movement piece of the system should service multiple decks simultaneously and increase throughput.

Throughout the handling process, the system must secure and maintain positive control of cargo at all times. In high sea states (greater than SS5), the system must restrain the load even though its operations have ceased due to sea conditions. The automatic securing and releasing of loads should reduce the use of dunnage, tiedowns, and bracing.

Selective offload

Future operations require "accessing any item in storage and rapidly repackaging loads for delivery ashore."[27] The seabasing concept specifies 100-percent selective offload, which entails being able to

[27] [10] pp 3-21.

locate, retrieve, and strike up cargo. The repackaging and reconfiguring of loads should be minimized. When it is necessary, it should be done exclusively in the holds (and not on the transfer deck). The tailored sustainment loads going to the warfighter ashore will be pallet-sized and smaller.

Therefore, total asset visibility, standardized packaging, and material handling systems combine to enable selective offload. Therefore, achieving their capabilities is a prerequisite for meeting the needed capabilities for selective offload. The total asset visibility piece identifies what material is available and where it is located in the pipeline, reaching all the way back to the supplier. Standardized packaging facilitates the interface between material and automation. The material handling system enables the specified cargo to be retrieved and transported to a transfer station.

Current capability gaps

Current capabilities gaps arise from a mismatch between current capabilities and the needed capabilities of the future sea base. Once capability gaps are identified, research efforts can be targeted toward addressing (or closing) them.

Total asset visibility

In today's logistics systems, ship's personnel know what cargo is on board and roughly where it is located. This means they have a list of items and approximate counts of each item and can narrow the item down to a hold. Ships generally do not have visibility into other ships' cargo.[28] The vagueness surrounding the logistics resupply available to the sea base needs to replaced by technology that accurately identifies and locates cargo. These real-time logistics data are then broadcast to the entire sea base (at a minimum) to give the complete logistics picture.

Total asset visibility does not exist today. Limited visibility at discrete portions along the pipeline, however, does exist. Therefore, the most critical capability gap is in supplier-to-end user tracking. Once this gap is filled, sharing the data among the Services can close the gap for total asset visibility. To achieve the throughput and level of automation required by the sea base, the AIT selected as part of total asset visibility needs to be non-line-of-sight.[29]

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28. Because of their mission, replenishment ships have the most transparent cargo availability.

29. Non-line-of-sight means that the data transmission path between the transmitter and receiver may be obstructed by physical objects

Standardized packaging

Today's packaging lacks standardization. Each Service uses its own packaging systems, and there is no consensus on which, if any, packages are standardized. Therefore, a capability gap exists for standardization. The standards must be compatible with commercial and military handling systems and equipment. Today's packaging comes in assorted shapes and sizes, but it lacks the flexibility to stand alone as a tailored package and to connect together to form package sizes up to the size of a TEU. The current packaging options do not fulfill the needed capability for collapsible and dunnage-free packaging for retrograde.

Material handling systems

Current material handling systems work well for today's operations, but they do not fulfill all of the needed capabilities for tomorrow's sea base. To facilitate the timely, seamless flow of material, the internal material movement needs to match the replenishment rates—of cargo both coming on board ship and departing the ship to the customer. Today's material handling consists of MHE picking up cargo, moving it, and putting it down where it waits for another piece of MHE. The system needs to be automated so that it can assume continuous control of all cargo on board.

NSWC-PC's study [10] identifies automated and integrated warehousing as a sea-base gap. Their use of automated and integrated warehousing includes material handling, SUSD, selective offload/onload, repackaging en route, and modular packaging. The gaps specify the horizontal and vertical movement of TEUs on MPF(F) ships; seamless material handling, including repackaging loads, handling heavier loads, and staging material faster; asset identification and maneuver space for selective access; and standardized, modular packaging for compatibility with automated material handling and securing systems.

Selective offload

One hundred percent selective offload means that any piece of cargo can be located, accessed, retrieved, and delivered to the deck. The first-on/last-off approach to cargo loading defines today's intraship logistics. The order in which the cargo is loaded directly affects the ability to retrieve the cargo. More specifically, the first piece of cargo loaded is virtually impossible to access and retrieve, while the last piece of cargo loaded should be relatively easy to access and retrieve. All the cargo in between has varying levels of accessibility. If the cargo is moved from its initial location according to the ship loading plan, it can be difficult (if not impossible) to find with the current manual inventory system. This legacy system is not able to quickly locate and retrieve a specific piece of cargo.

The ability to offload selectively relies extensively on manpower and time. The resupply items that may require selective offload are sometimes loaded either toward the end or as broken stow. This approach offers limited selective offload, but it falls short of the 100-percent selective offload demanded for seabasing.

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Closing the gaps

A mismatch between current logistics systems and needed capabilities creates capability gaps. This section describes the technologies currently in development with the potential to close these gaps. Table 1 maps the gap-closing technologies to the gaps.

Table 1. Correspondence of gap-closing technologies to gaps

	Total asset visibility	Standardized packaging	Material handling systems	Selective Offload
RFID	✓			
JMIC		✓		
ASRS			✓	
CAMM			✓	
HRVHMM			✓	
TransPORTS				✓
At-sea container discharge				✓

Total asset visibility

AIT currently exists in the form of barcodes, RFID, smart cards, optical memory cards, and contact memory buttons,[30] but the application of these technologies has not found its way into mainstream DoN logistics. DoD has initiated a policy for RFID, specifying the use of active or passive tags based on the level of packaging. The commercial sector, as well as the government, is actively driving the standardization, development, and implementation of RFID technology.

[30] [23] p. 35

USTRANSCOM lists cargo total asset visibility as a near-term (FY06-FY09) technology pursuit, which looks at various technologies to promptly track and pinpoint the location of material in austere areas.[31] USTRANSCOM's interest in AIT centers around source data automation—the ability for operators to update plan data with actual data and for the information to be updated and distributed automatically to systems requiring visibility and use of the data.[32]

RFID is attractive because it offers non-line-of-sight, wireless data collection technology. The technology consists of readers and tags. The reader (or transponder) transmits a signal that activates the tag and solicits data. The electronic tag responds by transmitting data pertaining to the contents of the package to which it is affixed. The data can include a list of the contents, the environmental conditions in which it has been stored, tamper alerts, etc. These data feed automatically into the warehouse management system, where they can be shared across the Services.

The technology is well-developed, but its implementation in a shipboard environment poses challenges. In the holds, reflections and multipath nulls make it difficult to pinpoint location. These issues arise from waves bouncing off metal. Reflections can cause multiple (adjacent) tags to be read simultaneously. Multipath nulls arise from a wave hitting a metal surface and reflecting back with a 180-degree phase shift.

Fontana and Gunderson report that narrowband RF systems are ineffective for such maritime applications.[33] Ultra-wideband (UWB) systems, however, do show potential. Gunderson et al. [25] report a location accuracy of 3–5 feet root mean square (RMS) for open space conditions and 11–12 feet for double-stacked containers. This technology is a potential approach to autonomous manifesting.

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[31] [23] p. 18

[32] [23] p. 18

[33] [24] pp. 147–150.

Standardized packaging

Under standardized packaging, there is the Joint Modular Intermodal Container (JMIC) concept and the JMIC container. The JMIC concept addresses the issue of developing and implementing standards within packaging. The JMIC container is an actual package design that adheres to the standardization proposed by the JMIC concept.

JMIC concept

The Joint Intermodal Logistics Working Group (JILWG) is working on the JMIC concept. This concept focuses on developing a standard package size and packaging concepts for ordnance and general cargo. The intention is to increase the efficiency and decrease the retrograde of material through the DoD supply chain.

Joint Modular Intermodal Distribution System (JMIDS)

The JMIDS is a USTRANSCOM S&T technology project that will:

> survey, model, investigate, and establish a base line for development efforts leading to the definition of an inter-service joint intermodal container system that specifically addresses modal interchange and emerging battlefield distribution issues. This is an Army-led ACTD,[34] which the United States Transportation Command (USTRANSCOM) is supporting.... It is also anticipated that this effort will reduce warfighter wait time for supplies by two-thirds and logistician work hours and equipment hours by 71% and 69% respectively."[35]

Joint Modular Intermodal Container (JMIC)

The JMIC provides a common modular building block, measuring 52″ x 44″ x 42″ with a 3,000-pound maximum weight capacity. As shown in figure 5, it can be used alone or in conjunction with other

34 Advanced Concept Technology Demonstration (ACTD).

35 [23] p. 42.

JMICs on an ISO flatrack to form a TEU equivalent. It is capable of cubing out the ISO flatrack, CROP, and 463L aircraft pallet. A family of JMICs will be available to pair the JMICs' construction, structural integral, and size with the contents. Their organic internal dunnage system (i.e., internal tiedowns) eliminates waste products, and they collapse for efficient retrograde (shown in figure 6).

Figure 5. Individual JMIC (left) and 16-interlocked JMICs forming a TEU equivalent (right)[36] (not to scale)

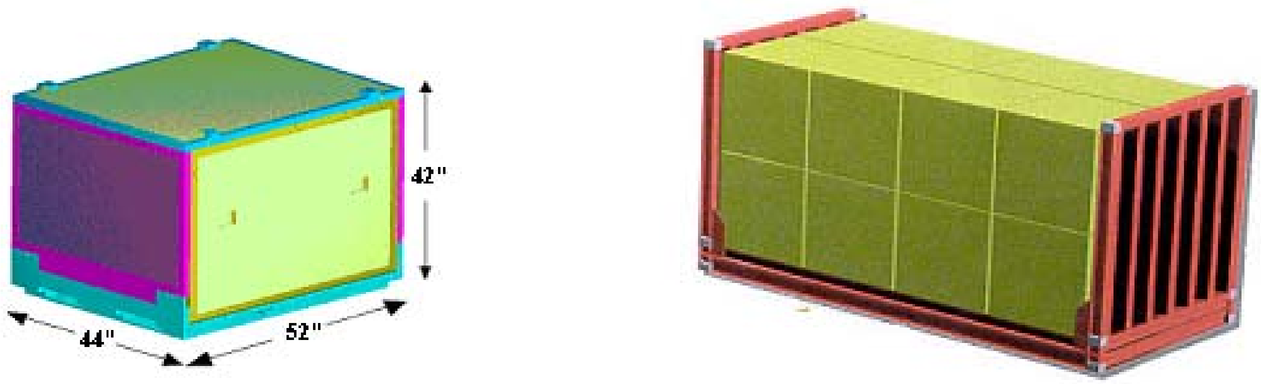
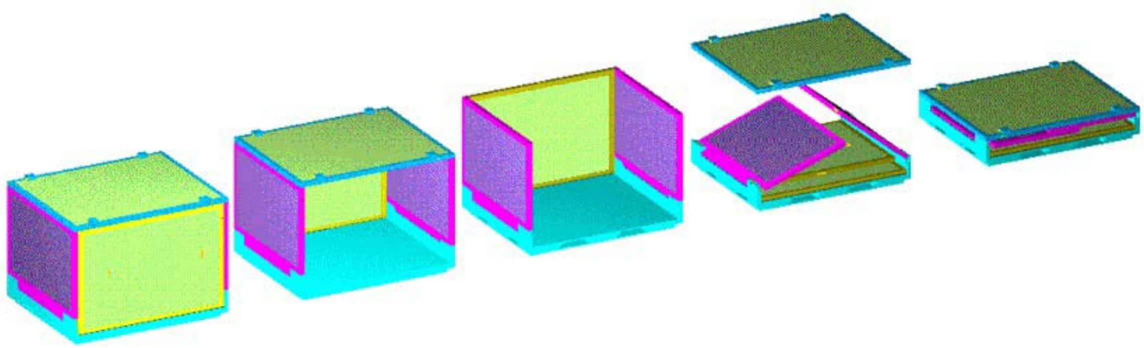


Figure 6. Collapsibility of JMIC for retrograde[37]



Sixteen JMICs together on a flatrack forms a TEU, thus making the JMIC compatible with commercial logistics systems. The JMICs in-

[36] [17] slide 3.

[37] [17] slide 3.

terlock in columns using a top-sided quick release or locking device. Provided the necessary UNREP systems are in place and the ships are able to handle TEUs, this feature would allow a TEU equivalent to be transferred between ships, thereby increasing throughput and saving time alongside. The JMIC-based TEU could be broken down into individual units upon receipt for compatibility with shipboard systems or for further transport to shore. Likewise, they can be modularized or treated as break-bulk for maximum compatibility with military platforms and systems.

The family of JMICs consists of different material and sizes. For example, the structural integrity and ruggedness required for packaging ordnance is unnecessary for general cargo. The sizes will be a multiple of the standard size (52" x 44" x 42") up to a TEU equivalent, which consists of 16 standard-sized JMICs [14]. There is also discussion of offering a half-sized version, measuring 26″ x 22″ x 21″ [14].

For ordnance, a JMIC with blast mitigation technology is being developed. The container uses Spectra® (a Kevlar® polymer) with blast coat to contain the blast caused by such components as fuses and primers [14]. This technology will enable previously incompatible materials to be stored together as kits. Low net explosive weight (NEW) components (less than one pound of C-4) conceivably could be stored with high NEW components [14]. This container would enable three key advantages: improved storage density, increased safety, and "mission ready" munition packaging [26].

The PHST Center is developing the JMIC.[38] The JMIC effort received initial funding from the CNO OpLog Program (N42). In November 2004, the Office of the Secretary of Defense (OSD) transitioned JMIC initiatives to USTRANSCOM, which functions as the Distribution Process Owner; Joint IA (Information Assurance) Working Group (JIWG) functions as the development and coordination lead.[39] USTRANSCOM lists JMIC as a near-term (FY06-

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38 Naval PHST Center at the Naval Weapons Station Earle New Jersey is a founding member and chair of the JILWG, who developed the concept [13].

39 [13] p. 13.

FY09) technology pursuit; this pursuit evaluates "inter-service compatible container system[s]" that reduce repackaging and handle battlefield distribution issues while increasing throughput.[40]

Material handling systems

Several technical challenges differentiate material handling systems used for commercial, land-based applications from military, at-sea applications. At-sea systems are space-limited, subject to 6-degrees of freedom, and must maintain control and restraint of loads at all times. Commercial systems normally handle only TEUs and pallets, and military systems must handle a wide variety of logistics resupply packaging.

Material handling systems include three particular technologies:

1. Automated Storage and Retrieval System (ASRS)
2. Compact/Agile Material Mover (CAMM)
3. High rate vertical/horizontal material mover (HRVHMM).

Automated Storage and Retrieval System (ASRS)

ASRS[41] is an ONR Seabasing FNC project under Enabling Capability (EC)-1A: Sea Base Integrated Operations. The ASRS effort adapts commercial automated warehouse concepts for shipboard applications. The automated warehouse will automate the storage and retrieval (including load restraint) of cargo and weapons within the ship. This technology aims to maximize cargo throughput through automation and maximize storage density while enabling 100 percent selective retrieval. Table 2 presents the storage and retrieval rates and design requirements for the system. The deliverable for this project is a full-scale prototype of the automated shipboard cargo warehouse [27].

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[40] [23] p. 18.

[41] [9] FY04 start.

Table 2. ASRS throughput rates and design requirements [29]

	Requirement
Storage rate	30 pallets per hour (Threshold) 40 pallets per hour (Objective)[42]
Retrieval rate	15 pallets/hr without pre-staging (Threshold) 40 pallets/hr with pre-staging (Objective)
Package capability	Pallets: 3,300 lb JMIC

According to the TTA,[43] the automated shipboard cargo warehouse will consist of four storage racks, each of which is two rows high and two rows deep, for a total of 16 storage spots; the approximate dimensions are 40′ x 15′ x 12’ (shown in figure 7). The storage and retrieval (SR) machine will travel along the front side of the racks to pick and place cargo. Cargo comes into the system through a pick and delivery (P&D) station. This system also includes a load handling device (LHD), collector/dispenser, AIT (recognizes and records cargo) and standard load interface (SLI) restraint system. The TTA states that the system will demonstrate fulfillment of the functionality requirements:

> By receiving a pallet at the P&D station, recognizing and recording the pallet located through the AIT system, transporting the pallet to the stowage location, and placing the pallet within the location while restraining the load at all times.[44]

This system reflects commercial automated warehousing concepts, which have been marinized through software algorithms, sensors, actuators and marine materials.[45]

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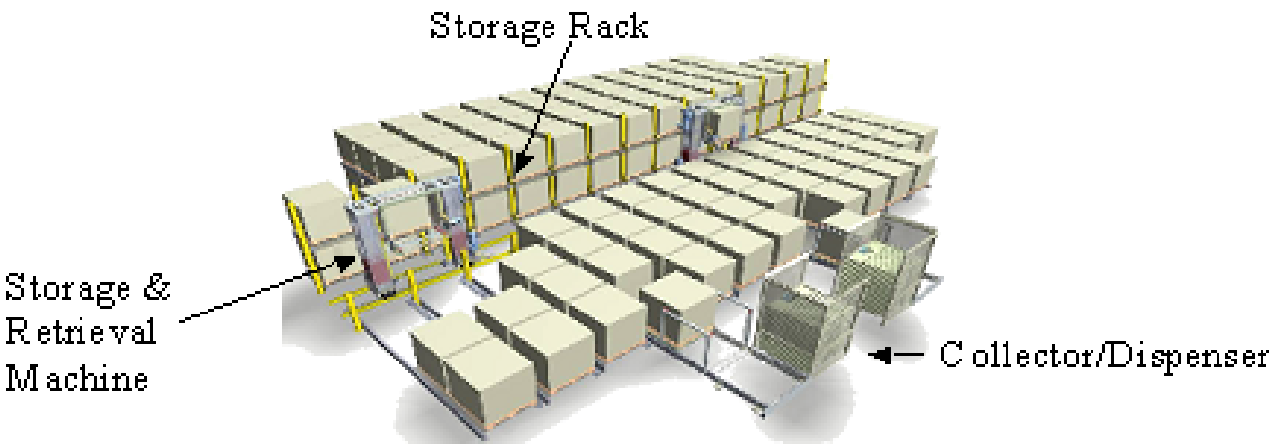
[42] According to the May 2005 project review, the ASRS moves 280 pallets per hour at SS5; this rate is seven times the objective rate [29].

[43] [28] p. 1.

[44] [28] p. 5.

[45] [28] pp. 4

Figure 7. Artist's rendition of ASRS [9, 30]



In FY05 this ASRS project was modified to handle JMICs in addition to pallets. A pick-up and delivery station and the storage racks were designed specially to handle JMICs. Pallets will flow to different P&D stations and storage racks. The SR machine was modified to handle both package configurations. ASRS can handle pallets and JMICs, but it does not have the flexibility to handle different sized and shaped packages without being modified.

The ASRS also incorporates an AIT interface. The ASRS reads RFID tags and barcodes to identify and select cargo. In these tests, a scanner moves down a row of cargo and scans for RFID tags and barcodes when it is directly across from the tag or barcode. Therefore, ASRS is not exploiting RFID's non-line-of-sight capability.

Automated Warehouse has a TTA in place with PMS 325.[46] The ASRS is being designed for the freeze/chill hold of the T-AKE.[47] PMS 325 and the shipbuilders of the NSRP developed the TTA exit criteria with the material performance requirements and ship design considerations in mind.[48] While the TTA specifies an exit crite-

[46] [9] and [30].

[47] [11] p 5 and [29].

[48] [28] p 2.

rion of Technology Readiness Level (TRL) 6 (see appendix B for an explanation of TRLs), [49] ASRS will likely transition at TRL 7 because there are plans to test a prototype system on board a ship [31]. General Dynamics Armament Technology Products, with Siemens as a sub-contractor, holds the contract for developing ASRS.

Compact/Agile Material Mover (CAMM)

CAMM[50] is an ONR Seabasing FNC project under EC-1A: Sea Base Integrated Operations. The term CAMM applies to "new shipboard material movement systems that are not designed into the ship's structure but fit within existing or future platforms."[51] The CAMM effort is responsible for delivering the following technologies [27]:

- Human Amplification Technology (HAT)
- Off-Center In-Line Omnidirectional Wheel (OCILOW)
- Ship Motion Compensation for Force Control-Based Systems (SMCFCS).

The intent of the CAMM is to move payloads of logistics resupply up to about 12,000 pounds with minimal manpower. HAT technology amplifies the amount a human can move using minimal exertion. For example, by amplifying human strength by a ratio of 500:1, a 5,000-pound payload feels like 10 pounds. OCILOW eliminates the extra space required to account for the turning radius by enabling a transporter to turn within its own footprint. OCILOW technology includes speed and force sensing and man-machine interface (MMI) sensors. The SMCFCS algorithms compensate for wave-induced ship motions, "enabl[ing] resupply operations in high sea states with minimal manpower."[52] This system contains control algorithms that mitigate the effects of low frequency dynamic loading

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49 [30] A land-based demonstration is planned for FY06. The land-based demonstrator will have 20 storage locations for a total footprint of 44″ x 54″ and a height of 42″.

50 [9] FY04 start. 500x reduction in "apparent" weight

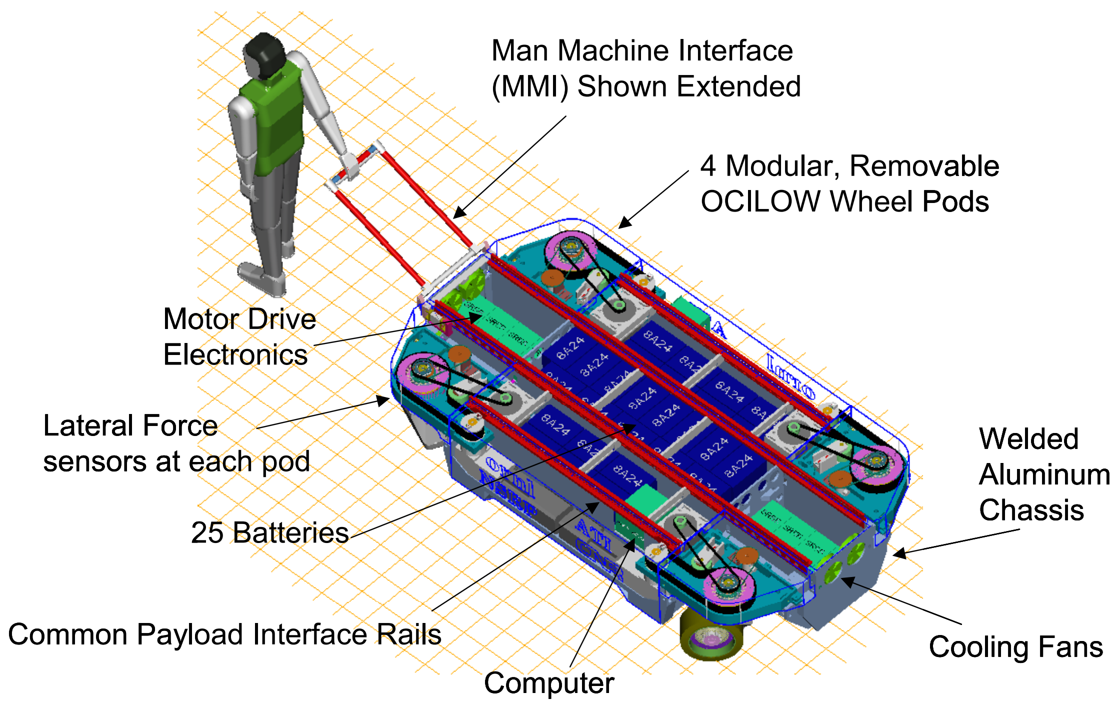
51 [22] pp 1.

52 [32] pp. 25.

caused by wave-induced ship movement during manipulation of heavy payloads [33].

The CAMM transporter [shown in figure 8] will have a minimum footprint of 113.5″ x 59.3″ x 23.5″ and travel a maximum of 4 mph [30]. In addition to maintaining operation in high sea states, the CAMM transporter can manage 15° ramps [30]. The operator steers the CAMM transporter via the MMI. An operator pulls the MMI in the direction in which she/he wants the transporter to go, and the force with which the operator pulls it determines the speed of the transporter. Four rails, called common payload interface rails, run the length of the transporter. This system is being designed (but not tested) to handle weapons should the Navy ever want to use it in such capacity.

Figure 8. CAMM transporter full-scale prototype [22]



CAMM currently has a TTA in place with Program Executive Office (PEO) Carriers.[53] Oak Ridge National Laboratory is developing it [34]. Key performance parameters (KPPs) for CVN21 seek to reduce manning and increase aircraft sortie generation rates. Therefore, the CVN21 Operational Requirements Document (ORD) specifies a strike-down rate equal to the UNREP rate (in contrast to the CVN 68 class, which strikes down at a rate three times slower than its UNREP rate).[54] The CAMM technologies are considered a move toward meeting the CVN21 KPPs.

Table 3 reflects the system capacity and manpower requirements defined in the TTA (see appendix C for the complete exit criteria). The current Proof of Principle Transporter (PoP-T) has a payload capacity of 10,000 pounds, which approaches the goal of 12,000 pounds.

Table 3. Payload capacity and manpower requirements for CAMM[55]

Criteria	Current Capability	Minimum	Goal
Increased system capacity	Various. Manhandling and 4,000 lb forklifts common.	Variety of Naval packaging and weapons up to 6,000 lb	Variety of Naval packaging up to 12,000 lb
Manpower reduction	Current weapons movement using non-powered equipment is manpower intensive	Estimated 5-15% reduction in manpower in weapons department	

Currently, the technology effort is for a single CAMM transporter; however, PEO Carriers could specify that they want a family of CAMM transporters with different capacity ratings. Foreseeably, the

53 [27] TTA signed August 2005. Under this project, there is a container breakout and repackaging letter of intent from PMS 325 and a request for proposal (RFP).

54 [22] p. 3.

55 Based on [22] Attachment B: Exit Criteria.

movement to a family of transporters would not generate new technology issues considering that HAT, OCILOW, and SMCFCS make up the foundation for CAMM. However, development of an autonomously guided CAMM would likely result in new technology issues, such as collision avoidance, vision systems, and intelligence systems [34]. Although current efforts are not considering an autonomously guided CAMM, such an advancement has foreseeable benefits in further reducing manpower and improving efficiency.

Human amplification technology (HAT)

HAT forms a human-machine interface that amplifies human strength. Therefore, one person can lift, move and control heavy payloads because HAT produces a reduction in apparent weight.

The SMCFCS is integrated into the HAT lifter. The HAT lifter, shown in figure 9, can be mounted to a bulkhead or onto a CAMM transporter.

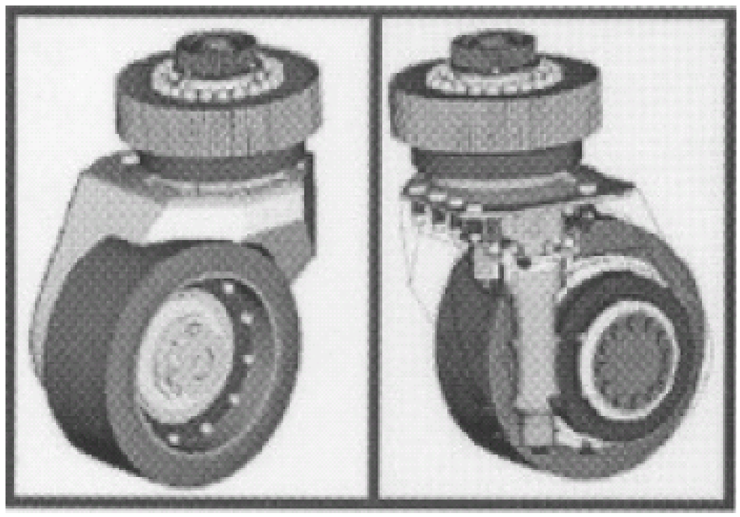
Figure 9. HAT lifter prototype [9]

Off-center in-line omni-directional wheel (OCILOW)

OCILOW achieves holonomic mobility. Being omnidirectional, it can move in any direction without turning; the ability to turn about within its own footprint means less space is required for executing turns.

ONR's OCILOW design, shown in figure 10, handles heavy payloads (up to 10,000 lb) without suffering from point loading problems. It can operate with only two wheels in contact with the deck and maintain stability with heavy loads on a 30° incline [30].

Figure 10. OCILOW[56]



Ship motion compensation for force control-based systems (SMCFCS)

The SMCFCS algorithms compensate for wave-induced ship motions, which enables safe operation in high sea states with minimal manpower.[57] This system contains control algorithms that mitigate the effects of low frequency dynamic loading caused by wave-induced ship movement during manipulation of heavy payloads [33].

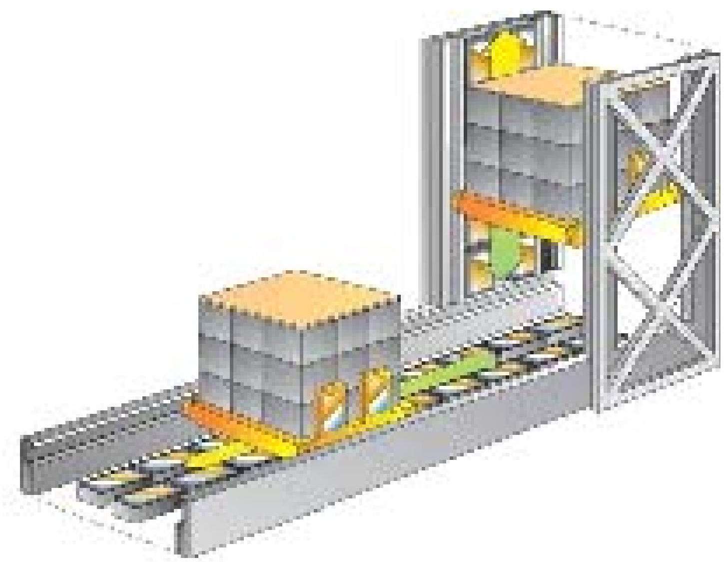
56 [22] Attachment A.

57 [32] p. 25.

High rate vertical/horizontal material mover (HRVHMM)

The HRVHMM[58] system is a piece of the total internal material handling system required for the sea base. HRVHMM addresses the automated horizontal-to-vertical-to-horizontal transitions. In other words, logistics resupply will transition seamlessly between horizontal and vertical planes without disrupting the material flow of other decks. Figure 11 illustrates the conceptual design of an HRVHMM. This technology should enable "strike-down to occur at the rate of receipt (UNREP), achieve required sortie generation rate, and reduce workload (i.e., manning) overall."[59] The technology focuses on automated vertical-to-horizontal transition, linear synchronous motors, ball and screw, rack and pinion, and cable/chain.[60] A three-deck high vertical-to-horizontal demonstrator is the deliverable for this project [27].

Figure 11. Artist's rendition of HRVHMM[a]



a. [30] and [9].

58 FY06 start.

59 [32] p. 27.

60 [27] and [30].

It will integrate with such future systems as automated warehousing, asset visibility and task management systems, and CAMMs. The HRVHMM system would replace existing elevators, conveyors, dumb waiters, chain falls, and their associated support equipment [6]. Whether the final design uses a single, multiple, or split carriage solution, the vertical portion will fit within the Navy's existing 12,000-pound elevator trunk. The system fosters parallel processing: it should service multiple decks simultaneously without interrupting operations on other decks, and loads should be able to enter and leave the system simultaneously. Table 4 summarizes the key system requirements.

Table 4. HRVHMM requirements[a]

	Requirement
Cycle Time	30 load-carrying trips per hour (Threshold) 60 load-carrying trips per hour (Goal)
Sea State	SS 5 (SS 9 survivable)
Payload Capacity	12,000 lb

a. Taken from [6] RFP design requirements.

The HRVHMM is an ONR Seabasing FNC project under EC-1B: Sea Base Mobility and Interfaces. The proposal package for the HRVHMM RFP [6] was due on 26 October 2005. PMS 325 has signed a letter of intent for this project [27]. Because the project has not yet begun Phase I, the exit criteria for acceptance (i.e., a TTA) are in progress [35]. A design scenario for the movement of cargo and a list of design requirements given in the HRVHMM RFP [6] are provided in appendix D.

Selective offload

Providing selective offload requires the ability to locate specific pieces of resupply material. It also requires maneuver space in the holds for MHE to extract material selectively. Modular packaging facilitates this process and enables combat-configured loads to be sent to the customer.

Transformational Package and Ordnance Rapid Transfer System (TransPORTS)

> The ultimate goal … is to demonstrate the ability for an operator to key-in a pallet-sized product and have it delivered to any specific ship location with minimal human intervention. — Broad Agency Announcement (BAA) Announcement # 05-018 [36]

TransPORTS is a fully automated cargo handling system [36]. It will move cargo seamlessly between topside access points and storage, in support of SUSD operations. In short, this system is like a vending machine [9]: the user enters a request for an item using an access station and the system delivers it. TransPORTS enables selective offload.

This effort integrates several technologies currently in development:

- Total asset visibility to provide real-time asset tracking
- Automation to move cargo inside the ship
- An automated warehouse to store the cargo.

Together these technologies provide a fully automated cargo handling system.

Cargo enters TransPORTs through a topside access station, which uses AIT to scan the cargo into the system as it arrives on board. Scanning the cargo updates the logistics inventory system. It also enables the system to direct the cargo to the appropriate storage location. Therefore, by logging the quantity and location of cargo, scanning provides a cargo tracking capability, albeit limited (and not real-time), because the cargo is scanned only at the point of entry and not throughout the ship.

Moving the cargo inside the ship then becomes the responsibility of the intra-ship cargo movement system. Vertical movement is necessary to move cargo between decks, and horizontal movement is necessary for movement to the appropriate cargo hold. The intra-ship cargo movement system saves time and streamlines the process by eliminating the hand-off problem experienced with legacy MHE.

Once the cargo arrives in the hold, it transitions to an automated warehouse system for storage. The automated warehouse and intra-ship cargo movement systems should maximize the storage density in the holds. Additionally, the entire system should handle various types of standardized packaging (e.g., pallets, JMICs, and Quadcons) for maximum utility.

Table 5 presents some of the desired capabilities of the TransPORTS prototype listed in the BAA [see appendix E for the complete list]. The specific technologies that TransPORTS comprises have not been selected; full proposals for TransPORTS BAA were due on 1 November 2005 [37]. The TransPORTS prototype demonstrator is one of ONR's INPs for seabasing.

Table 5. TransPORTS requirements [36]

	Requirement
Access-station throughput rate	**60 pallets per hour (threshold)** **180 pallets per hour (goal)**
Sea state	**SS 6+**
Package capability	**Pallets: 40" x 43" x 43"; 3,300 lb** **Quadcons: 57.5" x 96" x 82" ; 8,200 lb** **JMIC: 44" x 54" x 42"; 3,000 lb**

At sea container discharge

One of USTRANSCOM's current S&T investments for the near term (FY06-09) is in getting the capability to stow and retrieve TEUs selectively from the cargo holds of MSC ship(s) in the sea base.[61] Specifically, this effort seeks to prove that selective access can take place in SS5 without the use of an external crane.[62]

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61 [23] pp. 18 and 41.

62 [23] p. 41.

Future performance gaps

Future performance gaps result when gap-closing technologies are unable to address all of the current capability gaps. Another way of stating this is that the current and gap-closing technologies do not fulfill all of the sea base's needed capabilities.

Total asset visibility

RFID technology addresses where something is located and what is available, and its implementation will determine the extent to which it facilitates total asset visibility. The technical challenges of RF reflection and multi-path nulls within the ship have not been solved, which precludes the ship-wide implementation of RFID. To work around these EMI issues, current discussions[63] limit RFID's implementation either to line-of-sight scanning or within insulated portals, or access stations. If no one takes advantage of RFID's non-line-of-sight, real time data transfer capability, RFID offers the same capability as current barcode technology, and, thus, the gap remains.

To close this gap, real-time asset visibility must be available throughout the ship, RFID technology must be applied along the logistics passageways and in the holds to achieve real-time precision location. Therefore, regardless of where the cargo may be in the ship, readers can poll the RFID tags to locate or request specific information on a particular piece of cargo. These characteristics are needed not only for TAV, but also for selective offload.

In addition to the technology issues, two non-technology issues affect implementing RFID. First, the logistics software systems must exploit RFID technology. RFID offers a non-line-of-sight capability

[63] Furthermore, ONR's FNC and INP efforts do not specify that AIT should enable visibility of logistics resupply in real time throughout the ship.

to interrogate cargo and receive real-time data regarding the cargo. RFID enables a tremendous amount of data to be stored on the tags and available for transfer to the reader and, consequently, a logistics software system. The type (e.g., temperature, humidity, tampering, transportation transfer points) and format of the data need to be compatible with the logistics software systems. For maximum utility, implementation of RFID should capitalize on this technology's advantages: non-line-of-sight interrogation and a rich, real-time data offering. RFID technology enables asset visibility; however, the data must be integrated across the forces and along the supply chain to achieve total asset visibility.

Standardized packaging

We have not identified any future performance gaps as such for standardized packaging, but we highlight several areas where mismanagement could create a gap. The JMIC concept seeks to standardize envelop size and handling features, but the decision to implement standardized packaging resides with individual program managers. Yet standardized packaging establishes the foundation for seabasing logistics. Changes to the JMIC impact the material handling systems and the ability to conduct selective offload. For example, when the JMIC opts for the top-sided quick release over side interlocks, MHE/ODV designers need to understand how securing containers in columns vice in cubes affects their MHE/ODV systems.

Material handling systems

Although the right technology efforts are in place, future performance gaps may arise since they will not be incorporated into the ship's design. Backfitting is likely to result in degraded performance for both the individual technologies and the entire material handling system. Accounting for the backfitting issue and that these systems are still under development, the following technology issues are not all inclusive. They do focus, however, on the fundamental need for a flexible, fully integrated material handling system.

Presently, the ASRS has rigid racks and handles only JMIC- and pallet-sized and shaped loads. This design precludes handling odd-shaped or outsized cargo and requires either modification to handle all of the sea base's cargo or special procedures (or another system) to handle them. Although ASRS uses AIT (barcodes and RFID), reading the data can be done only within line-of-sight. The SR machine moves along the front-side of the racks and scans both barcodes and RFID tags as it passes in front of each package. Implementing RFID technology in this way does not take advantage of RFID's non-line-of-sight capability (see Future Performance Gaps: Total Asset Visibility).

The current CAMM prototypes still require manpower; when the system is adopted for Service use, it must be autonomous and self-guiding. Additional recommendations to CAMM are to include a vertical lift feature for hoisting ordnance onto aircraft and for aircraft maintenance, and to include a capability to bottom mount the CAMM on VERTREP loads to eliminate the additional step of transitioning the load from the deck to a transporter. These enhancements would help to remove the man-in-the-loop and achieve a fully automated material handling system.

One of the aspects of the seabasing concept that is still evolving is whether the sea base replenishment ships will handle TEUs, and if they do, to what extent will the TEUs be transferred, accessed, and (re)packed at sea. If the decision is made to handle TEUs in the sea base, current material handling efforts cannot support them. Either another technology solution will be required or the current efforts will have to be evaluated for their ability to scale to handle TEUs.

To achieve the maximum benefit of these individual material handling technologies, they must be fully integrated into a complete intra-ship material handling system. Complete integration should ensure the seamless, automated flow of cargo.

Selective offload

The automated material handling systems will locate, retrieve, store and transport material between the holds and transfer stations. These actions are critical to the sea base's ability to perform selective offload. Selective offload is imperative in view of the Navy's intention to reduce manning and to increase emphasis on timeliness, with sustainment arriving to the warfighter just in time.

Cargo should enter the automated material handling system as soon as it comes aboard ship. Entry into the system is twofold: one, AIT must scan the cargo and log it into the logistics system, and two, the automated material handling system must have control of the load with the CAMM, for example. Descriptions of the TransPORTS effort suggest a disconnect between the transfer stations receiving the cargo and the access station scanning the cargo. Furthermore, none of the current technology efforts address the injection of VERTREP loads into the automated material handling process. Without such a technology option as bottom-mounting a CAMM to VERTREP loads so they automatically enter the material handling process when they arrive on deck, VERTREP loads will be placed on the deck and then lifted onto a CAMM.

Selective offload is needed to support the warfighter. Sustainment of the warfighter will require automated repackaging of tailored sustainment packages (pallet sized at the largest), delivered ashore rapidly and reliably. It is not clear that current efforts are capable of this level of selective offload.

If the sea base handles TEUs, an automated system needs to be developed for packing, unpacking, build-up, and break-down [38]. Although ISO TEUs do not break down, Quadcon- and JMIC-configured TEUs can be broken down for minimal volume retrograde.

Technology implications for the sea base

Table 6 summarizes the particular products for the seabasing logistics systems. Both RFID and JMIC have more far-reaching applications than the sea base, and as such are being driven by higher levels—DoD and USTRANSCOM, respectively. RFID differs from the other products because its development is primarily driven by the commercial sector. DoD, however, has issued the mandate for its adoption within its purview. The initial operational capability (IOC) of RFID in the sea base can occur only after the EMI issues are resolved. The ONR projects transition from ONR to the transition sponsor after the technology has matured to the agreed-upon TRL. Only after the transition sponsor finishes the development process and fields the technology does it reach IOC.

While the existing seabasing technology efforts are concentrating on the correct technology areas, they will not mature in time to be incorporated into the new MPF(F) ships. In other words, the MPF(F) squadron may FOC in 2020 without the capabilities required by the seabasing concept. Although these technologies are being developed with a backfit capability, firm plans for backfitting do not exist at this time, nor has funding been set aside.

Table 6. Technology summary

	Technology Sponsor	Developer	Transition Sponsor	Transition Timeframe	IOC Timeframe (Approximate)
Total Asset Visibility					
RFID	DoD	Includes USN at Norfolk Ocean Terminal, VA & USA's assistant deputy USD for supply chain integration	N/A	DoD policy effective January 2005	Ongoing
Standardized Packaging					
JMIC	OPLOG N42 / USTRANSCOM (administratively)	PHST Center, NSWC-IHD, Det Earle	N/A	~ FY08 with Joint Concept Technology Development (JCTD) policy for JMIC's philosophy of standardization	~ FY08 depends on individual program managers to adopt
Material Handling Systems					
Automated Storage & Retrieval System	ONR (FNC)	General Dynamics Armament Technology Products, with Siemens as a subcontractor	PMS 325	To TRL 6 in FY07	FY10
Compact/Agile Material Mover	ONR (FNC)	Oak Ridge National Laboratory	PEO Carriers	To TRL 6 in FY07	FY10
High Rate Vertical/Horizontal Material Mover	ONR (FNC)	RFP award in February 2006	PMS 325 (letter of intent)	To TRL 6 in FY09	FY13
Selective Offload					
TransPORTS	ONR (INP)	BAA selection pending	unknown	~ 6 years from start to R&D transition	FY17

Table 7 reflects the overlap between the technology development and the shipbuilding budget and acquisition plan. The budget is expressed in millions of then-year dollars (TY $). The green shaded boxes indicate the years in which money is allocated for the purchase of a ship. The MPF(F) Capability Development Document (CDD)[64] defines the MPF(F) IOC as the delivery of the first LHA(R), T-AKE, MLP and LMSR, and the FOC as the completion of the post-shakedown availability (PSA) for the last ship in the squadron.

The IOC of the technologies will coincide with the arrival of the first MPF(F). Since the technologies will not be incorporated into the new ship designs and builds, the ability to backfit them becomes critical. However even with an ability to backfit, the likelihood that they will be backfit is low since there is no current plan or funding. In the absence of a backfit into the MPF(F), these technologies will not have an opportunity for implementation until the mid-century, with the procurement of the next generation of MPF(F) ships. Funding and programmatics will determine when and if these technologies are ever fielded.

[64] [39] pre-decisional draft

Table 7. Technology and shipbuilding development schedule[a,b]

	Fiscal Year														
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
RFID (TAV)	DoD policy														
JMIC (SP)			JCTD policy; PM adoption												
Automated Storage & Retrieval System (MHS)		TRL 6			IOC										
Compact/Agile Material Mover (MHS)		TRL 6			IOC										
High Rate Vertical/Horizontal Material Mover (MHS)				TRL 6				IOC							
TransPORTS (SO)							INP complete					IOC			
MPF(F) – TAKE[1]			36	406	424	444									
MPF(F) - LMSR[1]				134	998	1,005	998								
MPF(F) - LHA(R)[1]						1,241	1,236	1,257	1,257						
MPF(F) - MLP[1]				1,055		880	849								
MPF(F) –Squadron											IOC				FOC

a. [31,40] for mid-term FY 2012-2016 shipbuilding budget and acquisition, [41] for near-term FY 2007-2011.

b. **Note: Values are then-year dollars (TY $) in millions.**

Manpower implications

An important thrust toward automation comes from the fact that the sea base will not have the manpower to support the labor-intensive logistics operations that the Navy conducts today. So if the automation is not there—and we have shown that it probably will not be—then the manpower must be. With the military's plans to reduce manning, the sea base simply will not have sufficient manpower. Today a CV(N) UNREP requires more than 600 people working for 6 to 10 hours [11]. Two hundred stevedores can load an LMSR in about 15 hours using U.S. ports and unload it in about 110 hours using primitive port facilities [42]. The MPF(F) will not only have the additional responsibility of supporting the warfighter, but also will be operated by CIVMARs. CIVMARs operate with significantly smaller crews than the military; for example, 30 people crew the LMSR and 120 people crew the T-AOE. With such skeleton crews, the only option would be for the elements remaining on the sea base to have the added responsibility of supplying the warfighter. Manpower and automation can be traded for the near term, but ultimately automated systems must handle internal cargo movement.

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Future technologies

These are technologies that we recommend to close the future performance gaps.

Sense and respond logistics (S&RL)

Today's logistics systems are linear and highly optimized. They work well in predictable situations where past behavior is a good indicator of future demand. Traditionally, the *iron mountain* has absorbed the unpredictable demand caused by an unstable logistics system. In the absence of the iron mountain, the military needs an adaptive and flexible logistics system. S&RL proposes to trade optimization for reduced risk and fulfillment of operational objectives.[65]

According to the S&RL concept, each participant in the supply chain functions as both a supplier and a customer. This duality creates a distributed supply chain that is more adaptive than the conventional, unidirectional supplier-customer model. S&RL continually senses the logistics situation, determines demand, and responds accordingly. Decision support tools, also referred to as intelligent agents, recognize patterns in consumption and need to anticipate and respond to unpredictable demand. The speed of the pattern recognition and response depends on the flexibility of the supply and demand networks.

S&RL concentrates on sensing and processing sustainment needs, sorting and shipping material, and delivering the material in a timely manner to sustain the warfighter indefinitely. By bringing logistics into the COP, S&RL allows logistics to integrate with operations.

65 [32] p. 3, table 1-2.

The products relevant to logistics systems that were part of the proposed S&RL EC[66] are :

- End-to-end visibility
- Automated (re)packaging of individual tailored loads for delivery ashore
- Independent autonomous cargo/ordnances material movers.

End-to-end visibility in conjunction with DoD's RFID policy and standards gives the warfighter near real-time visibility of personnel and all types of supplies. It contributes to achieving TAV and, thereby, facilitates selective offload. Automated packaging of tailored loads builds up pallet- or JMIC-sized loads. The independent autonomous material movers are self-powered ODVs; this effort removes the manpower required by CAMM. These last two products tie into the material handling systems and selective offload portions of seabasing logistics systems. These products are not currently funded, but they have the potential to close the future performance gaps in TAV, material handling systems, and selective offload.

ONR sponsored a Sense and Respond Logistics wargame in August 2005. S&RL was one of the three potential FY08 New Start ECs . The total S&RL program was not selected for funding, but the condition-based maintenance sub-component of S&RL is awaiting a funding decision as an FY08 New Start EC.[67]

Autonomous, self-guided vehicles

In a previous section, Future Performance Gaps: Material Handling Systems, we pointed out the need for an autonomous, self-guiding ODV. As an autonomous system, the ODV would function independently (i.e., not rely on a human operator or controller). It needs to possess a self-guidance capability that allows it to sense an ever-changing environment and to move without using dedicated navigation paths. Developing an autonomous, self-guided ODV suit-

[66] [27] slides 29-33. In this reference, S&RL is a potential FY08 New Start EC; however, it was not selected for FY08 funding.

[67] [34].

able to the naval environment requires advanced navigation and intelligence systems.

Navigating on board ship is a complex task. Dedicated logistics paths do not exist. Humans, ODVs, and various other items all share the same passageways. The ship moves constantly, and the internal environment changes constantly. Therefore, the ODV's navigation system should incorporate an advanced vision system, such as stereo vision, for obstacle detection and collision avoidance. With stereo vision, two cameras provide depth perception, and high-quality image-recognition software provides the ability to locate and classify objects [43]. Self-reporting of the ODV's location, direction, and speed provides an additional means for coordination (thereby avoiding collisions) between the individual ODVs.

Data from the navigation system can serve as inputs to the intelligence system for intelligent path planning and obstacle avoidance algorithms. For example, an ODV's intelligence system can use the location and course data it receives from all the other ODVs to plan its travel route. Intelligent planning manages traffic flow, prevents bottlenecks, and improves cycle time. An intelligence system helps the ODV solve problems and achieve its tasking.

Although guidance and intelligence systems pertain to material handling systems, we handle the topic of artificial intelligence (AI), an advanced intelligence system, by itself because of its broad implications for the sea base. AI has the potential to affect material handling systems, selective offload, and logistics C2 [3].

Artificial intelligence

Tom Harris' article on *How Robots Work* [43] defines artificial intelligence as: "recreation of the human thought process—a man-made machine with our intellectual abilities."

Our intellectual abilities include learning, reasoning, communicating, and incorporating implicit and explicit knowledge into our decision process. AI enables autonomy by providing a system with a problem solving capability. The problem solving process [43] involves:

- Gathering situational input via sensor systems
- Comparing inputs with stored data
- Devising courses of action
- Predicting the likelihood of success for each course of action.

Robotics systems can then solve problems for which they have been programmed to solve. They need the ability to learn so they can increase their capability for handling dynamic situations.

Autonomic computing[68] is one of USTRANSCOM's technology interest areas. In autonomic computing, critical network components "learn" the networks architecture and connections, which allows them to know when there has been a change in the network. Once a change is identified, the network responds autonomously to solve the problem. The network also seeks to identify potential problems and initiate steps to minimize damage to the network. Depending on the severity of the problem, the system can simply reroute traffic or, for more severe cases, quarantine a portion of the network until it can fix the problem and then permit reconnection.

Fuzzy logic and artificial neural networks are two methods for implementing AI. Combining them results in a greater capability to react to dynamic, unknown environments and is referred to as a neuro-fuzzy technique. These methods are well-suited for realizing decision support tools such as intelligent agents. [3] discusses intelligent agents—software-based decision aids that apply reasoning to assist decision-makers in developing and choosing courses of action.

Fuzzy logic

Fuzzy logic enables the conversion of human language rules and cognitive processes to their mathematical equivalents that computers can use. It allows the use of mathematics and programming to mimic the characteristics of how the human brain makes decisions. Although computers do well managing numerical calculations and Boolean algebra, they do not understand human logic,

[68] [23] pp. 38.

which takes into account uncertainty and partial information. In classical set theory, an object either belongs to a set (value = 1) or it does not (value = 0), as shown in figure 12. In fuzzy logic, objects belong to a set with a certain degree of confidence, or degree of membership, as shown in figure 13. This graduation from 0 to 1 allows for an overlap of boundaries between sets. The real world rarely has clear-cut boundaries; more often, objects move from one group to the next in a gradual, smooth transition. Although fuzzy logic accounts for uncertainty, its outputs are not uncertain or unclear; they are "crisp" [44].

Figure 12. Classical set theory characterization of traffic flow

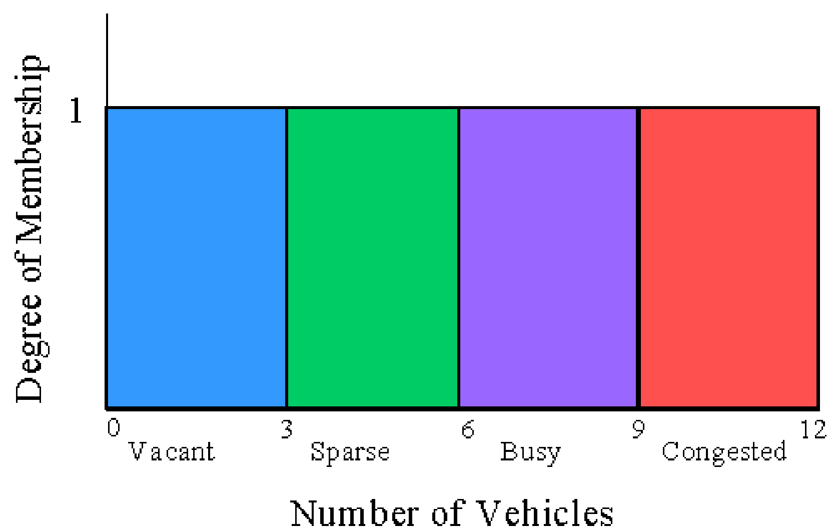
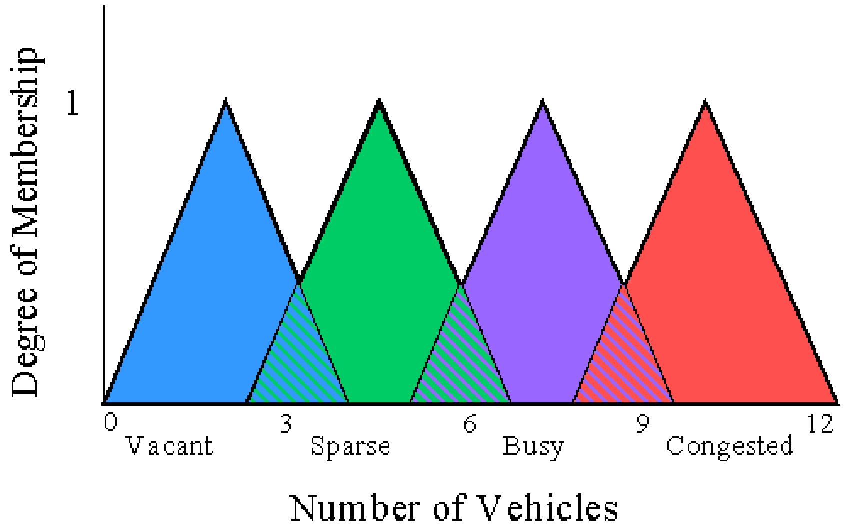


Figure 13. Fuzzy logic characterization of traffic flow



An object's degree of membership is adjusted using conditional "if-then" statements until the fuzzy logic model adequately represents the system [45]. Developing fuzzy logic models that adequately describe the future logistics system and logistics C2 would enable the level of decision support that a decision maker requires in the future sea base. Its ability to "describe a 'humanistics' problem mathematically" [45] could have positive impacts, such as:

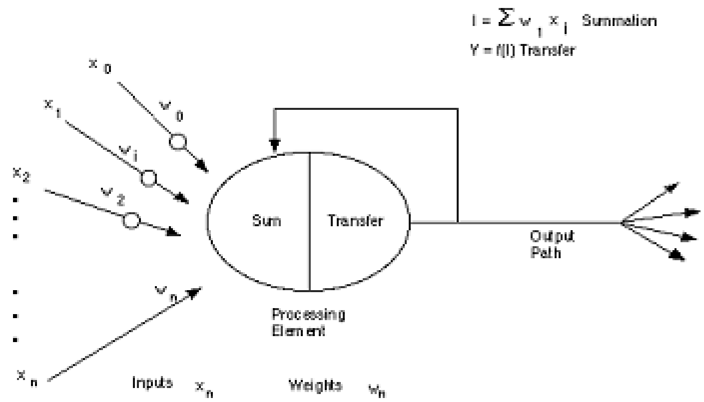
- Determining the best travel path and speed for ODVs
- Prioritizing sustainment requests for selective offload
- Developing potential courses of action based on operational, logistics, and intelligence situation.

Neural networks

Artificial neural networks are electronic models based on the brain's neural structure [46]. They are a method for solving problems involving patterns versus mathematical manipulation. The challenge with artificial neural networks is that researchers still do not know how human intelligence actually works [43]. Neural networks mimic the structure of neurons and the electrical connections that the brain forms between them. Making these structures add up to high-level reasoning, however, is the challenge for enabling human-like operations.

In figure 14, the inputs (x_n) to the artificial neuron are multiplied by weights (w_n) before entering the processing element. The outputs then feed back into the neuron's processing element and into the next artificial neuron.

Figure 14. Schematic of a neural network [46]



Most neural networks learn through supervised training. In supervised training, the networks receive the inputs as well as the desired outputs. As the networks learn, the developers and the network, through error propagation, fine tune the weights (w_n) so that the outputs are achieved with a desired accuracy [46]. Therefore, the network learns by adapting to the inputs (x_n) as well as from the outputs because of the feedback loop.

Thus far, neural networks have been well-suited for modeling complex relationships between inputs and outputs and for finding patterns in large data sets [47]. Examples [46, 47] of neural network applications include:

- Decision making, pattern (sensor processing) and sequence recognition (speech, pattern, and text)
- Data processing: filtering and clustering
- System identification and control (vehicle control).

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Conclusions

The U.S. Navy already has the large pieces of the new logistics resupply system in S&T. Our analysis shows that it is not as much a question of whether the Navy is looking at the right technologies for seabasing, as it is of whether its investments will transition to the sea base and, in particular, to the MPF(F). If the technologies currently under development are not incorporated into the MPF(F) squadron, the sea base will not have the capabilities outlined in the seabasing concept.

In terms of fulfilling the performance needs of the sea base, the benefit of these efforts comes not from the individual technologies, but from the integration of the individual technologies to form an automated intra-ship cargo handling system. This resulting logistics system—through automation and not manpower—would control logistics resupply throughout its entire life-cycle on the ship.

Table 8 summarizes the different technology generation's ability to close the capability gaps relevant to logistics systems. The table rows list the major needed capabilities for each logistics area:

- Total asset visibility
- Standardized packaging
- Material handling systems
- Selective offload.

The three columns represent the technology generations:

- Current – legacy systems, technologies, or products used in the field
- Gap-closing – systems, technologies, or products currently under development that are scheduled to mature in the near-term (~ 2015)

- Future – systems, technologies, or products we recommend that ONR consider for S&T investment.

Table 8. Technologies' ability to close gaps

	Current Technology	Gap-closing Technology	Future Technology
Total asset visibility			
Asset/resource identification	Limited	Yes	Yes
Location identification	No	Limited	Yes
Supplier to end user tracking	No	No	Yes
Total asset visibility across services	No	No	Yes
Standardized packaging			
Compatibility with commercial & military handling methods	No	Yes	Yes
Modular	No	Yes	Yes
Collapsible and dunnage-free for retrograde	No	Yes	Yes
Flexible (tailored package to TEU)	No	Yes	Yes
Automated warehousing system compatibility for maximum storage density	No	Yes	Yes
Material Handling Systems			
SUSD rate = supply/receipt rate	No	Yes	Yes
Vertical movement - throughput, multiple decks	No	Yes	Yes
Automatic securing and releasing of loads	No	Yes	Yes
Repackaging/reconfiguring of loads	No	Limited	Yes
Standardized, modular package handling	Limited	Yes	Yes
Compatible with legacy and future ships	No	?	?
Continuous control by automation	No	Limited	Yes
Selective offload			
Specific material located & retrieved in a timely manner	No	Yes	Yes
Warehouse management software	Limited	Yes	Yes
Automated Identification Technology (AIT)	Limited	Limited	Yes
Material handling systems	Limited	Yes	Yes
Standardized packaging	Limited	Yes	Yes

Considering the overlap between the development cycle of ONR's current efforts and the Navy's shipbuilding plan, we highly recommend that ONR reconsider the value of continuing to fund the logistics technologies currently under development. If ONR decides to proceed with current efforts, it should work with the transition sponsors to identify specific implementation strategies for the technologies.

We further recommend that ONR fund S&RL and artificial intelligence. Development of the S&RL products could arrive in time for the second generation sea base. ONR should consider applying artificial intelligence methods in seabasing logistics systems, such as decision support aids and autonomous, self-guided ODVs. Fuzzy logic and neural networks have existed for several decades within the research community, but they have not been applied to marinized logistics systems.

In addition to future technology efforts, the lack of overarching seabasing leadership and management warrants mention. Joint seabasing management must bring cohesion to and ensure alignment of the individual seabasing efforts. The disparate designs, ideas, programs, and initiatives for seabasing produce redundancies, and in some cases, they simply do not fulfill the needs of the seabasing. Currently, the seabasing changes rapidly, which rapidly makes efforts irrelevant (e.g., the analysis of alternatives (AoA) MPF(F) [48]). Management and leadership must alignment the appropriate technologies, platforms (ships, aircraft, etc.), concept of operations (CONOPS), policy, and funding.

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Appendix A: Classes of supply

The following table lists the U.S. Armed Forces classes of supplies.

Table 6-1. Classes of Supply	
Class	**Supplies**
I	Subsistence, gratuitous health and comfort items.
II	Clothing, individual equipment, tentage, organizational tool sets and kits, hand tools, unclassified maps, administrative and housekeeping supplies and equipment.
III	Petroleum, fuels, lubricants, hydraulic and insulating oils, preservatives, liquids and gases, bulk chemical products, coolants, deicer and antifreeze compounds, components, and additives of petroleum and chemical products, and coal.
IV	Construction materials, including installed equipment, and all fortification and barrier materials.
V	Ammunition of all types, bombs, explosives, mines, fuzes, detonators, pyrotechnics, missiles, rockets, propellants, and associated items.
VI	Personal demand items (such as health and hygiene products, soaps and toothpaste, writing material, snack food, beverages, cigarettes, batteries, and cameras—nonmilitary sales items).
VII	Major end items such as launchers, tanks, mobile machine shops, and vehicles.
VIII	Medical materiel including repair parts peculiar to medical equipment.
IX	Repair parts and components to include kits, assemblies, and subassemblies (repairable or non-repairable) required for maintenance support of all equipment.
X	Material to support nonmilitary programs such as agriculture and economic development (not included in Classes I through IX).
Miscellaneous	Water, salvage, and captured material.

Source: U.S. Army Field Manual 4-0 Combat Service Support [49]

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Appendix B: Technology readiness levels

These readiness levels govern DoD technology development and apply to maturation of hardware technology efforts. TRLs are assigned based on the maturity of the technologies, which is defined as “a measure of the degree to which proposed critical technologies meet program objectives; and, is a principal element of program risk” [50].

TRL	Definition	Description	Supporting Information
1	Basic principles observed and reported.	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development (R&D). Examples might include paper studies of a technology's basic properties.	Published research that identifies the principles that underlie this technology. References to who, where, when.
2	Technology concept and/or application formulated.	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.	Publications or other references that outline the application being considered and that provide analysis to support the concept.
3	Analytical and experimental critical function and/or characteristic proof of concept.	Active R&D is initiated. This includes analytical studies and laboratory studies to physically validate the analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.	Results of laboratory tests performed to measure parameters of interest and comparison to analytical predictions for critical subsystems. References to who, where, and when these tests and comparisons were performed.
4	Component and/or breadboard validation in a laboratory environment.	Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared with the eventual system. Examples include integration of "ad hoc" hardware in the laboratory.	System concepts that have been considered and results from testing laboratory-scale breadboard(s). References to who did this work and when. Provide an estimate of how breadboard hardware and test results differ from the expected system goals.
5	Component and/or breadboard validation in a relevant environment.	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment. Examples include "high-fidelity" laboratory integration of components.	Results from testing a laboratory breadboard system are integrated with other supporting elements in a simulated operational environment. How does the "relevant environment" differ from the expected operational environment? How do the test results compare with expectations? What problems, if any, were encountered? Was the breadboard system refined to more nearly match the expected system goals?

TRL	Definition	Description	Supporting Information
6	System/subsystem model or prototype demonstration in a relevant environment.	Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in a simulated operational environment.	Results from laboratory testing of a prototype system that is near the desired configuration in terms of performance, weight, and volume. How did the test environment differ from the operational environment? Who performed the tests? How did the test compare with expectations? What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems before moving to the next level?
7	System prototype demonstration in an operational environment.	Prototype near or at planned operational system. Represents a major step up from TRL 6 by requiring demonstration of an actual system prototype in an operational environment (e.g., in an aircraft, in a vehicle, or in space). Examples include testing the prototype in a test bed aircraft.	Results from testing a prototype system in an operational environment. Who performed the tests? How did the test compare with expectations? What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems before moving to the next level?
8	Actual system completed and qualified through test and demonstration.	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.	Results of testing the system in its final configuration under the expected range of environmental conditions in which it will be expected to operate. Assessment of whether it will meet its operational requirements. What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems before finalizing the design?
9	Actual system proven through successful mission operations.	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation (OT&E). Examples include using the system under operational mission conditions.	OT&E reports.

Source: DoD Technology Readiness Assessment (TRA) Deskbook [51]

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Appendix C: CAMM exit criteria

This table lists the exit criteria for the CAMM as agreed upon by ONR and PEO Carriers.

Exit Criteria – Compact Agile Material Mover for Carriers

(Testing/Validated at TRL 6)

Criteria	Current Capability	Minimum	Goal
Increased System Capacity	Various, many ships require manhandling. 4,000 lb forklifts are common.	Handle a variety of Naval packaging and weapons up to 6,000 lbs	Handle a variety of Naval packaging up to 12,000 lbs
Precision Control using Force Compensation	SUSD systems achieve precision control in a land based application only.	Achieve ± 0.5" load control positioning tolerance in a sea state 5 or higher environment.	Achieve ± 0.03" load control positioning tolerance in a sea state 5 environment or higher.
Manpower / Workload Reduction	Current weapons movements using non-powered equipment is manpower / workload intensive.	Based on previous carrier manpower / workload reduction studies, initial estimates are that CAMM technologies will provide a 5 - 15% reduction in ship's company weapons department manpower workload. This criterion will be updated to reflect accurate estimates of manpower / workload reductions for CVN 21 resulting from the use of powered transporters. This final criterion will be derived from a formal review of previously conducted studies on manpower / workload reduction for CVNX 2 (Report: TS 2.10-0039) appropriately updated to reflect the relevant differences between CVNX 2 and CVN 21.	
Deck Pressure	Carrier decks are suitable for current mobility equipment.	This critical criterion remains temporarily undefined as the deck loading specification for the target transition platform (CVN21) has not been finalized and approved at the time of this writing. Future revisions of this TTA will address the NAVSEA approved deck loading specification once finalized.	
Maneuverability	Equipment is not highly maneuverable.	CAMM shall be fully maneuverable in confined spaces.	CAMM shall be capable of rotating within its own footprint.
Powering	Current systems support replenishment requirements.	Non-tethered equipment shall operate for 6 hours at a 50% duty cycle without power re-supply.	Non-tethered equipment shall operate for 8 hours at a 65% duty cycle without power re-supply.
Life Cycle Cost	Life cycle cost of existing systems is adequate.	Life cycle costs shall be equivalent to systems being replaced.	Life cycle costs shall be less than systems being replaced.
Maintainability	Current systems are difficult to maintain.	Maintainability equivalent to current systems.	Improved maintainability and availability over systems being replaced.

From: CAMM Technology Transition Agreement [22, Attachment B]

Appendix D: HRVHMM proposed operation and system requirements

HRVHMM RFP outlines a notional scenario in which this technology effort should execute successfully; it also provides the design requirements. Both the proposed operation and design requirements of the system are taken directly from the RFP. The notional scenario,[69] which proposed HRVHMM systems should be able to perform, follows (see figure 15 for the deck locations):

1. Transfer loads between a multi-purpose storeroom located on Deck "A" and a position on an upper Deck "B"; Decks A and B shall be separated by a third deck, C.

2. Complete at least 30 load-carrying trips per hour between origin and destination points on A and B, respectively; While 30 trips per hour will be the threshold requirement for this system, the throughput goal for the system will be 60 trips per hour. These threshold and goal requirements were selected to provide sufficient throughput in loads per hour (JMICS/hr, Pallets/hr, etc.) to support CONREP, VERTREP, and automated warehousing.

3. Allow simultaneous entry of loads into the system at the origin point and removal of loads from the system at the destination point (parallel processing).

4. Single, multiple, or split carriage solutions are allowable.

5. The movement system must be capable of also simultaneously servicing Deck C.

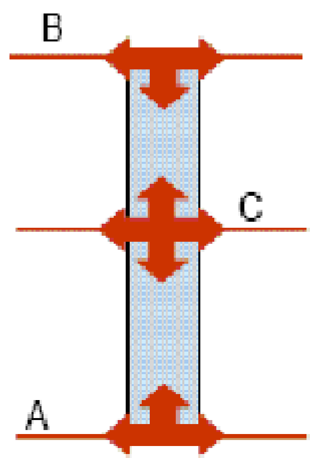
6. In keeping with the objective for parallel processes, it is desirable that the system be designed so that activities at C will not prevent similar activity at A and B or movement between A and B (in the case of multiple platform solutions).

[69] [6] p. 6

7. It is desirable that activities at A, B, and/or C not interfere with each other.

8. At main deck ("B"), elevator opens to the deck directly (e.g., there is no trunk above the deck) [30].

Figure 15. Material flow example for HRVHMM system[a]



a. From [6] – figure 1.

The HRVHMM RFP states the following design requirements:[70]

1. Sea state (ops/survival) - SS 5/SS 9
2. Roll (ops/survival) - 15/30 (degrees)
3. Pitch (ops/survival) - 3.5/10 (degrees)
4. Vertical load factor (ops/survival) - 1.48/1.72 g's
5. Transverse load factor (ops/survival) - 0.35/0.55 g's
6. Longitudinal load factor (ops/survival) - 0.21/0.28 g's
7. Trips per hour[71]

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70 [6] pp. 13–5.

71 Rate assumes a minimum of two JMICs/trip and the ability to transport MHE. These throughput requirements were selected to provide the throughput necessary to support UNREP and the automated warehouse. [29]

a. Threshold: 30 trips per hour strike-up or 30 trips per hour strike-down

b. Goal: 60 trips per hour strike-up or 60 trips per hour strike-down

8. Allowable Stress - Combined stresses acting both individually and concurrently in load bearing structural and mechanical components of the equipment shall not exceed 35 percent of the yield strength of the material used (20% for composites).

9. Maximum travel speed - 150′ (45,720 mm) per minute

10. Ship flexure

    a. Horizontal - 0.43″ per 100′ (11 mm per 30.5 m)

    b. Over the entire vertical trunk - ± 0.125″ (± 3.2 mm)

11. Payload capacity

    a. 12,000 pounds (5,443 Kg)

    b. The system shall be capable of carrying a variety of loads, examples of which are JMICs, Quadcons, and MHE.

    c. The technology solution shall be capable of being scaled for specific applications that may require lesser or greater capacity.

12. Trunk size - Vertical movement components of the system shall not exceed the footprint available in a single nominal Navy 12,000 pounds (5,443 Kg) elevator trunk (3,132 mm x 4,976 mm or 10.3′ x 16.3′). The technology solution shall be capable of being scaled for specific applications that may require smaller or larger footprints.

13. Horizontal/Vertical/Horizontal - Must be capable of automatic transition

14. Power usage

    a. 440V, 3 phase (MILSTD 1399, Type 1)

b. Capable of at least 8 hours continuous operation in Sea State 5 (Ops), assuming system oriented to transition loads transversely. Offerors shall provide power estimate for the threshold and, if achievable, the goal.

c. Threshold: 30 loaded (12,000 lbs or 5,443 Kg) trips per hour

d. Goal: 60 loaded (12,000 lbs or 5,443 Kg) trips per hour

e. Assume all loaded trips from A to B. (figure 15)

15. Payload clearance - Able to handle JMICs, Quadcons, and MHE with a minimum clearance between the load and any doors or obstructions of 300 mm

16. Hatch accommodation - Operate from a trunk and/or flush deck

17. Handling envelope - HRVHMM equipment and components shall not result in any obstruction outside of the trunk or hatch boundary that would hinder normal operations (i.e., movement of cargo, equipment or personnel) when the deck level is not being serviced by the system.

18. Braking system - Operational and emergency (e.g., loss of power)

19. Safety system - Appropriate for technology solution (safety equivalent to current elevators)

20. System reliability - >250,000 MCBF (Mil E 17807)

21. Reliability of control system - MTBF 3,750 hrs., MTTR 8 hrs. (Mil E 17807)

22. Shipboard environmental concerns

    a. Temperature- Exposed -10°F to 150°F (12.2°C to 65.6°C); Non-Exposed 32°F to 120°F (0°C to 48.9°C) (Mil E 17807)

    b. Humidity- 0% to 95%

23. EMI - Applicable sections of MIL-STD-461E

Appendix E: TransPORTS desired capabilities

The BAA [36] lists the following desired capabilities of the TransPORTS prototype:

1. Access station throughput rate: Threshold of 60 pallets per hour per station. Objective of 180 pallets per hour per station.
2. System must provide means of real-time automated tracking of handled assets. (e.g., barcode scanning, RFID tags, etc.). Wireless product demand.
3. System/platform must have:
    a. Multiple access stations that are capable of receiving and delivering cargo
    b. Multiple horizontal and vertical cargo pathways
    c. Multiple cargo holds
    d. Multiple decks and subdivisions.
4. Full inventory awareness at each access station.
5. System must demonstrate ability to efficiently deal with compound hull curvature and watertight boundaries while maintaining a high storage density. This applies to both the intra-ship cargo movement sub-system and the automated warehouse sub-system.
6. System must be compatible with the following:
    a. Pallets: 40″ x 48″ x 43″; 3,300 lbs
    b. QUADCONs: 57.5″ x 96.0″ x 82.0”; 8,200 lbs
    c. Joint Modular Intermodal Container (JMIC): 44″ x 54″ x 42″; 3,000 lbs
7. System must have some mechanism(s) to restrain stationary and moving loads at all times.

8. Autonomous, seamless transition between vertical and horizontal material movement.
9. Designed for future shipboard operations (MPF(F)/LMSR sized vessels) through the high end of Sea State 6. System must not bind under external loading such as:
    a. Must endure accelerations in all degrees of freedom:
        i. 0.2g lateral (sway)
        ii. 0.4g vertical (heave)
        iii. 0.2g axial (surge)
    b. Must handle flexure of supporting ship structure.
    c. Must be operable at single amplitude significant roll angles of 8 degrees and single amplitude significant pitch angles of 3.5 degrees
    d. Machinery vibration.
    e. System must be designed to handle ordnance. Future shipboard system will require ordnance certification (blast mitigation, sparkless operation, etc.).

Glossary

ACTD	Advanced Concept Technology Demonstration
AI	Artificial Intelligence
AIT	Automated Information Technology
AoA	Analysis of Alternatives
ASRS	Automated Storage and Retrieval System
BAA	Broad Agency Announcement
C2	Command and Control
CAMM	Compact/Agile Material Mover
CDD	Capability Development Document
CDR	Cargo Drop Reel
CIVMAR	Civilian Mariners
CLF	Combat Logistics Force
CNA	Center for Naval Analyses
CONOPS	Concept of Operations
CONREP	Connected Replenishment
CONUS	Continental United States
COP	Common Operational Picture
CROP	Container Roll Out Platform
DoD	Department of Defense
DSB	Defense Science Board
EC	Enabling Capability
EMI	Electromagnetic Interference
ERP	Enterprise Resource Planning
FNC	Future Naval Capability
FOC	Full Operational Capability
HAT	Human Amplification Technology
HRVHMM	High Rate Vertical/Horizontal Material Mover
IA	Information Assurance
INP	Innovative Naval Prototype
IOC	Initial Operational Capability
ISO	International Organization for Standardization
JIC	Joint Integrating Concept
JILWG	Joint Intermodal Logistics Working Group
JIWG	Joint Information Assurance Working Group
JMIC	Joint Modular Intermodal Container
JMIDS	Joint Modular Intermodal Distribution System
JMIP	Joint Modular Intermodal Platform
KPP	Key Performance Parameter
LHA(R)	Amphibious Assault Ship, Replacement
LHD	Amphibious Assault Ship, Multipurpose

LHD	Load Handling Device
LMSR	Large, Medium-speed Roll-on/Roll-off
MHAT	Material Handling and Transfer
MHE	Material Handling Equipment
MILSTD	Military Standard
MLP	Mobile Landing Platform
MMI	Man-Machine Interface
MOP	Metrics of Performance
MPF(F)	Maritime Prepositioning Force (Future)
MPS	Maritime Prepositioning Squadron
MSC	Military Sealift Command
NAVSTORS	Naval Stowage and Retrieval System
NEW	Net Explosive Weight
NSRP	National Shipbuilding Research Program
NSWC-PC	Naval Surface Warfare Center-Panama City
OCILOW	Off-Center In-Line Omnidirectional Wheel
ODV	Omni-directional Vehicle
ONR	Office of Naval Research
ORD	Operational Requirements Document
OSD	Office of the Secretary of Defense
P&D	Pick and Delivery
PEO	Program Executive Office
PHST	Packaging, Handling, Storage, and Transportation
PoP-T	Proof of Principle Transporter
PSA	Post-Shakedown Availability
R&D	Research and Development
RFID	Radio Frequency Identification
RFP	Request for Proposal
RMS	Root Mean Square
S&RL	Sense and Respond Logistics
S&T	Science and Technology
SLI	Standard Load Interface
SMCFCS	Ship Motion Compensation for Force Control-Based Systems
SR	Storage and Retrieval
SS	Sea State
STREAM	Standard Tensioned Replenishment Alongside Method
SUSD	Strike-up/Strike-down
SWMS	Shipboard Warehouse Management System
T-AKE	dry cargo, ammunition ship
TAV	Total Asset Visibility
TEU	Twenty-foot Equivalent Unit
TRA	Technology Readiness Assessment
TransPORTS	Transformational Package and Ordnance Rapid Transfer System
TRL	Technology Readiness Level
TTA	Technology Transition Agreement

TY $	Then-year Dollars
UNREP	Underway Replenishment
USTRANSCOM	US Transportation Command
UWB	Ultra-wide Band
VERTREP	Vertical Replenishment

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