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KNOWLEDGE-BASED COMMODITY DISTRIBUTION PLANNING

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ABSTRACT

This paper presents an overview of a Decision Support System (DSS) that incorporates Knowledge-Based (KB) and commercial off the shelf (COTS) technology components. The Knowledge-Based Logistics Planning Shell (KBLPS) is a state-of-the-art DSS with an interactive map-oriented graphics user interface and powerful underlying planning algorithms. KBLPS has been designed and implemented to support skilled Army logisticians to prepare and evaluate logistics plans rapidly, in order to support corps-level battle scenarios. KBLPS represents a substantial advance in graphical interactive planning tools, with the inclusion of intelligent planning algorithms that provide a powerful adjunct to the planning skills of commodity distribution planners.

INTRODUCTION

The complexity and dynamics of commodity distribution planning - both in commercial and military domains - require decision support tools that provide much more than data base access and spreadsheet solutions. This paper presents an overview of a Decision Support System (DSS) that incorporates Knowledge-Based (KB) and commercial off the shelf (COTS) technology components.

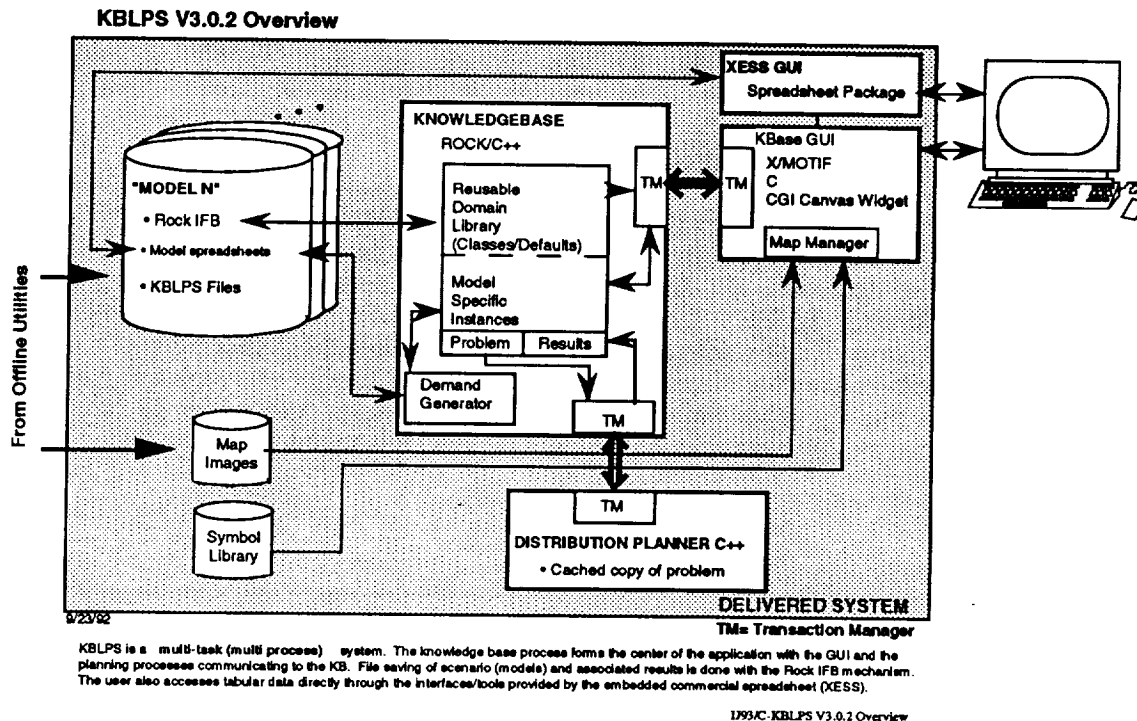
The Knowledge-Based Logistics Planning Shell (KBLPS) is a state-of-the-art DSS with a rich map-oriented interactive graphics user interface and powerful planning algorithms that has been designed and implemented to support skilled Army logisticians to much more rapidly prepare and evaluate logistics plans to support corps-level battle scenarios than currently possible. These plans may be developed as contingencies against future possible scenarios or in direct support of troops on the ground. In either case, the ability to build, evaluate, and improve plans in a fraction of the time now possible has been a major objective which is in the process of being met.

KBLPS is an appropriate blend of Artificial Intelligence, Knowledge-Based, conventional, and commercial off the shelf technologies that, taken together, provide a logistician with a powerful tool to help define, analyze, and evaluate very complex planning problems quickly. The Logistician can configure the problem/scenario with a through-the-screen object-oriented approach, as well as give guidance to the algorithm by (optionally) setting a number of parameters; the DP algorithm constructs distribution plans, involving significant computational complexity on behalf of the logistician. As a consequence, the logistician can spend more time analyzing and assessing plans than in generating them.

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At the heart of KBLPS is the commodity Distribution Planner (DP) algorithm (see Figure 1), which supports Ammunition Distribution and bulk Petroleum Distribution planning in a single framework. A major challenge - one that has been met - was to design a single algorithm flexible enough for use in these two domain-specific areas. The DP algorithm reasons and calculates at appropriate levels of data aggregation to demonstrate the logistics supportability of a battle scenario without overwhelming the user with too much detail.

Figure 1:



KBLPS represents a substantial advance in graphical interactive planning tools, with the inclusion of intelligent planning algorithms that provide a powerful adjunct to the planning skills of distribution planners. KBLPS has been designed and implemented as a Decision Support System (DSS), based on the recognition and appreciation of how complex and challenging the logistics planning problem is, and how many subtle and interacting factors and considerations must simultaneously be brought to bear in solving these kinds of problems. The Logistician and the DSS are a team that works together, to achieve objectives that neither alone could accomplish as well. We believe that it is unlikely anytime in the foreseeable future that it will be feasible to replicate all the thought processes and decision making abilities of a skilled logistics planner; it is unlikely that would be desirable in any case.

Major benefits of using a DSS like KBLPS include:

- Faster Generation of Distribution Plans - Demand/Forecast Generation and DP algorithm generation of large-scale plans for huge 5-corps 3-5 day scenarios can be completed in 1-2 hours (computer execution in 5-10 minutes) compared to 24-48 hours turn around with currently manual procedures.

- Far greater data precision; KBLPS supports ammunition and petroleum flow to combat unit company and battalion level with 1-hour time interval granularity. Manual operations typically make estimates at division level using 24-hour time intervals.
- Far greater precision in taking into account time-varying availability of inter-acting resources. This degree of complexity simply cannot be addressed manually; there are too many interactions.

Rapid decision-making turn-around supports Army doctrine to make accurate decisions within the decision making cycle of the adversary. Being able to do this much more quickly and accurately with DSS aids - and enabling the consideration of many alternative "what-if" contingencies not now possible - meet major doctrinal goals.

PROBLEM DEFINITION

Figure 2 depicts the nature of the commodity distribution problem. A network of storage and distribution installations and transportation/material flow links are defined by the user in order to satisfy user commodity demands. In the particular application at hand, these are combat and combat service (CS, mainly artillery and engineering units) who are significant consumers of petroleum and ammunition. They could as easily be civilian consumers shopping at commercial retail outlets, which in turn are supported and fed by up-stream district and regional warehouses. Note that Figure 2 is merely representational; it is much simpler and easier to interpret and understand than real distribution networks with which skilled logisticians typically deal.

Figure 2:

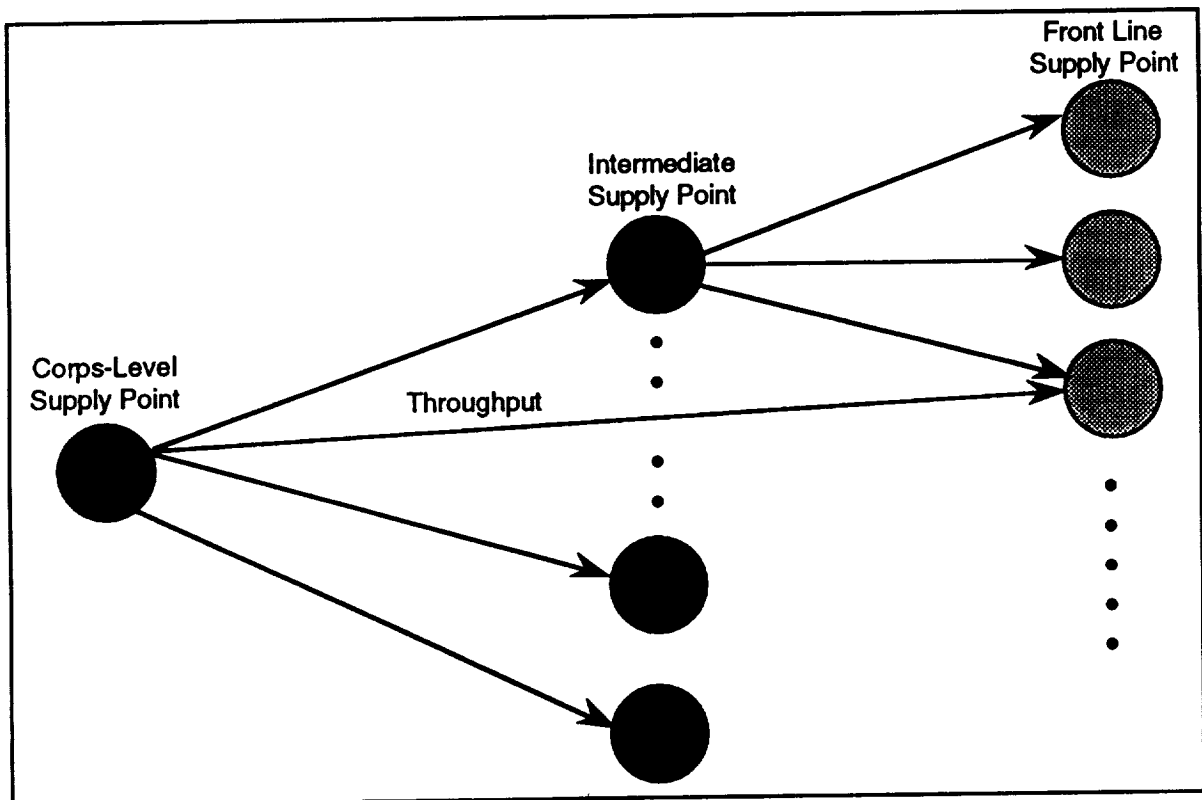
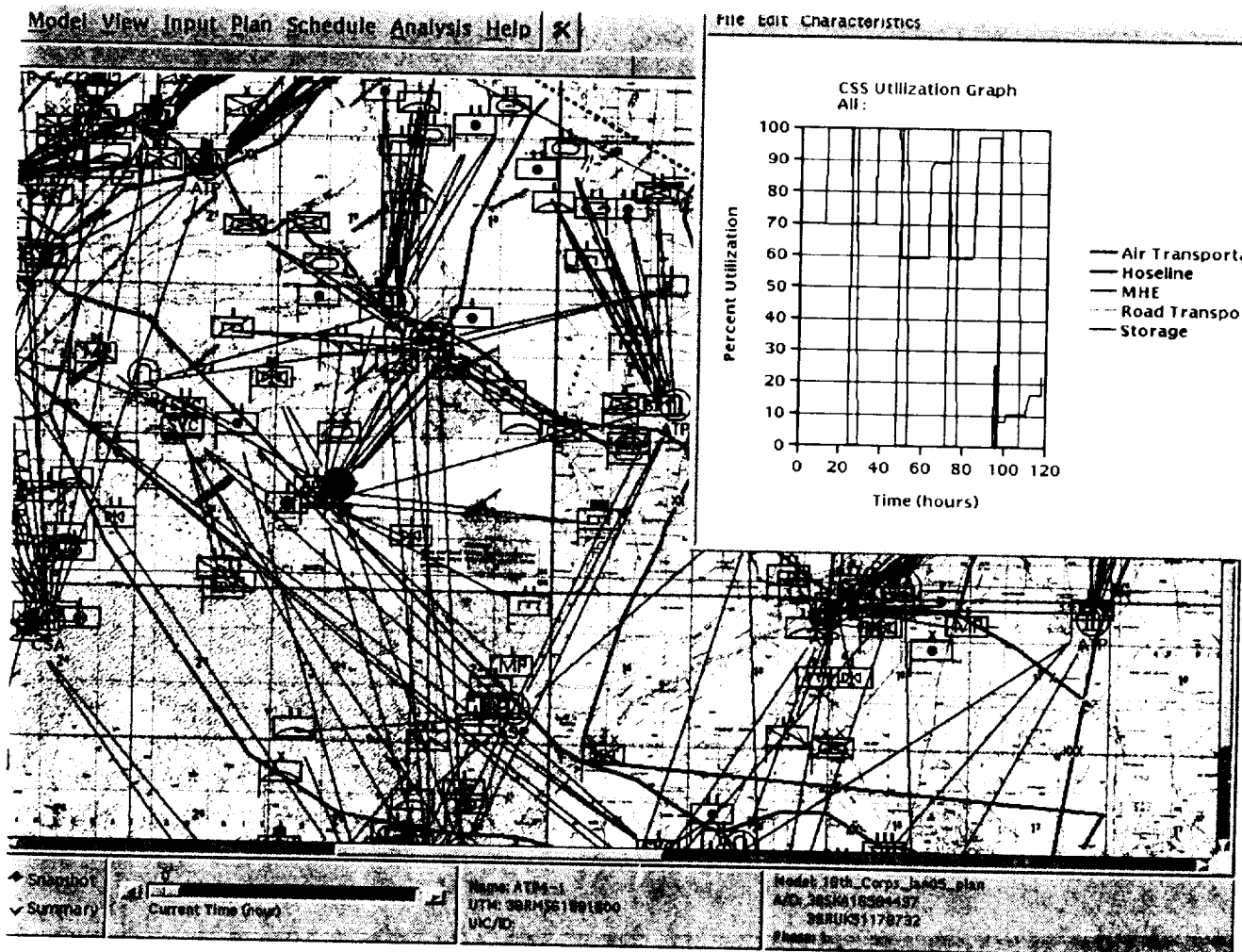


Figure 3 shows a typical screen view of a sector of the battlefield with Combat and CS units and their hierarchy links displayed. The black and white reproduction of the multi-color screen does not begin to do justice to the actual display, but is presented here as indicative of the richness and complexity of the display environment. The user has many controls to pick single 'layers' of displays, so that most screens viewed and used by the Logistician are far less complex and 'cluttered' than Figure 3.

Figure 3:



The Logistician's task is to configure the network, identify how much of each key resource (trucks, roads, material handling inventory), will be available (as a function of time), and assess whether that mix of resources will enable his customers (in this case combat and CS units) to do their job. In current practice with *situation maps* ("sit-maps") pinned to walls and transparent acetate overlays depicting various aspects of the problem (combat unit laydown, CS unit deployment, transport networks, etc.), logisticians perform this task with many approximations and heavy reliance on rules of thumb that may be inadequate or very difficult to adjust in new and unique circumstances.

KBLPS replicates the sit-map/acetate overlay paradigm electronically. The logistician can use through-the-screen commands to control which aspect of the planning problem to examine and manipulate. Because the displays are icon/object-oriented, the logistician can "click on and drag"

combat, CS, and Combat Service Support (CSS) units and installations to new locations on the underlying map in order to enhance the logistics network laydown. The KBLPS X-windows/Motif-based Graphics User Interface (GUI) provides the user with a complete and flexible environment which enables the Logistician to create and delete combat, CS, and CSS units at any echelon (level of command hierarchy), change support/supported relations, and change the capability and combat readiness of units to reflect actual or contingency conditions. A commercial spread sheet/graphics package was integrated into KBLPS to provide a complete and convenient way to manipulate the demand forecast model (unit structures, individual and roll-up to unit consumption rates as function of combat conditions, etc.), and to present summaries of generated plans from multiple perspectives.

KEY TECHNOLOGIES

Key elements of KBLPS are built on Knowledge Base/Artificial Intelligence foundations and state-of-the-art Graphics User Interface technologies.

(i) **The Knowledge Base (KB)** has been constructed using TM CGI's ROCK knowledge representation technology. ROCK provides a C/C++ implementation of KB functionality that enables application developers to build complex knowledge bases which capture complex and often *ad hoc* relationships. In this particular application there is a complex hierarchical command structure of an Army corps consisting of dozens of units (tens of thousands of troops), dozens of Combat Service (CS) units, and dozens of Combat Service Support (CSS) units and material storage/distribution installations. It was mandatory to use a KB approach in order to capture and effectively operate on such a complex and fluid domain, which includes extensive command hierarchy and support/supported relationships among different elements of the organization.

In addition, a KB approach provides significant flexibility in re-configuring a baseline (doctrinally defined) corps structure in light of particular combat situations that require some degree of command, support-supported, configuration and other modifications to the corps baseline. These same kinds of considerations apply as well in commercial commodity distribution networks.

(ii) **The Distribution and Transportation Planning Algorithms** apply a Constrained Heuristic Search (CHS) technique which analyzes key constrained resources (roads, pipelines, trucks, inventory, storage depots, material handling equipment) to build a *feasible* (i.e., no constraints violated) plan of forward material movement with rapid execution times on conventional engineering workstations.

CHS is a useful and powerful alternative to "conventional" approaches to solving complex planning, scheduling, and logistics problems. Techniques including Linear Programming (LP) and various forms of math programming, for example, have been used for many years in attempts to achieve optimal solutions, using formulated 'objective functions'. CHS provides a means to provide excellent (but sub-optimal) solutions that cannot be solved *quickly* (or at all) with LP, math programming, and other techniques.

CHS provides the opportunity to solve problems that cannot be formulated adequately in LP terms (given the significant degree of inherent non-linearity in the problems) or that would require an inordinate amount of time to compute a solution; by the time the solution is available, it may no longer apply when circumstances have changed in the meantime. The CHS formulation also makes it easier for the user to change the problem definition without having to rely on software engineers to re-code the problem.

This CHS/modeling approach is also fundamentally different from discrete event simulation (DES), another technique often used in planning and scheduling. The CHS model's view covers

the problem's entire time and geographical domain. Consequently, it can consider all up- and down-stream (in time and space) interactions while making its decisions. This is in contrast to DES, which is fundamentally a 'look downstream one step at a time' approach (although there are embellishments that can sometimes mitigate some of the shortfalls associated with DES), often leading to less than desirable results, and worse, usually does not provide the means to make changes to the problem statement/set-up in order to improve plan results.

(iii) **The Graphics User Interface (GUI)** has been implemented with X-windows/Motif layered on top of Government-furnished (electronic media) high quality maps. The GUI is an intuitively appealing and readily-learned means (as evidenced by how quickly skilled Army Logisticians have mastered the system) to set-up complex battle and logistics problems and evaluate and alter DP-generated plans. The GUI provides a convenient (control mouse) point-and-shoot approach to modify force and logistics deployment configurations, create or delete units at any echelon level in seconds, modify unit capability profiles in seconds, etc. The ability to see the entire problem at a glance and to be able to home in on particular elements of the problem quickly and easily is a key component to the User/DSS shared problem solving paradigm that KBLPS represents.

PLANNING OBJECTIVES & APPROACH

The purpose of the Distribution Planner (DP) algorithm is to help the Logistician prepare distribution plans that simultaneously meet these goals:

- Meet required delivery dates and quantities on time, or somewhat early ("Just In Time" delivery)
- Fill highest priority needs first
- Balance service across units (the customers)
- Balance service of high, medium, and low priority needs
- Maintain stockage objectives at distribution installations
- Make efficient equipment, transport, and supply route assignments

An important reality is the need to plan against multiple goals or objectives (some of which are conflicting) in a data-intensive, non-linear, time-varying context. For example, the goal to maintain certain time-varying stockage objectives may conflict with the goal to reserve 20% of main supply route (MSR) capacity for contingencies. Logistics resources are usually highly constrained; i.e, there is usually much more demand for ammunition and petroleum at the front lines than can be supplied by the available or projected distribution assets. The objective is to provide:

- Feasible robust (though not necessarily optimal - it is not at all clear how to define 'optimal' in this context to everyone's or anyone's satisfaction) plans quickly,
- Information and insight to the Logician that will help guide the distribution planning process, satisfying these multiple goals in as even-handed and balanced a way as possible,

- Insight to the Logistician and the commander where the plan has the most risk and how such risks might be mitigated.

The CHS-based algorithm cycles through the problem domain, step-wise building up a distribution plan across a user-defined time and geographic horizon. The CHS algorithm looks at the whole problem all of the time (this distinguishes it from dispatch-based planning and event-driven simulation approaches, for example), successively turning its focus to those resources at particular time intervals most in need of resolution before dealing with less-constrained and less urgent problem elements.

The DP algorithm constructs a plan by iteratively selecting an order (the 'next best' order not yet in the plan) and then placing that order into the plan. The DP reasons and plans "opportunistically", i.e., neither the sequence in which orders are planned nor the way in which orders will be planned are determined in advance. Since there are typically many orders which could be planned next, and numerous ways to plan them, the DP uses heuristics to guide the search to make these decisions quickly, efficiently, and accurately. Hence, the DP algorithm is fundamentally data driven, responding 'opportunistically' to different problem scenarios, 'floating bottlenecks', etc., thereby avoiding the need for the user to intervene (other than with input data modifications as appropriate) when problem circumstances change.

DETAILED DP ALGORITHM DISCUSSION

The DP algorithm can plan the distribution of commodities through a distribution network with sufficient flexibility to apply to both petroleum and ammunition distribution. In general, this problem is usually over-constrained - there are not enough assets (material handling equipment (MHE), trucks, main supply route (MSR) capacity, inventory) to satisfy all demand. Moreover, in different scenarios different resources will be most scarce. Thus, the algorithm must maximize efficient usage of all resources, and in particular the scarce resources, in order to maximize over-all order satisfaction. This must be done in light of commander intent/mission, balanced servicing of all combat units so they can adequately support the mission and each other, and available or anticipated assets.

The principal goal of the DP algorithm is to maximize the satisfaction of Combat, CS, and CSS unit demands for petroleum or ammunition. However, priorities must be respected so that higher priority orders are satisfied before lower priority orders. But the preference for higher priority orders must be tempered by the objective that lower priority orders cannot be completely ignored and starved; hence, there must be a balance between these conflicting goals. The DP algorithm provides a mechanism which allows a Logistician-specified percentage of higher priority orders to be satisfied first, then a percentage of lower priority orders, and then the remainder of the higher priority orders. In his way, priority is respected but lower priority units and orders are not starved. This balancing mechanism gives control to the Logistician, and is consistent with the KBLPS philosophy of being a Decision Support System.

An important secondary objective is to meet day-to-day inventory stockage targets, which are Logistician-specified in terms of number of days of supply in the context of the battle scenario being supported. When in conflict with the primary objective (i.e., service at the front line/'point of sale'), this objective is relaxed.

The DP must assign MHE, MSR, truck and available inventories to supply the user units consumption/demands in the best possible way over time. In general, this is an "over-constrained" problem - the net demand is generally substantially greater than inventory and/or material handling and carrying capacity can handle, at least in some time-frames. Hence, some of the demand will remain unsatisfied. It is the Logistician's task, with the aid of the DP, to find the means to move

as much material forward as possible and to set aside that subset of demand that can best be 'held back' and still meet the commander's intent. Procedurally, the Logistician uses the DP iteratively, successively refining the scenario definition and data elements, to move toward better and better scenarios.

Initial Use & Current Status

KBLPS has been undergoing early user evaluation by skilled logisticians of the XVIIIth Airborne Corps, Ft. Bragg, NC, over the past year. KBLPS has been used and stress-tested in the context of a series of large scale realistic logistics and force projection exercises at a number of sites and in diverse scenarios (including Prairie Warrior exercise at Ft. Leavenworth, KS, in May 1993, and Force Projection Logistics Exercise at Ft. Lee, VA, in July 1993). The speed with which skilled logisticians have learned to use KBLPS has been especially noteworthy. It reflects the degree to which the users know their business in depth and how well the KBLPS implementation matches the way they think about and solve their planning problems.

Further extensions to KBLPS are under development. These include: incorporation of other classes of supply - food, medical supplies, major end items, spare parts; enhanced plan analysis tools; integration of the more-detailed *Transportation Scheduler* with the 'rough cut' Distribution Planner, etc. Future plans include moving toward an on-line reactive re-planning capability to support 'current operations' (vs. look-ahead contingency planning) and cutting-edge visualization techniques, including such approaches as 2 1/2-D perspective displays and plan animation.

Potential Application to Commercial Domain

We believe that KBLPS can be readily applied to strategic planning in commercial environments. Rapid and effective evaluation of the logistics impact of a corporation's rapid growth or moving into new markets or introducing new product lines is a clear strategic need and opportunity. Other contexts would include mergers and acquisitions, providing third-party logistics/distribution services to other corporations, and contingency/disaster response planning. The basic JIT paradigm referred to earlier, the underlying flexibility of the "Activity Model" (process plan) implemented within the algorithm, and the richness and flexibility of the User Interface, are key elements to a straightforward transition into the commercial arena.

Some important extensions to KBLPS that we anticipate could be useful or required include changing the demand forecast model from a military planning factors structure to more conventional forecast models often provided by MRP systems, for example; changing time granularity from hours (currently) to days, weeks, or months; adding new modes of transport (sea, waterway) - straightforward, given the Activity Model paradigm; and extending the stockage/resupply model to accommodate stock carrying costs and re-order points which differ from the current inventory model. Map display quality and granularity could probably be relaxed substantially from the current implementation.

SUMMARY

The Knowledge Based Logistics Planning Shell is a cutting-edge Decision Support Aid which combines the best of conventional (X-windows, Motif, commercial spreadsheet/graphics package, etc.) and Artificial Intelligence (Knowledge Base and constraint-directed planning algorithms) technologies. There is substantial potential for extensions, including platforming new applications modules on top of the extensive knowledge base now in place.

We have designed and implemented a flexible algorithmic approach that quickly (3 - 5 minutes execution speed on conventional work-stations) provides feasible plans accurately for large

problems (2,000+ orders over 120 time intervals, dozens of customers and distribution points, hundreds of constrained resources).

This Decision Support System is currently in active use by skilled logisticians, supporting their on-going efforts to plan for regional contingencies in many parts of the world. The users', and their senior management's, current enthusiasm and support have been key elements in guiding on-going development.

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