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Title: Cognitive Support for Transportation Planners: A Collaborative Course of Action Exploration Tool

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Cognitive Support for Transportation Planners: A Collaborative Course of Action Exploration Tool

Abstract

To planners at United States Transportation Command (USTRANSCOM), a course of action (COA) is a transportation plan – a description of what vehicles, routes, and ports should be used to move sets of cargo and passengers throughout the world. A planner may be tasked with very quickly producing multiple COA options at any time in response to either real or projected needs. The current procedure relies heavily on planner experience and "back-of-the-envelope" computations to find feasible options for quickly moving cargo and people in a resource-constrained environment.

This paper describes a rapid COA exploration tool, uniquely designed around the cognitive workflow of experienced planners, to allow a planner to quickly and effortlessly investigate multiple potential plans. Map-based tools allow the planner to directly assess the usability of multiple ports, to evaluate the throughput over designated route segments, and finally to analyze the throughput across an entire COA. We designed this tool to seamlessly invoke calculations while planners naturally conduct COA decision making activities in the tool. Modifiable calculation assumptions are made explicit to the user at each step along the way, thus opening the entire COA exploration process to shared awareness and collaboration between multiple planners, each an expert in different areas.

Introduction

To planners at USTRANSCOM, a COA is a transportation plan – a description of what vehicles, routes, and ports should be used to move sets of cargo and passengers throughout the world. A planner may be tasked with very quickly producing multiple COA options at any time in response to either real or projected needs. The current procedure relies heavily on planner experience and back-of-the-envelope computations to find feasible options for quickly moving cargo and people in a resource-constrained environment.

Under the Cognitive Visualization, Alerting, and Optimization (CVAO) program, managed by the 711th Human Performance Wing, Human Effectiveness Directorate (711HPW/RHCV), we set out to understand the details of how planners go about solving COA problems – what tools and algorithms they currently have, what difficulties they run into, what level of detail needs to be taken into account in their COA solutions to ensure that a proposed COA can be relied upon as workable. Our end goal was to develop a prototype software tool aimed directly at this problem to: 1) enable the USTRANSCOM planner to more quickly explore a larger number of potential COA's; 2) to quickly evaluate candidate COA's individually; and, 3) to compare multiple COA's on several primary decision factors.

While there are no existing software tools to help the planners with this problem, there are (at least) two tools which attack a related problem. Both the Joint Flow and Analysis System for Transportation (JFAST) and the Model for Intertheater Deployment by Air and Sea (MIDAS) are models designed to simulate strategic air and sea movements. They are both very powerful tools in their own right, geared to modeling transportation problems orders of magnitude more complicated than the COA problems of our planners. But as we discuss in this paper, neither is immediately useful to our planners. Both require significant expertise to set up and run; neither, in their current incarnations, offers the sort of exploratory capability we see as necessary to solve this problem for our users.

Our solution here is to extend the work on "symbiotic planning" described in [Scott, 2009a] and [Scott, 2009b] in which we designed and prototyped a mechanism for a human user to work closely with an automated scheduler to solve air mission replanning problems. In this work we are designing and prototyping a mechanism for the USTRANSCOM planner to work closely with another type of opaque automated processing tool, in this case a transportation model. The current research is also related to work described by Klein and his co-authors[2009] in which shortcuts are taken with computational models in order to use them as inputs to tactical decision-making.

This paper describes the conceptualization, design, and implementation of the Rapid Course of Action Analysis Tool (RCAAT). Section 1 discusses relevant background domain knowledge about USTRANSCOM, its mission, and how planners do their work. Section 2 contains an analysis of the COA problem, breaking it down into a series of five separate cognitive tasks performed by planners, each of which requires support by the RCAAT tool. Section 3 details the design of the RCAAT tool, with a discussion of how each of the five cognitive tasks is supported by the design. Section 4 discusses the theory and practice of how we modified an existing large-scale strategic transportation model to serve as a computing engine for RCAAT. Finally, Section 5 summarizes this work and discusses planned future work in this area.

1. Background Domain Knowledge

USTRANSCOM is the US military command charged with directing and executing the overall transportation needs for deployment of troops and distribution of goods. This is a highly complex endeavor, covering air, sea, and ground movements. To give a sense of the size of the operation, in a typical week, USTRANSCOM conducts more than 1500 air missions, 10,000 ground shipments, and has 25 ships underway around the world.

Structurally, USTRANSCOM contains three Transportation Component Commands – Air Mobility Command (AMC), Military Sealift Command (MSC), and Surface Deployment and Distribution Command (SDDC) – which execute the movements of people and material. A Fusion Center, which contains command staff as well as experienced planning representatives from each of the three Transportation Component Commands, serves as a planning cell to synchronize and balance operations.

The planners we are attempting to support are employed in the Fusion Center. One of the elements of their job is, given a description of a prospective movement, to find one or more potential ways the movement might be accomplished – the modes of movement (air, sea, or ground), the ports to be used, the mix of vehicles to be used. While the phrase "Course of Action" has many meanings in various military problems, for us a COA for a prospective movement will be a transportation plan – i.e., a selection of modes and ports and vehicles to be used to execute that movement.

There is a broad range of constraints to be considered in such a COA problem. Just based on general principles, the space is complex: Air movements are much faster than sea movements, although the capacity of a typical ship is many times the capacity of an airplane – meaning that while movement by ship might well be the fastest way to get all of a large load delivered, in some cases it may be important to deliver at least some of a large load by air to get it there quickly as possible, and follow up with remaining movements by sea. Some cargo will not fit on an airplane, but can fit on a ship. Costs between air and sea movements vary greatly. A second class of constraints comes into play when we start to factor in port capacities. Military movements often make use of both airports and seaports that have severe limits on space or material-handling capability. A proper COA will have to take these limits into account. And a third class of constraints arises from the unfortunate (for the planner) fact that the movement he is planning is not the only movement going on in the world. The COA has to take into account any limitations on aircraft or ship availability due to other operations, and even more stringent limit on port usage because this movement may need to share port capability with other operations.

In the context of the problems we are discussing, the planner is often determining a "rough COA" before the problem is entirely nailed down – i.e., before it is entirely determined how much material is to be moved and exactly when it is to be moved. The movement may be a projected troop rotation nominally scheduled to occur several months in the future, for example. In this case, the precise number of people and amounts of goods will not be finally determined for months. But having a notion of what modes, ports, and vehicles might be used for this movement will enable a general deconfliction process to take place in the Fusion Center, to allow multiple projected movements to coordinate their use of the limited resources of ports and vehicles. A second example of a planner wanting to think about COA's before a movement is proactively thinking about world events. For example, he may see the possibility of his command wanting to send humanitarian relief to a part of the world where an earthquake has just hit. Even though he may not have any real notion of how much is to be moved, he needs to think through what ports (both embarkation and debarkation) could be used to quickly get supplies into the affected area.

The fact that planners are often tasked to come up with suggested COA's for speculative problems argues that any support tool should be designed with exploration in mind. It should be easy and natural for the planner to see how the COA changes if the total amount to be moved goes up or down by a factor of two, or to see what happens to the COA if more or fewer planes or ships are to be used.

The current procedures for such problems largely depend on the built-up expertise of very experienced planners. There are a number of "back of the envelope" kinds of calculations that can be done to estimate how quickly people or goods can be moved, particularly through the air. A planner will call on colleagues, often experienced planners in the Transportation Component Commands who have particular expertise, to collaborate on a single problem. In some cases, for an important enough problem, a "Joint Planning Team" will be constituted to collaborate over such a problem in a more structured manner.

2. Cognitive Task Analysis

In 2009 our team conducted observations and interviews in the USTRANSCOM Fusion Center with the goal of identifying areas ("leverage points") where additional cognitive support (generally in the form of newly designed software tools) could provide significant performance gains to the Fusion Center. Over the course of six months, we participated in several multi-day sessions in the Fusion Center, starting with introductory orientation sessions to various operational groups within the Fusion Center. As we became familiar with the details of Fusion Center operations, we identified two general task areas that require additional cognitive support for the users: 1) Providing better oversight and insight on Fusion Center demand (customer movement requirements); and, 2) interrelating demand with feasible transportation network capacity. The Research and Development (R&D) discussed in this paper supports the second focus area by providing cognitive support for exploring and evaluating potential transportation courses of action for prospective movements. We began work focused on a prototype COA exploration tool in early 2010.

One of the difficulties in acquiring knowledge about the COA exploration task area is that while problems of producing COA's are important, instances of producing new COAs can occur infrequently as they often depend on external events. We initially conducted structured interviews with users who had recently performed this task, but also needed to observe this action as it happened, to better understand the structure and pace of the work, the opportunities and ways in which collaboration happened, and additional constraints that may be added to this problem. We were fortunate in that USTRANSCOM participated in an exercise during April and May 2010 for which Fusion Center planners were tasked with producing COA's. We were able to observe several planning sessions, and to subsequently interview some of the participants about those sessions.

As we gained a thorough understanding of COA exploration and how planners were attacking it, we began to classify the cognitive tasks associated with its solution into five general categories. While there is something of a sequential nature to these five categories, it should be noted that not every planner will touch each of these five categories for each problem – there are problems, and solutions, that may leave any of these five entirely out of the process.

Before describing the five categories of cognitive tasks, we also note that each of the tasks represents an opportunity for the planner to collaborate with colleagues who may have more expertise about a particular area of planning. In fact, it would not be unusual to find a single planner pulling in expertise from a different colleague for each of these five areas.

Cognitive Task Areas:

1. A planner will often start out by thinking not about a COA as a whole, but about the individual ports – both airports and seaports – that might be used. In many cases this step can be skipped; often the prospective movement is to be moving to and from familiar areas of the world, in which the choice of ports to be used is second nature to the experienced planner. But this is not always the case; the COA may deal with an unfamiliar part of the world, or maybe even a familiar part of the world, but for some reason, the standard set of ports will be unavailable for this use.

The planner needs a way to easily browse through the ports in a particular part of the world. He needs to have some basic information about the availability of the port – is it politically (or commercially) available to the US military for the prospective operation? How many days a week, and hours a day is it open? What are the basic capabilities of the port – for airports, what are the runway details (i.e., what kinds of aircraft can feasibly use the runways); for seaports, what are the dimensions and depths of the various berths?

In addition to the fixed infrastructure of a port, there are various measures of material handling equipment (and the staffing to operate the equipment) that determine how much cargo can be moved through a port in a day. And while there may be nominal values for this, depending on the ownership of the port and the lead time before execution, there may be ways to "beef up" the port, allowing more cargo to be processed.

Generally, this task is one of acquiring information about ports, together with how current that information is, understanding which of that information represents hard constraints and which constraints might be eased, and finally comparing all this information across multiple ports that might be candidates for a particular operation.

2. In the next task, the planner is still thinking about building blocks that get put together to make up a COA rather than an entire COA. A planner often spends a fair amount of time thinking about what we've termed a "segment". A segment is a subpiece of a COA that begins with cargo having been onloaded at one port. Some number of vehicles carry that cargo to another port, where cargo is offloaded (or "transloaded" to other vehicles). There are many COA's that consist of a single segment; but quite a few that are made up of multiple such segments.

A segment is the natural construct to begin thinking about how much cargo can be carried by how many vehicles how quickly. Without having to worry about the complications of onloading, offloading, and transloading, the planner can use generally accepted formulas to get a quick "back of the envelope" sense of how many C17's will be needed to move his cargo from port A to port B, or how long it will take a particular class of ship to transit a segment carrying his cargo.

Depending on the COA problem at hand, the planner may need to refine the initial rough estimate for a segment – some COA problems are still quite speculative, where rough estimates are appropriate; some COA problems are less so, and strict feasibility of their proposed solutions will be important. A number of refinements can be made. For an air segment, for example, the length of the segment together with the type of aircraft chosen may force the planner to consider a refueling stop, (either in-air refueling or on-ground refueling). The ability to factor that in, as well as details such as crew duty day limits, and even availability of fuel at a proposed intermediate stop, will all play a part in being able to generate a feasible plan for moving cargo across this segment.

In practice, the experienced planner reasons about a segment to the level of detail he thinks appropriate to the COA problem at hand. He will often seek additional expertise among his colleagues to help refine his initial estimates. Even if he leaves the planning for a segment at a fairly gross level, as the time for a movement draws closer, it may be appropriate to revisit the COA and refine the estimates previously made.

3. Finally, given the building blocks of what ports and what segments to use, the planner can think about how to piece together a whole end-to-end course of action. While, as

discussed earlier, many COA's consist of a single segment, with cargo being picked up at one port (the "Port of Embarkation" or POE) and dropped at another port ("Port of Debarkation", or POD), there are reasons why many COA problems cannot be adequately solved by a single segment. It may be that the POE or POD have limitations upon them that make it advisable to use smaller vehicles to take cargo in or out of those ports, while transloading to larger vehicles for the bulk of the movement, for example.

While it is generally not difficult to come up with estimates for throughput across a single segment, once multiple segments have been pieced together into a COA, it is much more difficult to compute how fast cargo will be moved, and how many vehicles will need to be used.

This is not a simple problem. In fact, making the leap from thinking about transportation a segment at a time to a multi-segment COA is really the crux of the difficulty of the COA problem. The segment problem is essentially a linear problem – for the most part the planner can reason along the lines of, "if I have 4 C17's to use on this segment, I'll be able to move twice as much as if I have 2 C17's". (There are limits to the range of linearity, based on port capacities, but the experienced planner can generally understand where these limits are.)

The task for the planner at this stage is having strung together segments to make a COA, to get a sense of how this COA plays out. The key bits of information traditionally are overall closure time (how long it takes for the entire movement to finish), initial delivery time (how long it takes for the first bit of cargo to be delivered), and to a lesser extent, the profile of how much cargo is being delivered when. In our view, though, it is also valuable for the planner to be able to directly view how these parameters change as other changes are made to the problem – if we bump up the total cargo by 10%, what happens to the closure time? If we can add additional material handling equipment to this port, or add an extra two planes, how does that affect things? It is the ability of the planner to use the tool such as ours to explore this complex decision space that will lead to selecting better and more robust COA's.

Once we move to a multi-segment COA, the problem is decidedly non-linear. There may be no easy way to decide if adding more airplanes to service one of the segments will have any effect on throughput or closure time. These additional constraints dramatically increase complexity and make the problem infeasible for easy computation by the Fusion Center planner.

Even though there is not a simple tool available for analyzing a COA in the Fusion Center, there are more complex tools in use. JFAST is used to model transportation movements and analyze COA's. JFAST does require significant expertise to set up, however, and a run of JFAST is often set up to run overnight, taking hours. While JFAST has proven to be an invaluable tool in modeling transportation movements for USTRANSCOM, in our view it does not provide the exploration capability we see as important to Fusion Center planners. Our vision is that the prototype RCAAT tool will provide this exploratory capability, with the COA's resulting from a RCAAT session being further analyzed by JFAST runs when necessary.

A second, related tool is MIDAS, which is not often used in the Fusion Center; it is part of a set of tools called Analysis of Mobility Platform (AMP), whose primary users are skilled analysts in the Joint Distribution Process Analysis Center (JDPAC) providing transportation analysis support to USTRANSCOM. MIDAS and JFAST are both described in [McKinzie, 2004]. Both tools are transportation models, capable of taking the description of a COA and determining how the plan will play out, including closure time and initial delivery time.

Our task was to decide whether and how we could repurpose one of these large strategic models into a “COA analysis engine” for a much smaller problem. We chose to work with MIDAS, for the pragmatic reason that MIDAS developers were at Raytheon BBN Technologies, and were accessible to our team.

4. Having generated a COA, the planner is now faced with the task of analyzing it. While analysis based on the parameters mentioned above (closure time and initial delivery time) is useful, it is much more useful to be able to analyze this COA in light of other activity that will be going on in the world at the same time as the operation described by this COA. Up until this point, the COA has been treated in isolation – a port’s capability can be entirely dedicated to the service of this operation. A more useful and realistic picture can be obtained by trying to factor in the effect of other movements going on at the same time as this operation.

During this part of the analysis, collaboration with other Fusion Center colleagues is critical. The planner must interact with other planners to understand what other operations are likely to be using the ports of interest, and to what extent. Depending on the importance of the operation under discussion, there may be negotiation on how much port capacity is to be allocated to which operations. The exploratory analysis in RCAAT will be critical in enabling this negotiation – being able to quickly see how changes in allocation of port capability will affect delivery and closure of this operation is invaluable in making decisions on balancing port usage between operations.

5. Having produced a number of potential COA’s, the planner must be able to easily compare them based on operationally relevant metrics. Finally, the planner must be able to coherently brief the candidate COA’s to his commander, describing the comparison between them, the factors that argue for adoption of one or another, and finally a selection of a single COA.

Closure time, initial delivery time, and total cost are all clear metrics upon which COA’s can be compared. Less clear, but potentially of use, is how to compare COA’s based on port usage profiles. Port capacity can be a limiting constraint affecting not just this operation, but also other operations occurring in the same time frame. This argues that the ability to compare COA’s based on how much of a port’s capacity is used by a COA would be critical.

3. Description of RCAAT Design

This section describes both the challenges and prototype solutions designed and developed under the R&D effort to build an RCAAT tool that assists the user in performing the 5 cognitive tasks associated with exploring and defining courses of action as described in the previous section. The team defined the following important factors in designing a successful RCAAT prototype:

The ability for the user to *rapidly*: 1) explore the building blocks of a COA such as ports, asset utilization, and segments; 2) define a COA; and, 3) analyze multiple COAs.

Provide the user with capabilities better than back of the envelope solutions, but not optimal detailed COA modeling and analysis.

Provide mechanisms for the users to understand the assumptions behind calculations and estimations along with the ability to modify them as needed (while not requiring the user to modify or review the details of the underlying assumptions).

The design centers around a map based visualization that provides a "home" base for the 5 cognitive tasks performed by a user in developing and analyzing multiple COAs. While not every task can be performed using this visualization, important components of each of the 5 tasks can be represented and analyzed collectively in this view. The map-based home view provides the users with an easy to understand geographical and spatial context in which to work in, much like drawing on a map to plan a trip. We found that the graphical representation is somewhat self-explanatory to the users, as well as an accepted form of collaboration and presentation within the Fusion Center and USTRANSCOM. The map-based view depicts ports and routes on the map and provides the basic map functions such as pan, zoom, searching and layers. We have developed one solution to allow users to tooltip over ports that are co-located (literally) or co-located due to the zoom level of the map, thereby allowing access to information without requiring the extra steps of zooming in to detailed map layers simply to find the port they are interested in browsing. Figure 1 depicts a "splay" functionality that provides the user the ability to see each port in a geographically congested area – this is essentially a "local zoom", in which a small area around the point of the mouse cursor is dynamically zoomed out to show all the ports in the area. In addition we have scaled our port icons in association with the map zoom level to help keep the geographical regions recognizable and visible, however the tooltip and splay functionality works at all

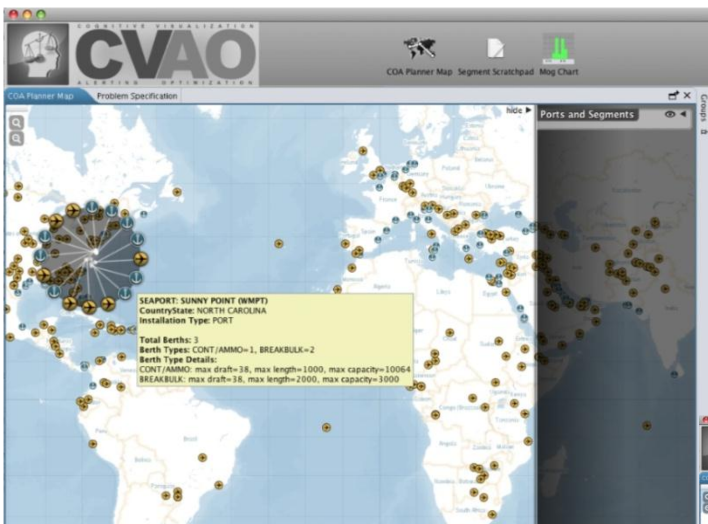
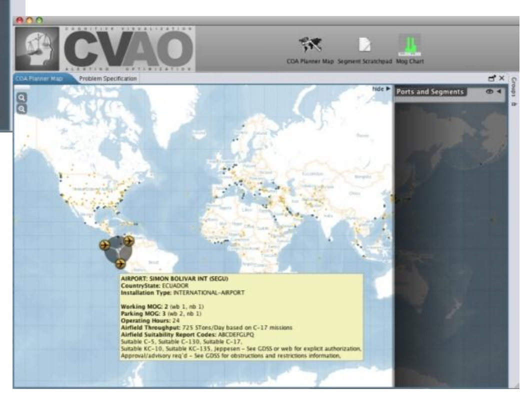


Figure 1:Map-based visualization with port splay.



zoom levels as depicted by the lower right screenshot in Figure 1 which is shown at a lower zoom resolution.

Port Browser Design:

The capabilities associated with the first cognitive task of port browsing are almost entirely designed within the map view. In some cases, the planners are familiar with the ports they intend to use to generate the COA, but often need to double check the details of the port capabilities such as the ability of an airport to handle a certain type of military aircraft landing, refueling, or cargo handling. In other cases, the planner may be very unfamiliar with both the location and types of ports in a region as well as the infrastructure capabilities in and around the port. For example, when planning to transport much needed supplies to Haiti, most planners were unfamiliar with the Haitian ports and their capabilities. Today, much of this information is available, but the sum of the information needed by a planner to consider the best port options for a mission is dispersed among many applications, databases, the Internet, and human experts. Besides the obvious data challenge to provide all of this information in one place, we found a challenge in developing an interactive visualization that effectively provides enough information at a glance on a geographical display for the user to quickly grasp the extent of the ports and capabilities in a region. We have designed the map to include tooltips, user "sticky" notes, filtering, and search capabilities in an attempt to fulfill much of the planners' port inquiries; however, we have also considered the ability to allow port drilldown views that will provide more in-depth information such as satellite images of the port infrastructure, intelligence reports, detailed port capability reports and more. Figure 2 shows a filtered view of airports in Spain with capabilities matching 2 types of military aircraft with a tooltip over the Rota Naval Air Station that describes airbase capabilities along with a user generated note about other options in the area. The content of the tooltip has been refined over many knowledge acquisition and user feedback meetings in order to provide the most meaningful port capabilities to the broad set of planners. The ability to view data from multiple sources

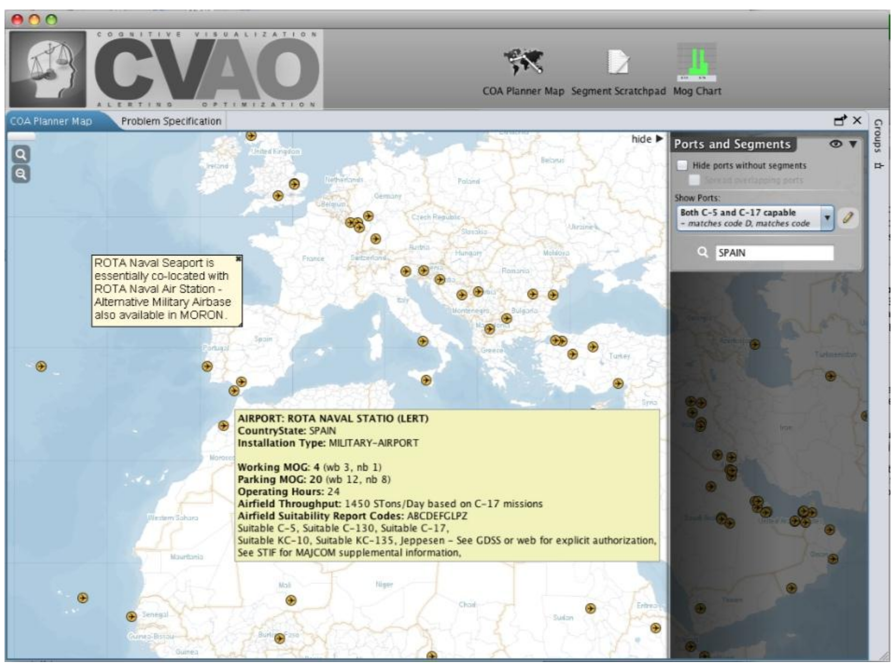


Figure 2: Port Browser map with port capabilities displayed as a tooltip using a hover gesture over a port.

for a large number of sea and air ports in one place with a quick tooltip gesture provides a huge reduction in time and research required by a user.

Figure 3 depicts some potential “drilldown” links for the Rota Naval Air Station to include a satellite image. The principle behind this visualization is to provide (in a single

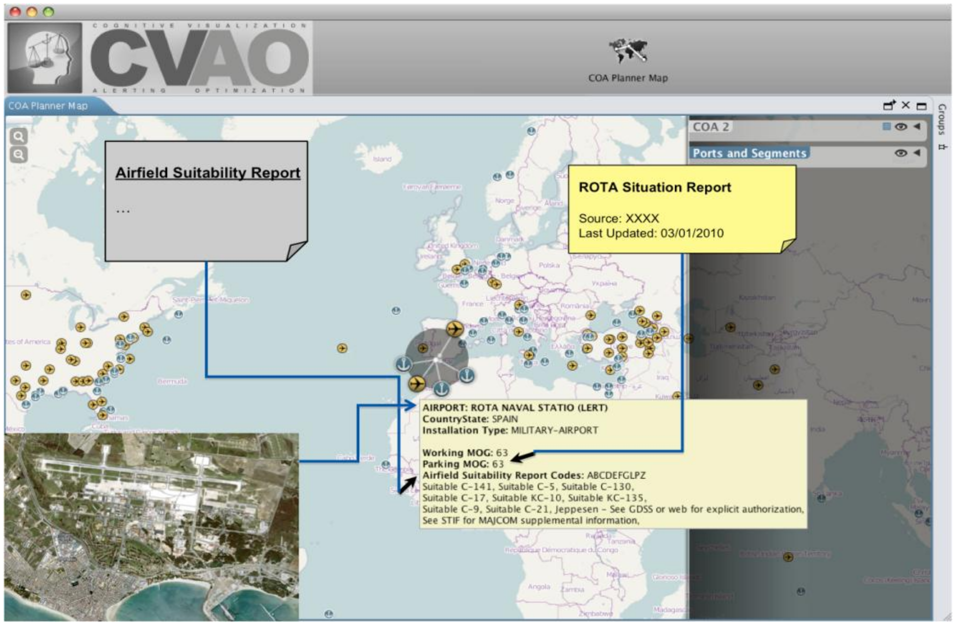


Figure 3: Drilldown port details linked from the port capabilities tooltip.

gesture) a mechanism to quickly “pull-up” additional port details that help the user decide which ports are good options as well as the port constraints that may hinder the missions in the COA.

Segment Exploration:

The second cognitive task is one in which the user explores various routes between ports in support of transporting cargo from one location to another. These “building blocks” in support of generating a COA are referred to in RCAAT as *segments*. In order to best support this task, we wanted to develop a visualization that included natural gestures that allow a user to draw many segments on a map and immediately understand the implications and constraints of such a route. For example if a user draws a route from a location on the East Coast of the United States to the Middle East, one would immediately want to understand not only the distance associated with that route, but the implications of that distance such as travel time or the time it would take to load a plane, travel to the destination, unload, refuel the plane and return to the U.S. This time is often referred to as “cycle time” and it allows planners to consider how many round-trips or “cycles” planes could make in a day. Additionally, planners would like to know what the constraints of such a route are; these might include things like, “Will I need to refuel enroute?”, or “Will I exceed the maximum flying hours for a crew?”. For some common routes, planners often have an idea of the route distance and whether it requires refueling, but slight variations in destinations can often push a segment just over the threshold.

Planners need to understand when a flight is close to an edge case as winds or other factors can certainly affect flight time and fuel usage.

In order to help answer some of the above questions, we developed a mechanism that immediately performs calculations and seamlessly provides the results in the same visualization as soon as the user completes the segment drawing gesture. Included in the information box are warnings if certain thresholds are exceeded such as fuel; see the segment annotation box for the Charleston to Kandahar segment in the top left of the Figure 4 below. The screenshot also shows multiple segments on the same map palette.

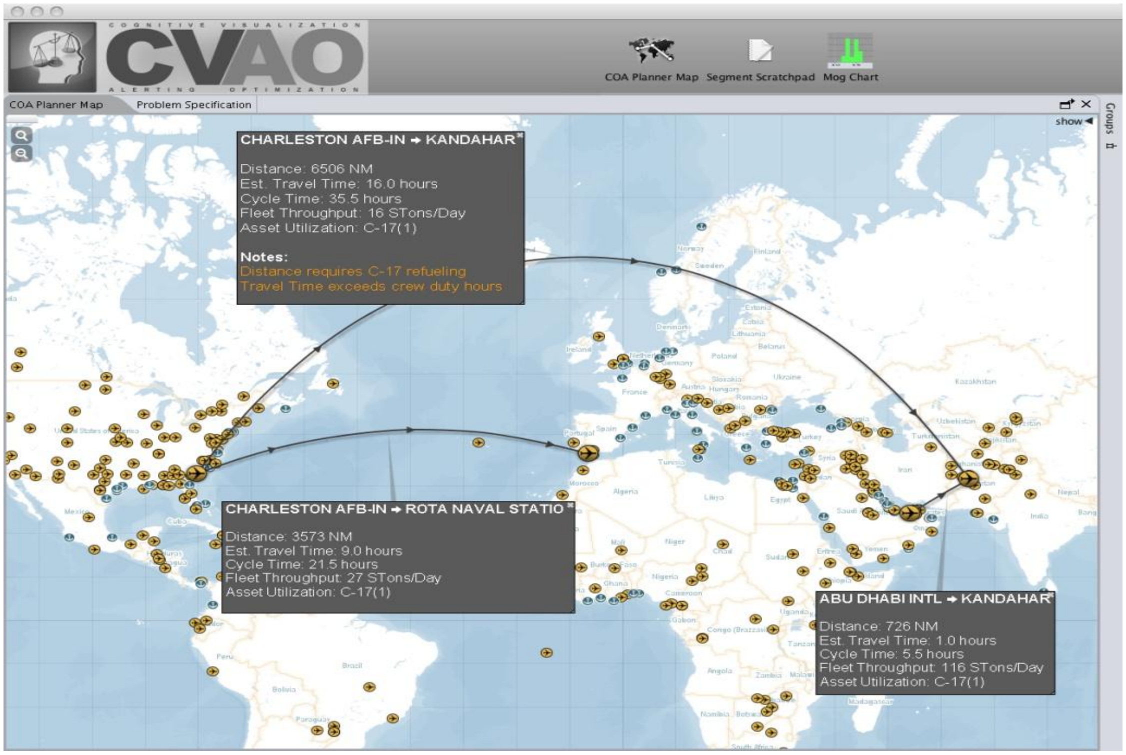


Figure 4: Segment Exploration with travel time, cycle time and segment warnings calculated as the user draws the segment.

This visualization was designed to allow users to explore multiple segments on one screen for comparison and decision support purposes in determining segments to include in a COA. Segments can be deleted from the map by simply selecting "Delete Segment" from a menu associated with a right mouse-click. Also, the segment annotation boxes can be hidden or resized to help manage the screen real estate during exploration or collaboration with other planners.

If the user wants to view or edit the underlying assumptions of a specific segment's calculations, they can right mouse-click to bring up the segment assumption editor. This editor details the "math" behind the values listed for cycle time or fleet throughput that consider the characteristics associated with a type of aircraft. The user can also modify the default type of aircraft to be used for the segment and immediately see the effects. Additionally, the user may specify enroute stops such as refueling or a crew change to better understand how these additional stops affect the segment overall. In Figure 5, the assumption editor is displayed for the Charleston to Kandahar segment where the user has specified an enroute refueling stop in Germany. The map has automatically redrawn the segment route to include this stop. The segment distance, travel time, and cycle time values have automatically updated as well to take the stop into account. As we began to build more details into this editor, it became apparent that the users would like to be able to "remember" which values they changed and as well as the original assumption values. We designed a scheme where edited values are colored blue and the original default values are located next to the edit within brackets (see the Onload hours section of the Cycle Time calculation in Figure 5). This technique provides immediate feedback and visual cues to the user to remind them of their modifications. These types of editors allow the users to make modifications based on their own knowledge or expertise regarding specific ports, routes or differences in cargo being carried on aircraft for a specific mission as each plan is unique. It is never necessary for the user to dive into these details and make modifications, but the editors provide a simple mechanism for an important and often forgotten source of data – the user.

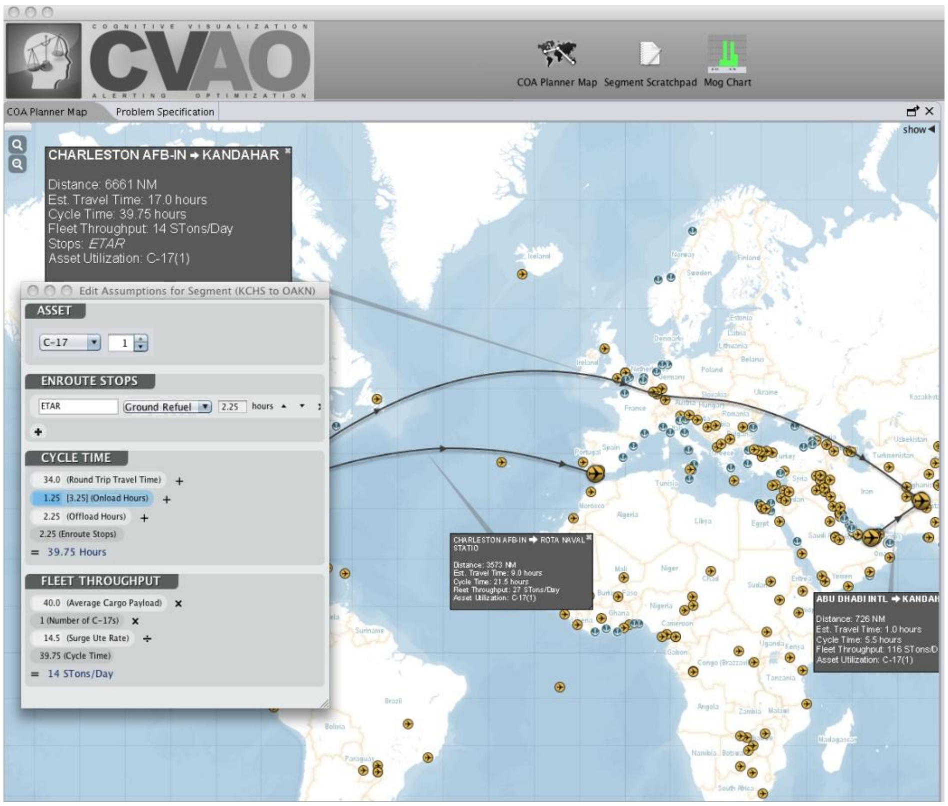


Figure 5: Segment Assumption Editor

COA Building:

Now that the user has a good idea of potential ports to use as well as some segments that will provide different options, they can start to string the segments together to build a COA. This will allow the user to better understand the full implications of routing cargo by air and sea through multiple ports which each have their own capabilities and constraints that will affect the mission overall. The COA building map where the user builds a complete COA is not a new visualization; rather, it is designed as a type of layer on top of the map that the user has already been interacting with to explore segments and ports. This allows the user to continue to browse ports and use either existing segments as part of a COA, or explore new segments to use in a COA. We believe this is an important design concept as it lets the user continuously explore and redefine solutions as they understand more constraints about each COA without having to completely switch tools, visualizations and "cognitive-gears".

The COA layer allows multiple COAs to be built on the same map so that the user can begin to compare COAs at a very high level. The user can also make modifications to the COA including changes to the segments that make up the COA, the assets being used for the transport of the cargo between ports, port capabilities and much more. In order to reduce the information overload that can occur when using a single layered visualization, we have designed mechanisms to hide certain layers on the map to de-clutter the view and allow the user to focus on specific COAs or segments without requiring them to switch to a different view or lose work.

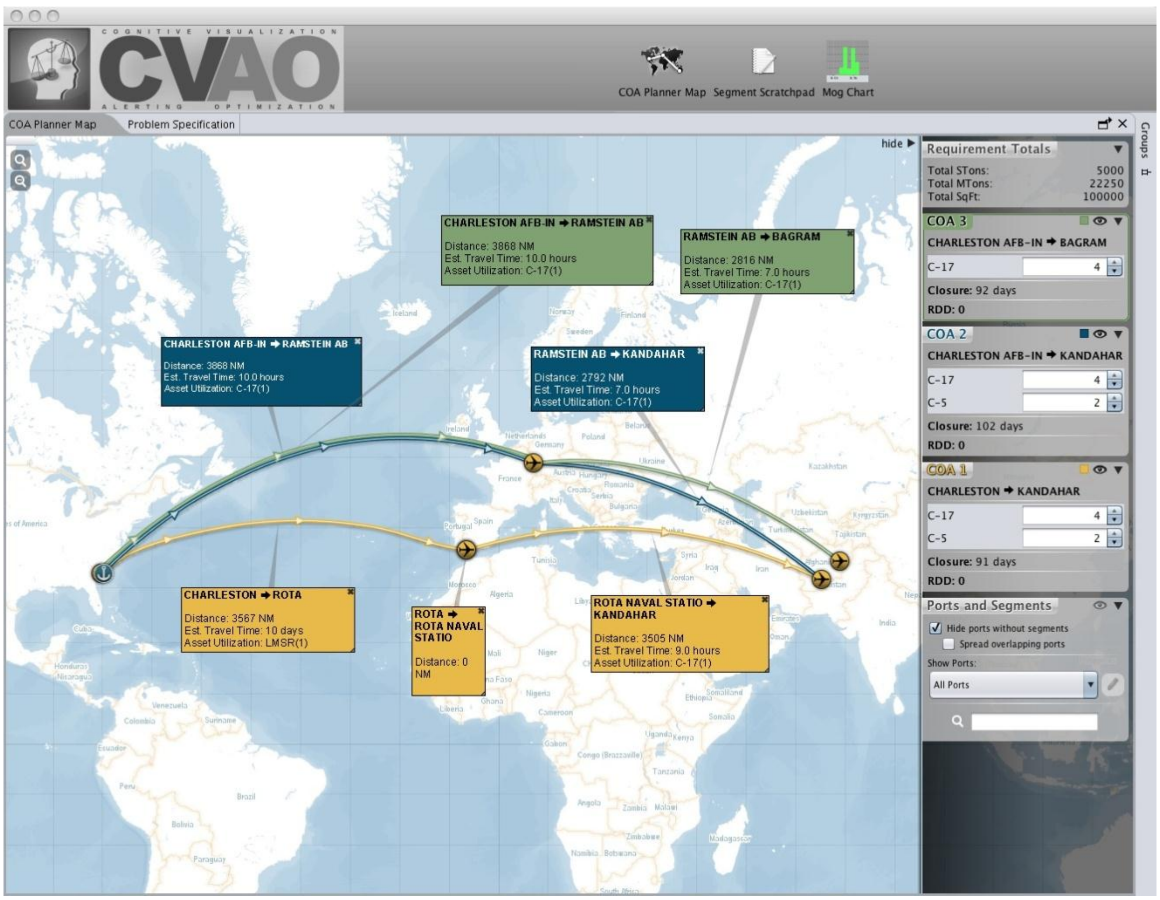


Figure 6: COA Map depicting 3 possible COAs

In Figure 6 above, 3 COAs are depicted on the visualization; the first (in yellow) shows a COA that uses a multi-modal solution using ships from Charleston to Rota, Spain and then a transfer of cargo to the Rota Air Station to be taken by plane into Kandahar; the second (in blue) shows an air only mode from Charleston to Kandahar with a stop in Ramstein, Germany to refuel; the 3rd COA (in green) is an air route from Charleston to Bagram instead of Kandahar with a refueling stop in Ramstein – note this COA uses only one type of aircraft, C-17s for it's plan. Notice the right panel with a summary box for each COA along with a summary of the cargo being moved in the "Requirement Totals" panel. Simply toggling the eye icon in the top right of each COA summary box can hide any COA on the map. Also, note the closure time in each COA. This is an estimate, in days, of how long it will take to move the cargo as defined in the movement requirements, taking into account the vehicles used, the routes and the constraints at each airport and seaport.

The MIDAS model, a detailed transportation modeling application, generates the closure day along with other important information regarding throughput and usage of the port capabilities. This information is important to the user as they begin to further compare and analyze the COA options developed during this task. RCAAT is sending information to the MIDAS application when a COA is generated on the map and subsequently gathering results from the MIDAS model. The design and technical challenge in this area is to effectively gather and translate high-level requirements from an interface such as the one provided by RCAAT to a complex model such as MIDAS. MIDAS was designed to model movements that require months if not years of transport missions to complete. Such missions are defined by expert analysts who provide input to the model at fine-grained level of detail. Our users are often looking at missions which take days to complete and they may not have the exact details of the mission as they are exploring different COAs. To bridge this gap, we developed some utilities that provide default breakdowns of high-level specifications into lower level specifications that the model needs to run. Again, the user is allowed to view and modify these assumptions, but they are not required to do so to get an answer from the model. This is an area ripe for more research as many complex software modeling and simulation tools such as the previously mentioned JFAST and MIDAS already exist, doing very good job at detailed modeling. The research however, is how to make these models accessible to more planners at a different level of fidelity allowing high level planning to take advantage of these systems in an accelerated, early planning cycle.

COA Analysis:

Up to this point the planner has been thinking about a COA or multiple COAs in terms of isolated feasibility. That is, how feasible is *this* plan given certain assumptions. However, much of the time plan feasibility cannot be fully assessed without considering what other transportation plans (COAs) will need to share the same resources. If the plan utilizes ports that are also being used or planned to be used by other movements at the same time, these resources are likely to be further constrained because you can not assume that your movement and only your movement can utilize the full capabilities of a port. At this point in the COA analysis process, a planner needs to understand how much of certain port resources are being used by his plan. We have proposed a visualization that will allow the user to view the projected plan in terms of throughput and port capabilities used over time with respect to the maximum capability available at that port for all activities. This provides the user with a better understanding of, "How much of a port is projected to be used by my COA?" and "How much capability in total does the port have?" as well as visual cues to any bottlenecks or threshold concerns. Using this visualization, planners can modify the maximum threshold for certain capabilities of a port for use by a single COA so that ongoing or projected concurrent movements can appropriately share the port resources. This visualization provides a focal point for multi-planner collaboration sessions to help ensure that concurrent plans are mutually feasible.

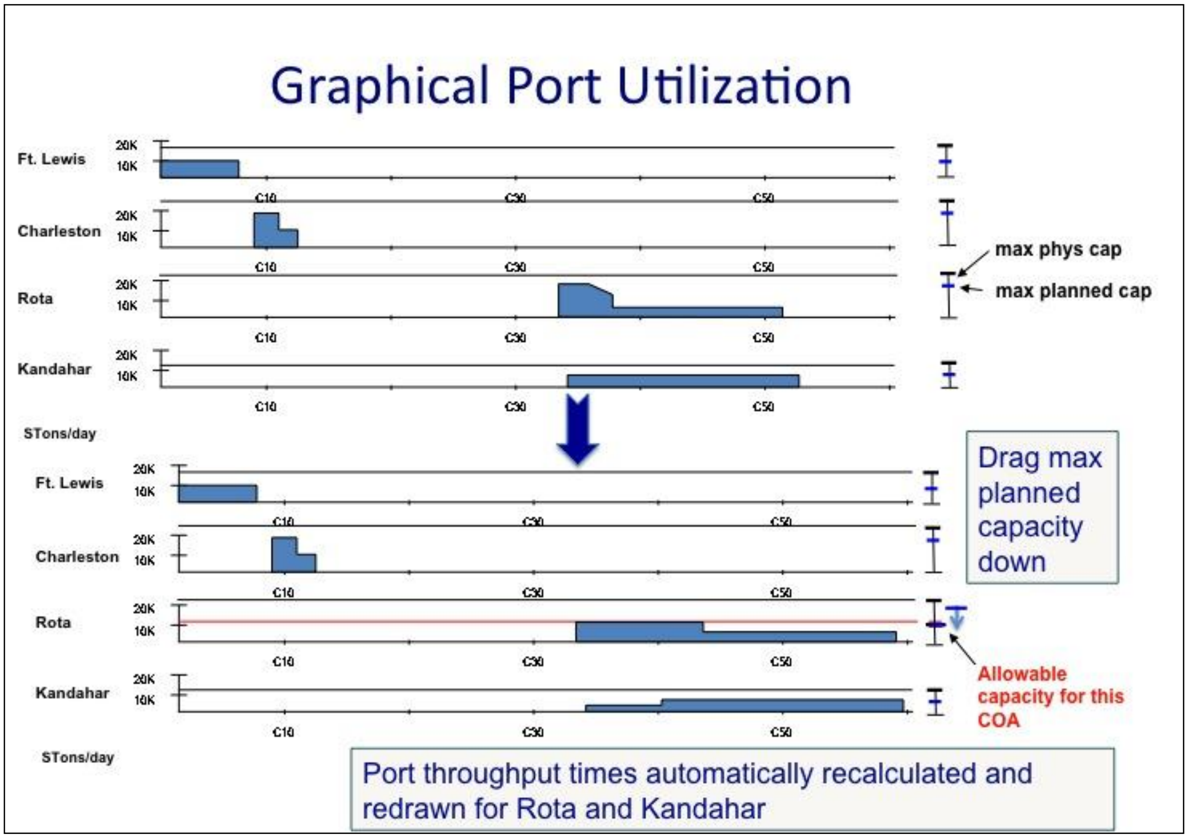


Figure 7: Interactive Port Utilization charts

In Figure 7 above, the blue bar charts depict the cargo throughput per day at each port across the entire projected plan as determined by the MIDAS model. The black lines at each port depict the maximum throughput per day; the blue marker shows the maximum used by the COA being analyzed. As the planners collaborate over the usage at Rota for example, it may be determined that due to other activity at that port, the maximum allowable throughput for the current COA should be about 10,000 Short tons (STons) a day. Given this information, the user can simply drag the allowable threshold down as indicated by the red bar and RCAAT will replan with the adjusted port assumptions. This technique can be used across many different capabilities at a port such as: airport MOG (Maximum on Ground), number of seaport berths available and many other limiting factors to provide insights into multi-COA, real-world feasibility analysis.

COA Comparison:

Once the user has more than one COA defined that meets the transportation mission problem criteria, the next task is to compare the COAs and make a COA recommendation to leadership. As discussed early in the paper, there are many factors for what might make one COA "better" than another. Such factors may include closure timeliness, vehicles needed to complete the missions, ports utilized and their constraints, or political status. At this time in the process it is important for the user to be able to "build" visualizations that display their notes and a high level summary of their chosen COAs. The map visualization provides an easy mechanism to turn off or hide unneeded information to display only certain COAs and associated information. The planner will also need supporting drilldown views of each COA that support further comparison and analysis. We designed two comparison table visualizations in support of such COA comparisons. These views will also highlight areas of concern such as port capabilities reaching maximum capacity for each COA and allow the user to add annotations to further describe their conclusions. The first table shows a summaryof 3 COAs, the associated ports and assumptions in a single table along with summary results for each COA (see the bottom of the figure below).

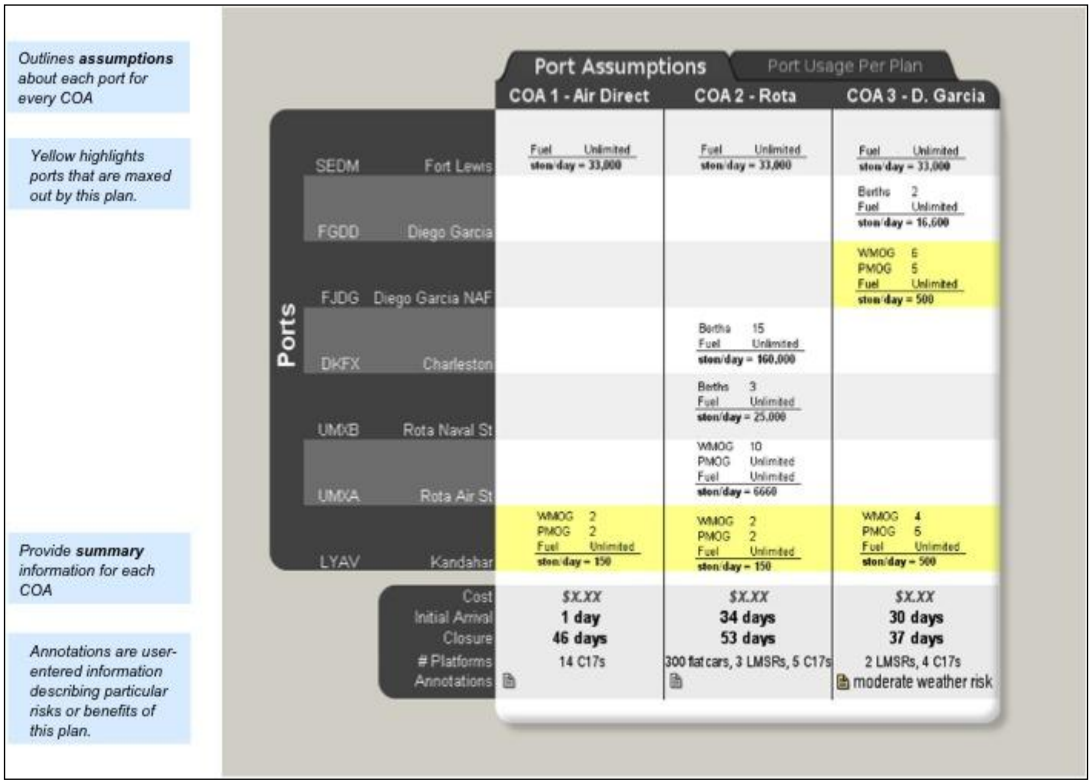


Figure 8: COA Comparison focusing on port assumptions and capabilities.

The second table (really just another tab within the same table visualization), displays the port utilization details, providing a way for the user to compare utilization details of multiple COAs at once.

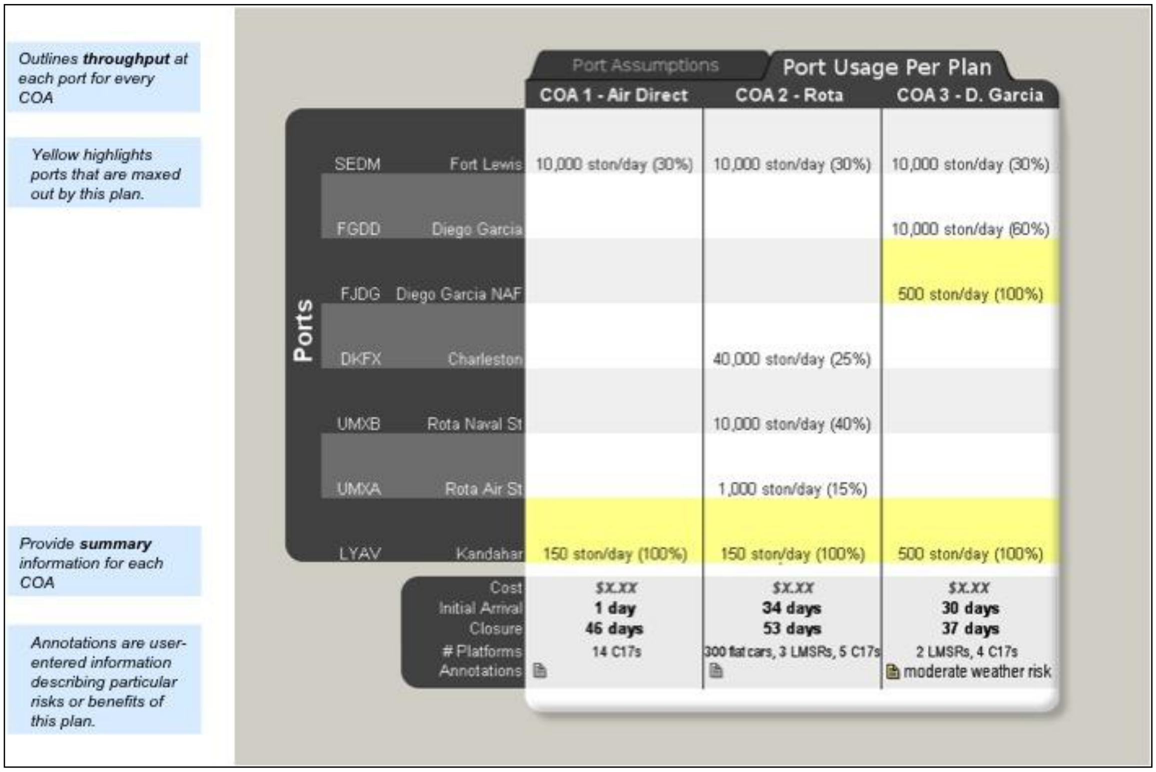


Figure 9: COA Comparison table depicting port usage for each COA.

4. Repurposing a Model to Support a Collaborative Decision Tool

Having laid out both the cognitive structure of the planning tasks and the software structure of the prototype tool, we can now discuss the modifications we made to MIDAS to support the work model we had in mind for the Fusion Center planners as well as the overall framework we built up to let the planner interact with MIDAS.

In [Scott, 2009b], the problem under discussion is the design of a "Joint Cognitive System" [Woods & Hollnagel, 2006] in which the human operator is working jointly and iteratively with a software optimizing scheduler tool to find ways to solve difficult air mission scheduling problems. In that paper (which follows principles laid out in Woods & Hollnagel), some of the key factors to allow for the successful collaboration between human operator and automated system are that the automated system must be both *directable* by the human and *observable* by the human. An additional factor, related to the other two, is the availability of visualizations that can serve as a *shared frame of reference* between the human and the automated system.

These same factors, reinterpreted for the current problem, turn out to be the critical design features to allow the Fusion Center planner to use MIDAS as the "engine" to this COA exploration tool.

"Directability" of MIDAS means that the planner is able to specify exactly what the course of action to be modeled by MIDAS is. That is, the MIDAS simulation should use exactly the ports specified by the user (and no other ports), exactly the planes and ships specified by the user, in the numbers specified by the user. In addition, the user should be able to alter port characteristics (number of spaces for simultaneous plane loading, or number of berths, for example) to reflect his needs.

This directability property turned out to be surprisingly difficult to arrange with MIDAS. MIDAS has existed as a strategic distribution model for well over two decades. During that time it has been tailored in various ways for the large analytical and programmatic problems for which it has been used. It has, along the way, been designed to make certain assumptions about its problem setup that were convenient for its users for these large-scale model runs. And some of these assumptions do not translate so well to the small-scale runs that our planners will be making. The general problem is that there is a mismatch between what the model has previously been used for and what we now want to use it for - we are using MIDAS for a set of problems for which it has not previously been used. It should be no surprise that we must allow for a period of revalidating the model for our new purpose.

In the end, the directability of MIDAS has been achieved by carefully designing the map-based visualization (and supporting widgets) to let the user select the ports, specify the ports to use, and choose the numbers and types of vehicles. All of these "inputs" are accomplished through simple user gestures that mirror how the user would mentally "sketch out" the COAs.

"Observability" of MIDAS by the planner is a little more difficult concept. While it is certainly true that we want the planner to be able to observe the results of MIDAS – the closure date of the COA and the utilization profiles of the various ports that are used – we actually want more than that. We want the planner to be able to quickly and easily "explore the decision space" – i.e., make changes to the ports used, to the numbers or types of vehicles used, to the amount of cargo to be carried, and (nearly) immediately see what difference it makes in the MIDAS results.

We need this extended observability property for two reasons. First, it is only with this exploratory capability that the planner will learn to have trust in the answers that come back from MIDAS. Even though, as we've said, the planner does not have the capability to easily check the answers – to compute the closure date, for example – for a complicated COA, he does have some sense of how the closure date should vary with some of the changes he can make for simpler COA's. By trying out various test cases, the planner will quickly find out if the MIDAS results match his mental model of what effects the changes should have, and quickly decide if he is willing to trust this tool.

Secondly, we argue that this exploratory capability is critical to helping the planner understand the COA's he is evaluating. It is not enough to take the single datum of the closure date as the metric by which a COA should be evaluated. The planner needs to understand how robust that estimate is. What if cargo doesn't move as quickly through one of the ports as the data in the database suggests it will? What if one or two of the C5's allocated to this COA break down for a couple of days? The ease of changing a number or two and nearly immediately seeing a revised result allows the planner to do quick sensitivity analyses to get a feel for best case, likely case, and worst case estimates for his COA's. This is exactly what is needed for the planner to not only choose a COA, but defend that choice to his superiors.

This notion of observability was enabled not only by the user interfaces we designed to allow the planner to interact directly with MIDAS, but also by the significant work it took to get single MIDAS runs down to two or three seconds. As is typical of large simulation models, MIDAS can take quite a bit of time (on the order of 60 seconds) to initialize itself. We certainly did not want any user action that required a new MIDAS run to take that long, so we found a way to initialize MIDAS only once when the RCAAT tool is started up. Every interaction with MIDAS after that essentially is a message to the running MIDAS to alter the scenario it is running, and to rerun it from the beginning without reinitializing the entire run, generally allowing the run to complete in just a couple of seconds.

Finally, we point out that our visualizations form the shared frame of reference between the planner and MIDAS. Certainly the map-based tool that really serves as the planner's sketchboard to task MIDAS is one component of this shared frame of reference. But model results are not themselves, in our system, portrayed on the map. The natural visualizations to view model results are the linked port utilization graphs that directly give the planner a sense of how his limited port resources are being used, as well as give him a direct manipulation method of altering the constraints on port utilization.

5. Summary

This paper describes the analysis and design that led to a prototype implementation of a course of action exploration capability for USTRANSCOM Fusion Center planners. Our cognitive analysis led us to the conviction that instead of a tool that will directly generate a COA, or a tool that will let a planner deeply analyze one COA at a time, the planner would be better supported by a tool that will let him quickly and roughly analyze multiple COA's. By allowing the planner to try out multiple variants of each plan, we can let him directly get a feel for the overall decision space and allow him to understand the sensitivity of the COA to small modifications. The understanding of a COA not as an unchangeable plan, but a family of related possibilities (with the corresponding appreciation for the magnitude of end effects that arise from small changes) will lead the planner to better choose from his possible COA's.

In order to enable this COA exploration capability, we connected a number of rough estimation equations to a map-based graphical user interface. These calculations mirror the coarse analysis that experienced planners do now when faced with COA problems. To produce a more refined analysis of a potential COA, which goes further than planners can now go, we adapted MIDAS, an existing strategic transportation model, to be tightly integrated into our tool.

While MIDAS is a validated computation engine for modeling the flow of transportation assets through a set of ports, it is designed for use by experienced operations research-savvy analysts on transportation problems much bigger than our typical scenarios. Our design challenge was to enable our user to easily task MIDAS, to make sure that there would be no mismatches between the COA scenario laid out by our user and the problem that MIDAS would solve; and that our user could easily interpret the MIDAS results. This design drew from, and extended, ideas we've previously described as symbiotic planning – a particular variety of mixed-initiative planning in which the user is enabled to directly task and observe an automated process. This paradigm supports the user in integrating the results of the automated process into their own workspace and workflow.

We expect to, in future work, further explore the collaborative possibilities of the design we've already laid out, and further enable automated processes to help inform the planner about variations to courses of action he is already considering. A user evaluation, with Fusion Center planners using our prototype tool in realistic COA planning scenarios is also planned for the near future.

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