ICODES: A Load-Planning System that Demonstrates the Value of Ontologies in the Realm of Logistical Command and Control (C2)

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Over the past decade the Collaborative Agent Design Research Center (CADRC) at California Polytechnic State University (Cal Poly, San Luis Obispo) and its sustaining sponsor CDM Technologies, Inc. (CDM) have developed a suite of information-centric software tools in support of military deployment and distribution processes. At the heart of each of these tools are expressive context models or ontologies that are partnered with select communities of software agents capable of reasoning about domain-specific information and concepts to provide their user communities with meaningful decision-support. Collectively these tools represent an evolving suite of adaptive Knowledge Management Enterprise Services (KMES) that can be readily configured into a net-centric, Service-Oriented Architecture (SOA) based planning and decision-support toolset for a particular application domain. As a set of KMES tools the Integrated Computerized Deployment System (ICODES) is configured to support the movement of supplies in the military deployment and sustainment operational domain. The application focus is conveyance load-planning, including the staging of cargo in marshalling yards, assembly areas, and rail heads.

ICODES has been a program of record (POR) successfully employed by the United States (US) Department of Defense (DoD) since 1997. Incorporation of progressive technologies such as ontological representation and agent-based analysis was a reaction to (1) the Army's experience with the movement of supplies by ship in support of Operation Desert Storm showing that the traditional manual approach to load-planning impeded operations due to the unanticipated changes and subsequent problems that inevitably arise and (2) DoD's realization that it was increasingly infeasible to employ the number of people needed to continue using a substantially manual approach to load-planning operations. These operational and fiscal realities forced DoD to find ways to use progressive computer-based technologies to reduce costs and improve operational effectiveness.

Command and Control (C2)

ICODES was developed as an information-oriented, agent-based system in direct response to the complexities inherent in military load-planning. To effectively apply ontology-based technology to C2, it is important to keep in mind its primary definition and set of objectives. The authoritative definition of C2 is:

> *"The exercise of authority and direction by a properly designated commander over assigned and attached forces in the accomplishment of the mission. Command and control functions are performed through an arrangement of personnel, equipment, communications, facilities, and procedures employed by a commander in planning,*

> *directing, coordinating, and controlling forces and operations in the accomplishment of the mission."* (Joint Publication [JP] 1, *Doctrine for the Armed Forces of the United States*)

Stated simply, C2 is commanders: (1) learning what they need to know to make good decisions that lead to the successful accomplishment of their missions; (2) making these decisions; (3) issuing directions; and, (4) supervising the execution of such directions. Warfare is inherently non-deterministic and therefore the ability of the military decision maker (or commander) to have access to timely, accurate, and actionable information is absolutely critical. Prior to ICODES, the data and information used in planning and executing a shipload was employed almost entirely by shipload specialists. From inception, the development of ICODES focused on the user's business processes, the very nature of information relevant to C2 operations, and translating the large volumes of data into meaningful information that users need. Equipped with ICODES, shipload specialists found that they could process data and information to produce valuable information that commanders could easily understand and quickly exploit to make important decisions. As a result of the situation awareness and related information provided by ICODES, commanders have seen a significant reduction in uncertainty and therefore improved the quality of their decisions.

Throughout its use as a DoD load-planning resource, operational experience with ICODES showed that an information-based approach provides commanders and their staffs with a set of C2 support-tools that can process very large quantities of data to produce accurate information that is presented in easy-to-understand displays. Such transformation of what is typically an overwhelming sea of data into relevant, actionable information is critical as the US reduces the size of its armed forces.

Load-Planning as a Complex Problem

The rapid deployment of military assets from the US to overseas locations is a complex undertaking. It involves the movement of large numbers of tracked and wheeled vehicles, weapon systems, ammunition, power generating and communication facilities, fuel, food supplies, and other equipment and goods, from military bases to the area(s) of operation. Several modes of transportation are typically involved. Depending on the location of the military base the assets are preferably moved by road to the nearest railhead, from where they are loaded onto railcars for transportation to the appropriate air or ocean port of embarkation.

Alternatively, if rail transportation is not an option, all of the cargo must be shepherded through the public road corridor from the base to the port. At the port of embarkation the assets are briefly assembled in staging areas and then loaded onto aircraft or vessels for shipment. Points of debarkation may vary widely from a commercial air or ocean port with fairly good facilities to a secure airfield in the theater or an amphibious landing on a hostile shoreline under fire. Once the cargo has been disembarked in or near the theater it, must be transported to its final destination by road, rail, air, or barge. In many cases this becomes an inter-modal affair with the need for frequent re-planning due to changes in priority or as routes in the theater become temporarily unavailable due to inclement weather or enemy activities.

Speed and in-transit visibility are of the essence (Figure 1). The total time required for the loading and unloading of the conveyance is a critical factor and largely determined by the quality of the load-plan. Ship load-planning, for example, has many of the characteristics of a complex problem situation (Figure 2). First, there are continuous information changes. The vessel that arrives at the port may not be the vessel that was expected and that has been planned for. This means that the existing load-plan is no longer applicable and a new plan has to be developed. Similarly, last minute cargo changes or inoperative lifting equipment may require the existing plan to be modified or completely revised. Second, there are several complex interrelationships. The cargo on any one ship may be destined for several ports of debarkation, requiring careful consideration of loading and unloading sequences. However, these sequences must take into account unloading priorities that may be dictated largely by tactical mission plans. In addition, the placement of individual cargo items on board the ship is subject to hazardous material regulations and practices. These regulations are voluminous and complex in themselves. At times they are subject to interpretation, based on past experience and detailed knowledge of maritime risks and practices. Finally, the trim and stability characteristics of the ship must be observed throughout the planning process. This includes listing, draft and deck stress limitations.

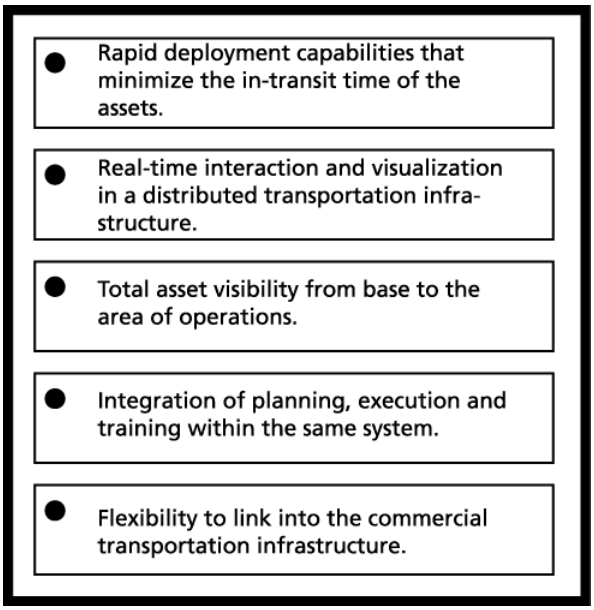

Figure 1: Military deployment objectives

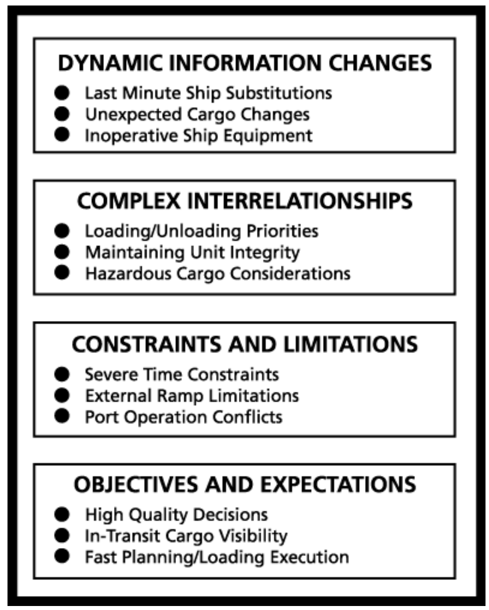

Figure 2: Complexity of ship load-planning

Third, there are many loading and unloading constraints. Some of these constraints are static and others are dynamic in nature. For example, depending on the regional location of an ocean port external ship ramps may not be operable under certain tide conditions, or an airfield may be able to accommodate only a small number of aircraft concurrently on the ground for loading purposes. Local traffic conditions, such as peak hour commuter traffic and rail crossings, may seriously impact the movement of cargo into staging areas or from staging areas to the pier or aircraft loading area. While these constraints are compounded whenever loading operations occur concurrently, the general complexity of the load-planning problem is exacerbated by the number of parties involved. Each of these parties plays an important role in the success of the operation, but may have quite different objectives. Certainly, the objectives of the commercial stevedore crews that may be under contract to carry out the actual loading tasks are likely to differ markedly from the prevailing military objectives that include rapid loading and unloading operations, unit integrity, load density, documentation accuracy, and security.

The ICODES Solution

To effectively address the complexities inherent in military load-planning it is necessary to have a solution that incorporates intelligent software capable of analyzing the large amounts of data, the concepts critical to the load-planning activity, and most importantly the extensive relationships that bind these components together.. Within such a decision-support facility, expressive information models, or ontologies, provide the context necessary for in-depth analysis to occur.

ICODES is an example of a new generation of *information-centric* military decision-support software tools that feature expert agents with automatic reasoning and analysis capabilities. This is made possible by an internal virtual representation (i.e., domain model or ontology) of the load-planning environment, in terms of conveyance and cargo characteristics and the complex relationships that constitute the context within which load-planning operations are performed. ICODES agents employ these rich ontologies to monitor the principal determinants of cargo loading, including: the placement and segregation requirements for hazardous cargo items; the trim and stability requirements of the conveyance; the accessibility of stow areas; the correct placement of cargo items in respect to restricted areas and inter-cargo spacing tolerances; and, the accuracy of cargo characteristics (e.g., dimensions, weight, type, and identification codes) relative to standard cargo libraries and associated reference tables.

Expert Agent Capabilities

There are many definitions of software agents in the literature (Wooldridge and Jennings 1995; Bradshaw 1997). To the authors, a software agent in its simplest form is a software module (i.e., service) that is capable of communicating with other software modules or human agents to facilitate some action. However, at this level of definition an agent is not necessarily intelligent. An intelligent agent would need to communicate using a common language (such as the ontology represented by the Semantic Network in ICODES) to support reasoning capabilities. In addition, an agent may have deep information and expert skills within a narrow domain and would then be referred to as a knowledge-based agent that has the ability to act on its own initiative. Such agents typically collaborate with other software and human agents to accomplish goals, and use local information to manage local resources.

The expert agents in ICODES are designed to assist the load-planner in the knowledge domains of hazardous material, trim and stability of the ship, cargo access paths, cargo attribute verification, and the actual placement of cargo in stow areas. The agents do not communicate directly with each other, but are totally decoupled. In fact, they do not know about each others existence. They collaborate indirectly as clients through a subscription service that allows them to post interests to data changes within the context provided by the ontology.

When the user is developing a load-plan while operating in *User Stow mode*, where users manually place cargo items within the various stow areas, the agents continually analyze the evolving load-plan and alerting the user to any violations or concerns that may arise. Agents communicate with users through computer-monitor displays by turning the surround of the appropriate agent status window red. By selecting the highlighted agent icon, the user can interact directly with the agent and obtain an explanation of the violation and related implications.

When users operate in what is referred to as *Assisted Stow mode*, they perform an initial configuration of preferences and restrictions used to drive the automated formulation of a load-plan. The agents then collaborate among themselves to place the cargo in such a manner that there are guaranteed to be no violations. Cargo items that could not be placed in any stow area without causing a violation are simply not loaded and identified to the user along with applicable details. Taking the vessel conveyance domain as an example, brief summaries of the functional capabilities of each ICODES agent are provided below.

The ***Stow Agent*** supports both manual and automatic load-planning operations. Using default settings in the automatic mode (i.e., Assisted Stow), the Stow Agent attempts to place the heaviest cargo items as low as possible on the ship without causing a violation. This results in a low center of gravity for the ship, which is desirable in most cases. The Assisted-Stow mode provides a comprehensive set of settings. This allows the user to define exclusive and inclusive constraints and preferences in respect to both the cargo that is required to be loaded and the stow areas that have been designated as being available. The Stow Agent checks to see that the placement of a cargo item does not overlap another cargo item, a fixture of the ship such as a stanchion or fire lane, or if the item is not entirely within a stow area. In Assisted-Stow mode, the user can also set the front/back and side to side spacing requirements of a cargo item (e.g., 18 inches front and back and 6 inches side to side) and the Stow Agent will abide by these settings so as not to place items within that imagery buffer around each cargo item.

Other parameters checked by the Stow Agent include the ports of embarkation and debarkation to ensure that they match the ports indicated in the voyage documents, and the height of each cargo item to ensure that the latter can reach their final locations. The Stow Agent automatically adds a safety cushion (specified by the user) to the actual height, which is set by the end-user, to make sure that height plus the cushion does not exceed the maximum allowable height for cargo in that stow area and the access path to the stow area.

In the Assisted Stow mode ICODES ensures that the automatically generated load-plan has no violations. In the manual mode (i.e., User Stow), ICODES will allow the user to load cargo items that are in violation. However, the Stow Agent will alert the user of the violations and provide an explanation.

The ***Trim and Stability Agent*** checks the placement of cargo items on the conveyance to see if they violate any desired (i.e., user specified) or mandated parameters, such as maximum draft settings, strengths (i.e., bending of the ship) or deck stress limitations in the case of vessels. The Stow Agent in automatic mode will rearrange the placement of cargo during the Assisted Stow process if the placement of cargo causes the upper limits of the strengths properties of the ship to be exceeded. For example, if the predefined loading order requires the center two stow areas of a deck to be loaded first and second, this would result in a sagging condition of the deck. Under these conditions, the Stow Agent will automatically redefine the loading order used by the Assisted-Stow process, so that the placement sequence of the cargo will begin with the forward and aft areas of the deck (thereby preventing the occurrence of a sagging condition).

ICODES calculates the effects of the exact placement of every cargo item loaded on the ship in three different planes. These planes are: forward to aft often referred to as the Longitudinally Center of Gravity; side to side or Transverse Center of Gravity; and, up and down or Vertical Center of Gravity. The Trim and Stability Agent takes into account the combined effects of all of the cargo items, the ballast, and the original condition of the ship to provide the user with fairly accurate estimates of the center of gravity in each of the three planes, as well as an overall assessment of the stability of the ship.

The ***Access Agent*** checks all paths to ensure that a cargo item can be moved into a particular stow area. This includes openings, doors and hatches, differentiating between cargo that is loaded with cranes through hatches (i.e., LOLO: Lift On Lift Off) and cargo that is driven or pulled into stow areas (i.e., RORO: Roll On Roll Off). If in the Assisted Stow mode and if there is a violation in the loading path of a particular cargo item, the Stow Agent will not place this cargo item in that stow area but will attempt to place it in another stow area. In this situation the violation is transmitted indirectly from the Access Agent to the Stow Agent without notification of the user.

In manual mode (i.e., User Stow), on the other hand, if a cargo item is placed in a particular stow area for which all of the possible loading paths register an access violation, then the Access Agents will inform the user that the cargo item has a violation for every path to the final location. In addition, the Stow Agent will identify for the user the shortest loading path and the nature of the violation that is associated with that path.

ICODES allows the user to edit the ship characteristics, including the usability properties of the cranes and the dimensions of doors, openings and hatches. Since the Access Agent utilizes the current ship characteristics as the existing constraint conditions, these changes will be reflected in the actions of the Stow Agent in automatic mode and the alerts provided by the Access Agent in manual mode.

The ***Cargo Agent*** checks the characteristics of each cargo item against the expected characteristics for that cargo item recorded in the Marine Equipment Characteristics File (MECF) or Tech Data cargo libraries. Not all cargo characteristics can be verified in this manner. These cargo libraries currently contain more than 20,000 items, but are restricted in terms of the attributes that are provided for each cargo item. Typically, this verification process is complete and reliable only for dimensional (i.e., length, width and height) and weight attributes. If discrepancies are detected the Cargo Agent generates warnings.

The ***Hazard Agent*** verifies the proper placement of hazardous cargo items in reference to the various hazardous material codes and regulations discussed previously. In the case of vessels, it considers issues such as: Is the cargo item in an acceptable deck location according to its loading requirements? What are the segregation requirements for the cargo item, taking into account both the type of cargo item (e.g., break-bulk, container, vehicle) and the proximity of any other hazardous cargo items? Again in the vessel domain, for containers the Hazard Agent considers the hazard category of each item in the container in assessing the hazard condition of the container and its location relative to any other hazardous cargo item on the ship.

To effectively perform the extensive analysis described above the ICODES agents depend on a rich information model capable of providing the necessary domain knowledge and ever-changing context as the load-plan evolves. This critical content is provided by a set of domain models, or ontologies, which sets ICODES apart as an information-based, decision-support system.

Representation of Context – ICODES Ontologies

As a cohesive set of domain models the ICODES ontology in its entirety encompasses the concepts and entities that essentially comprise the view that ICODES has of the *world of load-planning*. In other words, the ICODES domain models provide expressive, context-oriented descriptions of both the tangible entities (e.g., conveyances in terms of loading areas, on-board facilities, etc., and cargo in terms of geometry, weight, etc.), as well as the intangible concepts (e.g., hazardous constraints, mobility, preference, accessibility, sequencing, etc.), and the large number of relationships necessary to support the decision-support capabilities offered by the ICODES suite of tools.

The ICODES model contains a number of sub-domains, including the Vessel Domain, Air Domain, Rail Domain, Yard Domain, Cargo Domain, and Plan Domain which describes the logistics of space planning in general. The following sections discuss three of these domain models in more detail; namely, the Vessel Domain, Cargo Domain, and Plan Domain.

Vessel Domain

As the name implies, the ICODES Vessel Domain model (Figure 3) provides a logistically biased view of a vessel. This representation has evolved substantially since the first version of ICODES was released in 1997. Both the advances in maritime technology, as well as the increasing demands from the user-base to support different types of load operations and cargo types, have triggered the evolution of the Vessel Domain model. A clear example of this need for enrichment of the Vessel model is the increase use of containers in the world of maritime transportation over the past 10 years. This requirement has resulted in model extensions to support container cells and tiers, as well as different container cell numbering systems such as the Baplie and MILSTAMP conventions. The following is a description of each of the primary elements comprising the Vessel model:

> ***Stow Areas and Zones:*** The stowable space in the vessel is represented by *StowAreas* that keep track of the weight and area occupied by the cargo located in them. Further, to facilitate trim and stability calculations, *StowAreas* also record their center of gravity. Existing as a less formalized loading area, *Zones* allow the user to represent a subsection of a *StowArea*. Among numerous other attributes, *Zones* record their maximum cargo height and maximum deck stress. They can be used to represent a variety of loading conditions, each imparting their distinct semantics. For example, *NoStowZones* can be used to demarcate areas of the vessel where cargo should not be placed. Likewise, *OffLoadZones* can be used to represent temporary loading locations external to the vessel where cargo is to be off-loaded.
>
> ***Access Entities:*** The Vessel model supports many different types of access entities, as those parts of the vessel that have to be traversed by cargo items as they move to their final location on the vessel. Examples of such access entities include booms, bulkheads, doors, elevators, hatches, openings, and ramps. These transition points must be richly described within the vessel domain in order to allow analytical agents to both identify and resolve potential accessibility issues.

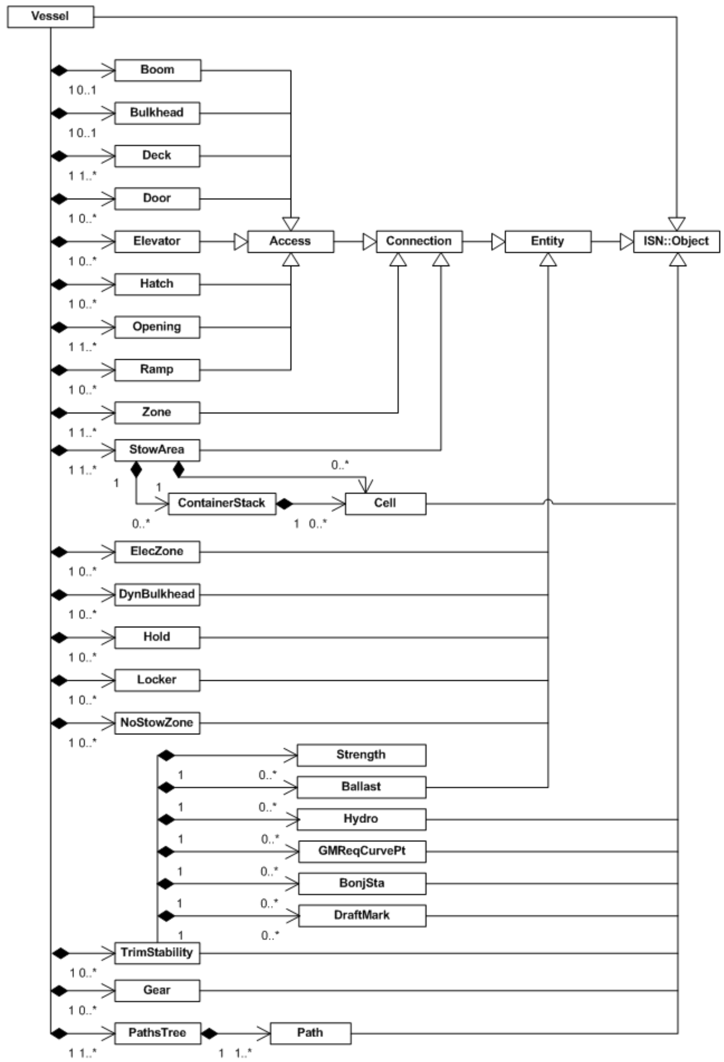

Figure 3: The Vessel Domain model

Trim and Stability: Most of the trim and stability information in the vessel domain is derived from a standard Ship Data file (i.e., SDA file) provided by the Maritime Administration (MARAD). The vessel model contains expressive descriptions of available tanks, ballast, hydrostatic properties, bonjean curves, strength, and draft marks critical for accurate trim and stability analysis.

Container Representation: The Vessel model employs the notion of *container tiers* to support vessels that are equipped to transport containers. Each container tier has a collection of container cells that represent the locations where individual containers can be placed. These container tiers provide the user with a top down view of the locations where container can potentially be placed. Container cells can also be grouped into *container stacks* and *container bays* that provide a cross-sectional representation of where containers can be placed. Supporting referential standards, these container cells can be identified by either Baplie or MILSTAMP numbers.

Ship Gear: The Vessel Domain also supports the notion of *gear*. As part of a particular vessel such equipment can be used in support of loading operations. Examples include forklifts, pallets, sweepers, and scissor trucks. As an integral part of the ICODES trim and stability analysis, the Vessel model representation of such on-board gear includes both weight and dimensional information.

Cargo Domain

The ICODES Cargo Domain model encompasses data and relationships directly related to the placement and tracking of cargo items (Figure 4). The representation of *cargo* within this domain includes not only the dimensional parameters of each cargo item, but also descriptions of hazardous material constraints (if any) and other logistical information required to effectively support the agent-based decision-support capabilities housed within the ICODES space-planning environment.

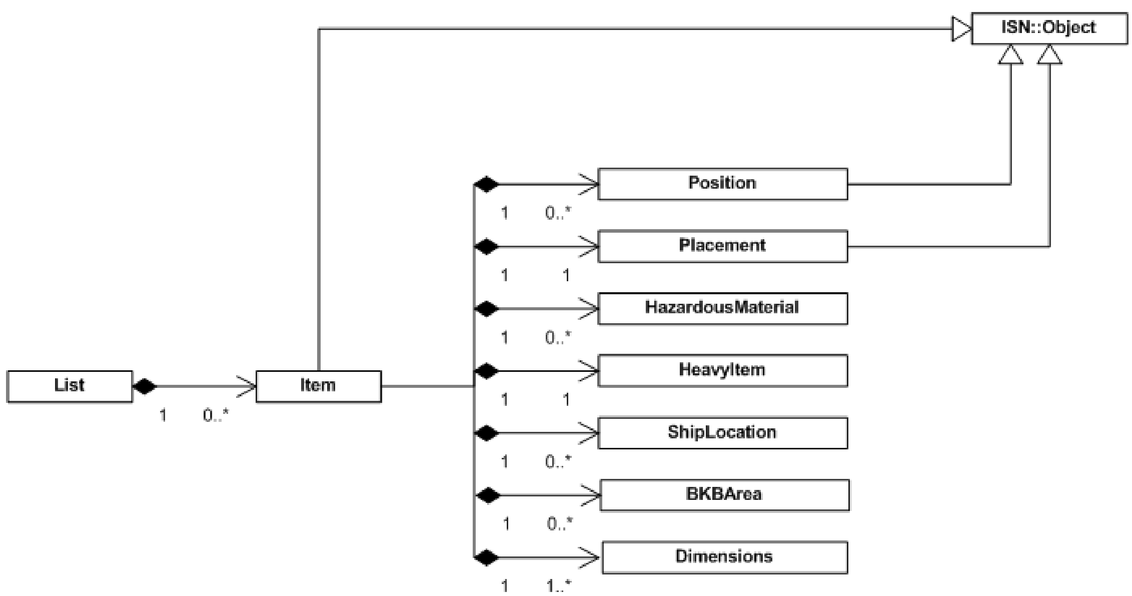

Figure 4: The Cargo Domain model

Each cargo item records information about its location to support the precise tracking of cargo as it moves from staging area to berth and through the ship to its final location. As such, items may contain multiple locations representing not only their current position but also where they have come from and where they are going and they are moved from staging area to their location on the ship. Within the user interface, ICODES uses ghost images of cargo to provide users with an easily discernable view of this dynamic locality information.

As mentioned earlier, cargo items include one or more hazardous information objects as integral parts of their description. Each of these objects represents information about the particular hazardous material(s) that comprise them.

Although ICODES allows the user to create a complete cargo list from inception, it is a more typical procedure for the cargo list to be imported from an external system such as the Transportation Coordinator's Automated Information for Movements System II (TC-AIMS II), the Marine Air Ground Task Force Deployment Support System II (MDSS II), or the Global Air

Transportation Execution System (GATES). Each of the external systems that ICODES supports may have several attributes unique to that system. Through various formal interface agreements, ICODES supports such attributes and is capable of displaying the information in the same fashion as ICODES' native attributes. Since these external attributes are considered *pass-through* data from one system to another, ICODES only provides a limited ability for the user to alter these values.

Plan Domain

The ICODES Plan Domain essentially aggregates all of the information relating to a load-plan into a cohesive Plan (Figure 5). Some of the information contained within an ICODES Plan includes relevant conveyances, cargo, and outstanding agent reports including violations. With the exception of agent reports, which are represented within this domain, each of these elements is described in terms of the Vessel Domain and Cargo Domain models discussed above.

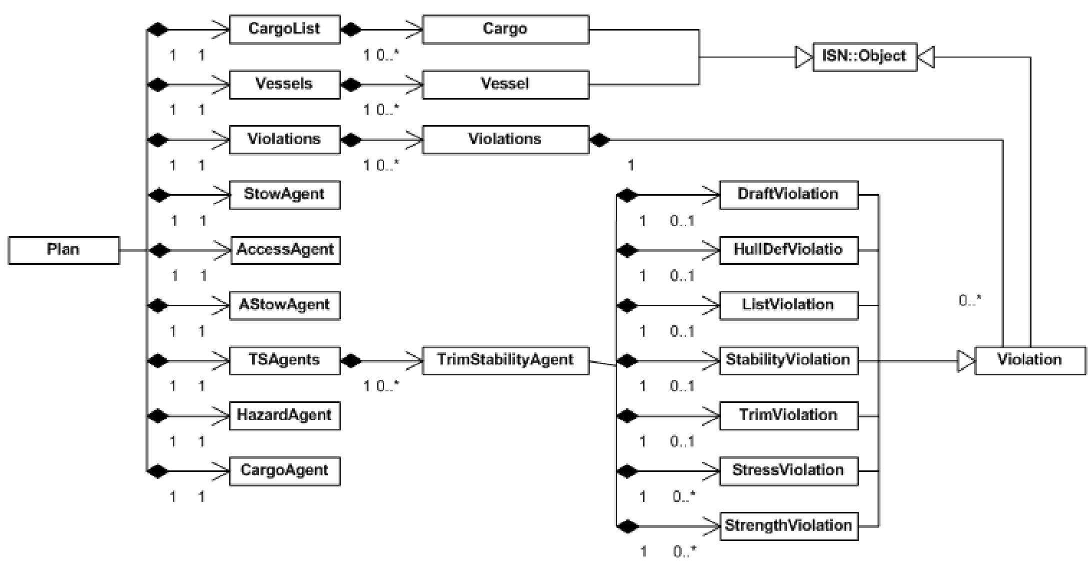

Figure 5: The Plan Domain model

Collectively, these domain models form the ICODES ontology. Each model represents a distinct set of information, concepts, and binding relationships relevant to specific aspects of load-planning operations. This ontology provides the context within which agents continuously analyze the evolving load-plan to identify emerging issues, explain those issues to users, and suggest mitigating actions.

Operational Performance Assessment

Empowered with a context-oriented representation that feeds intelligent software agents, ICODES provides its user communities with a technologically progressive approach to C2. It is generally accepted within the military load-planning community that ICODES has been responsible for a dramatic improvement in decreasing the loading time of ships and berthing costs. In addition, ICODES further proved its utility in unanticipated areas, such as ship selection for the movement of supplies, cargo in-transit visibility, historical analysis of cargo movements, and ship design. The following selected areas of military load-planning operations may serve as indicators of the improvements in operating efficiency and cost savings that have been achieved through the deployment of the ICODES suite of adaptive tools over the past several years.

Load-planning efficiency: Previous to the fielding of ICODES in 1997, the creation of a load-plan would often take one load-planner using the DOS-based Computerized Deployment System (CODES) software at least two days. Once the cargo list had been cleansed, through the laborious manual process of comparing the data pertaining to each cargo item with the official equipment library, often a multi-day process, the load-planner would copy-and-paste the cargo symbols on the ship deck drawings. Then other planners with expertise in hazardous cargo, trim and stability, and cargo flow would check the plan, which often took another day. This time consuming cycle would begin again for each time the cargo list was updated, often up to 30 times during the development of a load-plan.

With ICODES, and in particular through its agents (i.e., Cargo, Access, Trim and Stability, Hazard, and Stow Agents), a load-planner is able to create a similar load-plan in about three hours. When updated cargo lists arrive, the ICODES *merge* function allows the same plan to be updated within minutes without re-starting the planning process.

Marine Corps cargo specialists have indicated that prior to the availability of ICODES the planning of the equipment for a force involving 10 to 14 ships would take an Operation Planning Team five to seven days. With ICODES this task has been reduced to about 14 hours.

In-transit visibility: An area of support that did not exist prior to ICODES is the electronic submission of cargo manifests and cargo ship placement reports to the ship personnel and the Port of Debarkation (POD) staff. This capability has provided visibility of cargo on the ship to assist with in-transit issues, to the POD for off-load planning and/or load-planning of new loads, and to military administrative personnel for tracking and historically reporting on cargo movements.

At a POD, prior to ICODES, immediately after the arrival of a vessel, a cargo survey and meeting would be held to discuss cargo placement and off-loading strategies. With the availability of ICODES documentation, this half-day delay is no longer necessary resulting in a significant saving of berthing costs. In addition, the off-load planning that can now be accomplished with ICODES prior to ship arrival results in substantial labor and off-load space assignment savings.

For ships with multiple ports of loading and discharge, ICODES load-plans are now passed electronically from port to port so the effects of the loads and off-loads on the ship can be determined and personnel in different ports can have a common operating picture. Beyond the port, the Army Logistic Operations Center uses a database of ICODES-generated load-plans to estimate off-load times. In the past this has been a labor intensive operation, often resulting in missed deadlines.

Trim and stability analysis: Since the ICODES Trim and Stability Agent utilizes certified formulas for ship trim and stability calculations, the results are not only used by load-planners but also by the ship's crew to confirm ship loading conditions. Because of the trusted quality of the validated ICODES trim and stability analysis, ships are much less prone to unsafe load configurations and further, sail up to a day earlier than in the pre-ICODES era. The earlier departure of ships leads to fuel savings since ships are able to proceed at reduced speed and still stay on schedule. In addition, ships loaded with the precision and operational knowledge offered by the ICODES system experience decreased port costs associated with berthing and service fees.

Prior to the availability of ICODES, ships were often loaded with little concern for the distribution of weight along the ship's perpendicular axis, eventually causing several classes of ships to develop stress fractures. The continuous monitoring of the condition of the ship during load-planning has led to better load distributions and the resultant reduction in costly ship repairs.

Reconciliation of planned cargo placement: Using the ICODES Automatic Information Technology (AIT) capabilities, the staging area cargo placement and the ship as-loaded plan is confirmed by people with hand-held Personal Digital Assistants (PDA), as opposed to people using manually drawn sketches and tally sheets. Using the ICODES AIT functionality, personnel costs have been reduced about 80%, i.e., to about 20% of the cost of the manual process, and the number of port cargo administrative personnel have been reduced by about 50%. With the increasing availability of AIT wireless communications at ports cargo, locations are updated automatically to an ICODES computer in the port command center, allowing near real-time visibility of cargo to port administrative personnel and preventing the misplacement of hazardous materials.

Since its first release as a system of record in 1997, the granularity of the cargo data has increased greatly as ICODES moved from Level 4 to Level 6 detail. A typical Army cargo list in 1997 seldom included more than 2,000 individual cargo items. From 2004 onward ICODES has been required to process Marine Corps cargo lists with more than 30,000 individual cargo items. Despite this increase in the volume of data the performance of ICODES, in terms of response time, has continued to improve. The typical performance results shown in Table 1 are based on periodic metrics collected by the ICODES Program Management Office over the past eight years.

Table 1: Historical ICODES performance metrics

Tested Procedure	V 3.0 (1998)	V 5.0(2001)	V 5.4 (2005)
Create two-ship load-plan with 2,400 normal cargo items	20 min	8 min	1.5 min
Create two-ship load-plan with 1,200 hazardous cargo items	25 min	11 min	2.5 min
Unload inventory of 2,400 items from two ships	10 min	5 min	1.0 min

In-Field Impressions

With a user-base of over 2,500 military users that spans across the entire globe, ICODES is an example of the successful employment of an ontological approach to logistics and C2. This success highlights the capabilities and extensive decision-support that the use of ontologies can provide to C2. Significantly increasing the efficiency and accuracy of logistics and C2 operations, ICODES has been received exceedingly well by its relatively large user-base as an effective decision-support tool for load-planning. For example, a Marine Corps Captain wrote after using ICODES:

> *"My battalion […] used ICODES to support the embarkation for our […] deployment in 2005 with the […] MEU [Marine Expeditionary Unit]. This deployment included dozens*

of onloads and offloads with over 200 pieces of rolling stock. We also used the program to support disembarking in preparation for movement into Iraq and our subsequent retrograde. We were one of the first Marine Corps units to use ICODES on deployment and it reduced the time required to develop a ship load plan and greatly simplified the onload process. It also made it easy for the U.S Navy to quickly understand how we wanted our equipment loaded on the following amphibious warships and landing crafts: LHA, LHD, LSD, LPD, LCACs and LCUs.

"More importantly, once the ships were loaded, the battalion had a very accurate computerized plan of a how its equipment was tactically loaded. If my battalion commander received an unexpected mission, he would call on our Embarkation Officer to give him an estimate of the tactical offload process. These estimates were developed using ICODES and proved very accurate in planning for a tactical amphibious assault or raid. ICODES truly proved its reliability and viability with us on this deployment."

Providing information to commanders in support of their decision making is the essence of C2. ICODES has been used by the Marines for C2 as well as for the technical work of planning ship loadouts as exemplified by the following quotation from another Marine Corps Captain:

"As far as how we used ICODES, in the embarkation world it was a necessity. We used it constantly during our deployment on the […] MEU –[…] for the planning & execution of onloads, offloads, and the re-arrangement of vehicles & cargo aboard ship while we were underway.

"The version we used in 2004-2005 was fairly accurate in terms of reflecting the actual dimensions of the cargo we loaded, which was the critical part as we utilized every inch of space we had. ICODES not only provided us (the embark people) with a good planning tool, but also painted an easy-to-understand picture for higher ups and other staff and commanders that would be helping execute the plan."

This usage included relief operations after the 2005 Tsunami in Indonesia.

"We not only used ICODES during the tsunami relief, but in some ways use of the program was more critical during this period than during some of our more basic administrative or tactical offloads. Even though we didn't send a lot of our gear ashore during the tsunami relief (more food & water than gear), we nevertheless had to re-arrange our embarked vehicles and cargo to allow for enough room to load supplies onto the landing craft.

"Although the commanders never used ICODES, we often showed them Powerpoint briefs copied from ICODES so they could be aware of how the ships were currently loaded & what gear would be available for offload first."

ICODES has proven to significantly shorten the OODA loop (i.e., Observe, Orient, Decide, Act) by increasing in-transit visibility, automatically generating warnings and alerts with associated explanation, providing intelligent decision-assistance tools for the development and evaluation of plans, and most importantly providing commanders with easy-to-understand images.

The Next Generation ICODES – *ICODES v6*

A critical requirement for the ICODES suite of load-planning services is the ability to grow to meet increasing needs. With an initial narrow focus ICODES was designated as the United States (US) Department of Defense *migration system* for ship load-planning in 1996. However, as the user-base of ICODES increased so did the number of requests to support specialized problems and application domains that were not considered in the original design of the ICODES toolset. In November 2007, after an extensive evaluation of alternatives, ICODES was designated by the US Transportation Command's (USTRANSCOM) Distribution Steering Group (DSG) to become the Single Load-planning Capability (SLPC) for all types of conveyances. Consequently, by 2011 ICODES v6 Global Services (GS) is expected to provide planning and execution support for cargo movement by ship, rail, air, trucks, warehousing, staging, and other domains that require space planning and in-transit visibility capabilities (Figure 6). The foundations of each of these additional domains exist as carefully crafted ontology domains that express the concepts and tangible features which allow software agents to effectively reason about the particular load-planning activity at hand.

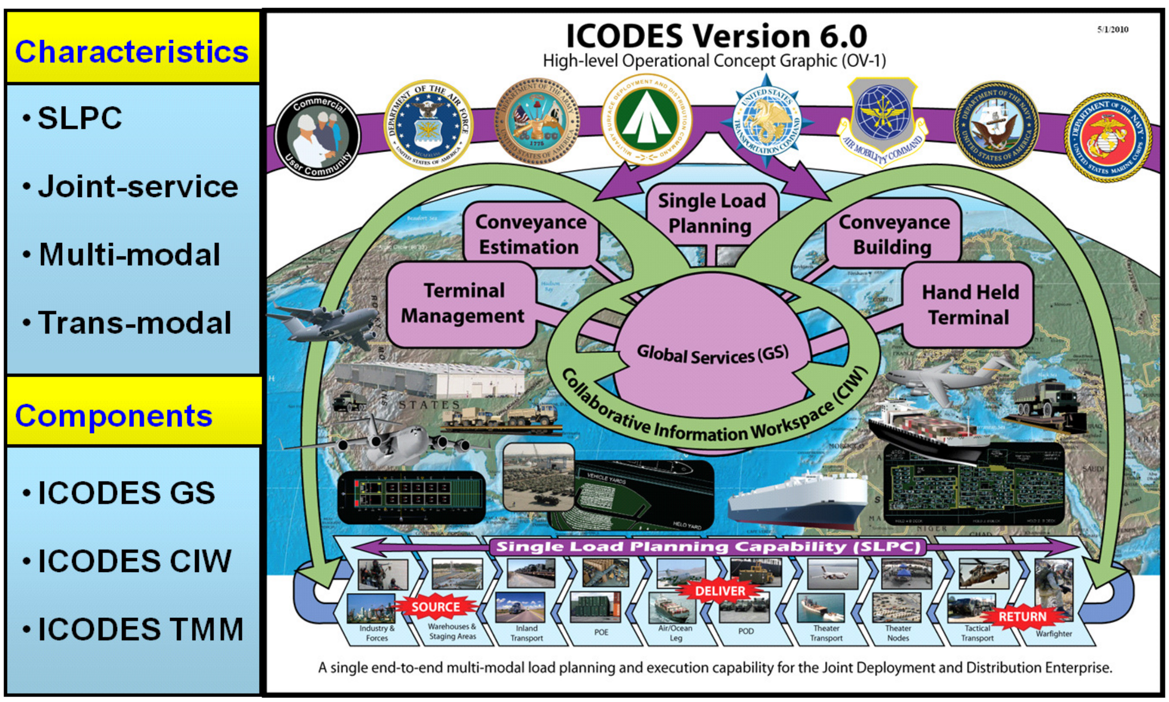

Figure 6: ICODES v6 operational vision

Although designed to support an expanded set of functionality necessary to accommodate this multitude of transportation modes, ICODES v6 must also be architecturally ready to integrate additional capabilities or services, such as viewers tailored to specific operational needs, critical data feeds from external sources, and newly available capabilities such as *smart tags* and other emerging technologies. Designed as a Service-Oriented Architecture (SOA) solution allows ICODES GS to incorporate such additions in a manner that is efficient and preserving of overall system integrity. Figure 7 illustrates the collection of layered services comprising ICODES GS.

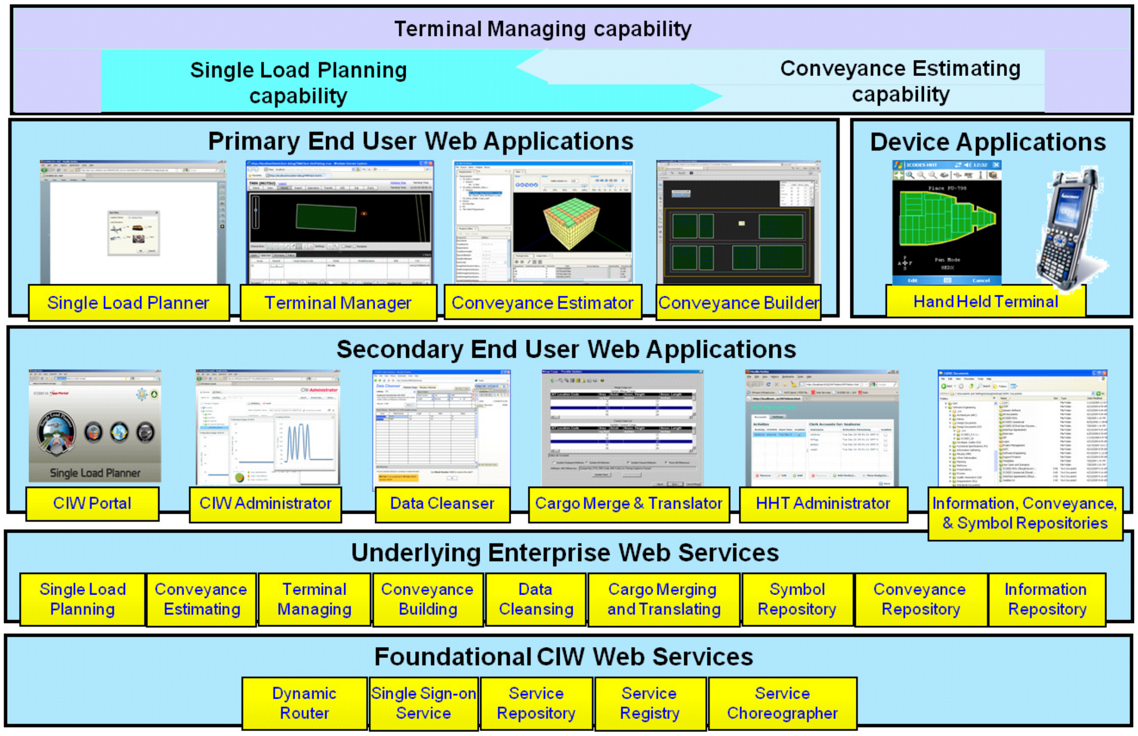

Figure 7: ICODES v6 as a collection of layered services

ICODES GS is designed to be deployed in three distinct forms. The first of these deployment models is to SDDC's Common Computing Environment (CCE) enterprise. Within this deployment, ICODES GS services will be hosted and managed alongside other enterprise services within a virtualized computing environment. As this environment evolves into a fully capable cloud computing environment, the SOA design of ICODES GS will allow such capabilities to seamlessly transition to this distributed enterprise.

The second deployment model supported by ICODES GS is similar in form to the CCE except that it is targeted to installations that require a higher degree of control over their computing environments, such as is often the case with terminal management operations. These *satellite* installations still benefit from local distributed computing environments and make particular use of the Terminal Management Module (TMM) capability available within ICODES GS.

The third deployment model supported by ICODES GS is targeted directly to those operating environments that exhibit limited ship-to-shore connectivity, such as is often the case for operations at sea.

However, with simplicity and manageability in mind, all three of these deployment models use the exact same ICODES GS software code. Tailoring this suite of capabilities to the particular computing environment is managed externally by the installer. Adopting this approach allows the application code comprising ICODES GS to be essentially agnostic as to the particular form of the deployment. This approach avoids the complexities involved in maintaining specific application code dedicated to particular deployment models.

The Challenges of Effectively Supporting C2

The operational and economic benefits of ICODES suggests that it is a matter of when, not if, DoD will develop and implement a C2 ontology. However, there are four significant aspects of C2, Congressional guidance, and DoD guidance that must be understood by those developing a C2 ontology.

***First*, there are authoritative definitions of C2** as well as associated systems through which C2 is implemented. The definition of C2 is given at the beginning of this paper. The authoritative definition of a *C2 system* according to Joint Publication 6-0, *Joint Communications System*, is:

> *"The facilities, equipment, communications, procedures, and personnel essential to a commander for planning, directing, and controlling operations of assigned and attached forces pursuant to the missions assigned."*

Those developing a C2 ontology must *accept*, *understand*, and *work within* these definitions. Although it may be tempting to "improve" upon them, basing a C2 ontology on a set of definitions that differ from those adopted by warfighters threatens to reduce the acceptance and effective utility of the resulting model.

***Second*, Congress and senior DoD leaders** are providing very specific guidance on the execution of IT and C2 efforts. These include a requirement for those developing a C2 ontology or other elements of information technology systems to (a) support rapid prototyping of new or improved capabilities and (b) gain and maintain a close relationship with users to insure delivery of products the users find effective. In response to the latter of these mandates, efforts to build C2 ontologies will likely need to explicitly demonstrate how development is achieving a strong connection with users. Congress's guidance on this concern is outlined in the Fiscal Year 2010 National Defense Authorization Act (NDAA). Section 804 of that act directs:

> *"The Secretary of Defense shall develop and implement a new acquisition system for information technology systems. The acquisition process developed and implemented pursuant to this subsection shall, to the extent determined appropriate by the Secretary—*
>
> *be designed to include—*
> *(A) early and continual involvement of the user;*
> *(B) multiple, rapidly executed increments or releases of capability;*
> *(C) early, successive prototyping to support an evolutionary approach; and*
> *(D) modular, open-systems approach."*

In addition, DoD guidance regarding this issue is found in the "DoD Command and Control Strategic Plan" which states:

> *"While advanced concepts and technologies associated with net-centricity can enable seemingly ubiquitous access to information and unprecedented situational awareness and timely collaboration among mission partners, the Department's efforts in the C2 capability area will still be guided by the principal maxim of command and control: that*

> *technology enables the human interface and supports "command" and the decision-maker, rather than forcing the decision-maker to operate within the constraints of the "control" technology. The force development community will remain cognizant of this to ensure C2 technical solutions meet commanders' needs."*

This critical direction is further reflected in the "DoD Command and Control (C2) Implementation Plan" which states:

> *"The Department's efforts in the C2 capability area will be guided by the principal maxim of command and control: technology enables the human interface and supports 'command' and the decision-maker, rather than forcing the decision-maker to operate within the constraints of the 'control' technology. The force development community will remain cognizant of this to ensure C2 technical solutions meet commanders' needs."*

It is further likely that the new acquisition system for information technology systems that the FY 2010 NDAA requires the Secretary of Defense to develop will include a requirement for developers of a C2 ontology to be able to explain how they are keeping warfighters involved. In large measure, ICODES has been successful because from its very inception in the mid-1990s, the ICODES development team embraced the same user-centric philosophy that is now being formally reflected in such Congressional and DoD guidance.

***Third*, warfare is a non-deterministic activity, a battle of wits**. Although the equipment of warfare attracts much attention, success is achieved by the side whose commanders outwit the commanders of the opposition. If we are proficient at performing a certain activity or perhaps well-equipped to process a particular category of data into actionable information, our adversaries will seek to neutralize such abilities by shifting the conflict towards activities where such skills are essentially irrelevant, or perhaps constantly require adaptation. The agility necessary to stay one-step-ahead of the enemy inevitably involves equipping commanders with tools capable of providing meaningful information and intelligent analysis capabilities that can quickly adapt to the dynamics of warfare. While success within this arena is ultimately a matter of commanders outwitting those of the opposition, technology can play a vital role in equipping commanders with an arsenal of capabilities to support their decision-making.

***Fourth*, C2 systems must seek to free commanders to outwit the enemy.** Warfare is inherently a complex, data-intensive activity. As a result, data-overload can be a common scenario facing decision-makers. Ontology-based C2 tools can help commanders make sense out of this sea of data by providing the means to quickly build a concise operational picture. In this manner, users are not only freed from much of the routine processing involved in achieving such rapid and focused situation awareness, but are further equipped with analysis capabilities (e.g., communities of intelligent agents) that can significantly help offset the effects of an increasingly reduced DoD staff.

Conclusion

The ICODES application currently provides a comprehensive tool-set of software agents to assist the cargo specialist in the development of ship load-plans for military deployments. It is one of the earliest military examples of information-centric software that incorporates an internal, relationship-rich information model to provide context for the reasoning functions of collaborative software agents. With the upcoming release of ICODES GS, functionality along with the ICODES ontology will be extended to support the load-planning of all types of conveyances (i.e., ships, aircraft, trains, and trucks) and assembly areas. At the same time the ability of its underlying SOA-based design will be severely tested as ICODES scales from a stand-alone application to a global environment of integrated intelligent services.

As an information-oriented, agent-based system, ICODES adheres to three notions that are fundamental to its decision-support capabilities.

1. ICODES processes information (i.e., data with relationships) as opposed to legacy systems that normally process data only (even though the data may be in the form of objects with characteristics). The key to the assistance capabilities of ICODES is that the system has some understanding of the information that it is processing. In the ICODES ontology cargo items are described in terms of characteristics that relate each item to hazard, trim and stability, accessibility, and ship configuration, constraints. This internal information model provides context for the automatic reasoning capabilities of software agents.
2. ICODES is a collection of powerful collaborative tools, not a library of predefined solutions. This overcomes the deficiencies of legacy systems in which built-in solutions to predetermined problems often differ significantly from the complex operational situations encountered in the real world. In this respect ICODES is a collaborative decision-support system in which the operator interacts with computer-based agents (i.e., decision making tools) to solve problems that cannot be precisely or easily predetermined.
3. ICODES incorporates agents that are able to reason about the characteristics and the relationships of cargo items, the internal configurations of conveyances and the constraints that must be considered during the development of load-plans. Although these agents are decoupled (i.e., do not know about each other's existence) they are able to indirectly collaborate through a data blackboard and subscription services, as they assist the user throughout the load-planning process.

The advantages of an information-centric software system have been evidenced in three areas by the performance of ICODES in the field over the past several years. First, if all necessary data are available, ICODES is capable of automatically generating the load-plans of four medium-size ships in around two hours. This is a significant improvement in load-planning speed over the legacy application that it replaced. The predecessor application typically required two person-days for the development of a single load-plan. Second, the assistance capabilities of the ICODES agents elevate the performance of a novice load-planner to at least an acceptable level. This is an important consideration in view of the attrition rate of military cargo specialists during the past decade. The performance of an expert load-planner, on the other hand, is raised to an exceptionally high productivity level. And third, the ability of ICODES to continuously evaluate the evolving load-plan in respect to accessibility, hazardous material, and trim and stability conditions, has greatly increased the quality and accuracy of the resulting load-plan.

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