New Graphical Techniques for Strategic and Tactical Planning

D Moitra, GD Montanaro, C Chalek, H Chang

General Electric Co., Corp. R&D, PO Box 8, Schenectady NY 12301

Abstract

We present novel interactive graphical techniques for performing Air Force planning tasks such as deploying aircraft and weapons against desired targets, determining the availability of resources, performing a cost benefit analysis to improve resource utilization, and coordinating inter-dependent missions. The most fundamental aspect of force-level planning is that it is an iterative process, during each cycle of which it is important to be able to visualize the inter-dependence among the decision variables, and to be able to gauge the impact of modifying specific decisions. Traditional text-based techniques deny the planner the power of the interactive graphical medium for visualizing these dependencies, and for gauging the impact of proposed changes. In contrast, our techniques help the planner to understand arbitrary fragments of the current state of the mission plans, and incrementally improve them to achieve tactical objectives. We believe that our techniques can be easily generalized to support other planning tasks.[1]

1 Introduction

In this paper we present novel interactive graphical techniques for performing strategic and tactical planning tasks such as deploying feasible combinations of aircraft and weapons against a given set of targets, determining the availability of resources, performing a cost benefit analysis to improve resource utilization, and coordinating inter-dependent missions. Traditional techniques [1, 2, 3, 4] for these planning tasks are primarily text based, and may be used in conjunction with an expert system, which tries to maximize the potential value of deploying the resources. What is lacking from the traditional approaches is the ability to visualize the inter-dependence between the various planned missions, to see why particular resource deployment decisions were made, or what would be the effect of modifying a selected subset of the mission parameters.

We have applied the techniques of graphical interface design [5] to create novel interactive techniques for performing Air Force planning tasks. The main strength of our techniques stems from the ease with which the planner may simultaneously visualize multiple facets of the given planning tasks. Our techniques provide greatest support during the following steps of the planning process:

- Visualizing the geographical relationships among the targets and the assets.
- Visualizing the available resource allocation alternatives.
- Determining the tactical, temporal, and resource directed dependencies among the set of planned missions.
- Determining the cost benefit tradeoffs among the various resource allocation alternatives.
- Suppressing the display of information which is not relevant to the specific subtask on hand.

2 Mission Scheduling

The first task during mission planning involves visualizing the spatial relationships among the targets and the bases within range, and their relationship to the geography of the gaming area. The most powerful and time-honored planning tool is the wall map with colored flags and pencilled paths. We have retained the *map metaphor* as the visual interface to all of our planning tools. A map of a user-selected

Sponsored by the Rome Laboratory of the US Air Force under contract no. F30602-89-C-0078.

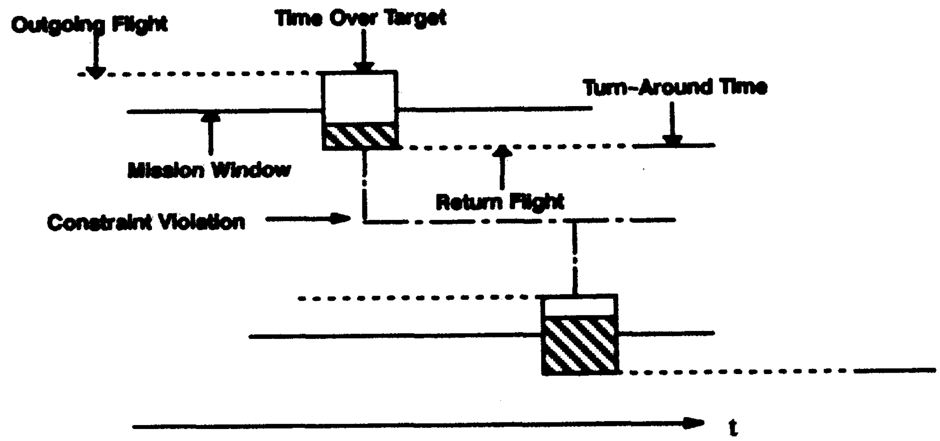

Figure 1. TOT slider

portion of the *gaming area* is presented in a workstation window. A planner can choose a target or an airbase by *pointing and clicking* with a mouse, which triggers *database queries* about the gaming area. Using a popup menu, the planner can retrieve desired information related to specific objects of interest on the displayed map. The information for targets subsumes the following:

- Data on the physical composition and layout of the target.
- Combinations of weapons and aircraft that can feasibly eliminate the target, and the attainable kill probabilities.
- Bases which are within range of the target and have the appropriate weapons and aircraft available.
- Information about the planned missions which relate to the targets visible on the map.

A map-based query provides two levels of *context sensitive filtering*. The first level filters out everything except the data that pertains to the objects currently on the map. The second level filters out data that would not pertain to missions currently planned against targets displayed on the map. This prevents the planner from being overloaded with information. In addition, the visual cues from the map in the background provide the planner with the spatial information that is itself the basis for planning. By examining the displayed information, a planner can allocate preferred weapons and aircraft from a selected base, to define a mission against a desired target.

2.1 Scheduling Sorties

After the planner has selected the weapons and aircraft which are to be used for a mission against a desired target, he must determine the timing of the mission. For the purposes of this discussion, a *mission* is a collection of related *sorties*. A sortie consists of one or more of the same type of aircraft, flying from the same air base and attacking the same target, and has the following properties. Its *geographic properties* define which base it is leaving from, which target it will attack, and where it will interact with other sorties. Its *temporal properties* determine how long it will take to fly the sortie (when its aircraft will be unavailable) and when it will interact with other sorties. Additionally, a sortie has *resource properties*, which define its impact on various resource pools such as fuel, aircraft and weapons.

The most important property about a sortie is its timing. We have designed a novel graphical device called *tot slider* to represent the temporal properties of a sortie, as shown in Figure 1. A tot slider displays the *mission window* (the acceptable time window during which aircraft can be over the target), the currently planned *time-over-target*, the outgoing and returning *flight times*, and the *turn-around time* (the time it takes to refuel and rearm the planes).

The sensitivity of a sortie to schedule slippage, resource availability, or other parameters is indicated by the relative amount of the time-over-target box that is colored red. As the planned time-over-target approaches the end of the mission window, more of it becomes red. If the box is moved completely off one end of the mission window or another, the box, the flight times, and the turn-around-time are all colored red.

Recall that the planner defines the resources and targets for a mission by making selections from the displayed map. This action automatically creates one tot slider for each sortie in the mission. The outward and return flight times for a sortie are automatically determined from its geographic properties, and the performance constraints of the participating aircraft. The mission window is provided as a higher level input to the planning process. The planner has the freedom to select the time-over-target anywhere within the given mission window, by moving the tot slider along the time axis. (The lines for the outward and return flight times for the sortie are attached to the tot slider, and move together with it.)

In order to plan missions effectively, a balance must be struck between the limited resources available and the targets to be attacked. Planners must know the type and numbers of aircraft at each base so they can ensure that no resources are overcommitted and that the planned schedule is not overly sensitive to slippage. We use a two-dimensional *resource plot* to represent the availability of reusable resources such as aircraft, as well as consumable resources such as weapons and fuel. A resource plot is automatically generated for each kind of resource at every base, by using the timing information from the tot sliders associated with each sortie.

2.2 Tactical Constraints

Many missions consist of more than one sortie. Coordination is required so that intermediate targets are attacked in proper sequence and that rendezvous take place properly. We associate a *precedence constraint* between two sorties, which defines the amount of time by which one sortie must precede the other. We represent a precedence constraint graphically by drawing a line between the tot sliders representing the desired pair of sorties. The length of this line corresponds to the desired time separation. If the constraint is violated, an alert action is executed, which normally displays the constraint. When a constraint is satisfied, it is not displayed.

3 Resource Allocation

We use a network of resource and target icons to visualize (and modify) the allocation of resources to specific targets, and also to show the alternative uses for each resource. Meters are asociated with each target to indicate the probability of mission success attainable by using any of the alternative combinations of resources. Meters are also associated with each resource to indicate the costs and rewards for the current deployment and its alternatives. Our technique permits the user to visualize the probabilities of success of the feasible alternative plans and to use the pre-assigned strategic values of the given targets in order to obtain a resource allocation plan which provides the best risk weighted return over the entire set of missions

Traditional tools for job scheduling and resource allocation include GANTT charts and PERT charts [6, 7]. The combined use of these techniques permits the visualization of: (i) the variation in the usage and availability of several resources spanning the duration of the planning horizon, (ii) the sequential dependence amongst related tasks, and (iii) the reuse of resources across consecutive tasks. The main novelty of our technique is that it permits a better analysis and visualization of the risks and rewards associated with each of the several feasible resource allocation alternatives.

3.1 Resource Allocation Networks

Figure 2 shows an example of a resource allocation network and the meaning of the symbols. On the network, time flows from left to right, as in a PERT chart. Resources are represented by circular icons and show the resource type, location and available quantity. Stacked boxes beside a resource indicate simultaneous feasible (and infeasible) allocations of units of that resource to different targets.

A target is represented by a rectangular icon and shows its location and type. Its strategic value is indicated by a green vertical meter to its right. Stacked boxes beside a target indicate alternative weapons and aircraft combinations which may be used against that target. A box with a dot indicates the currently selected plan for that target. A horizontal meter next to the target indicates the kill probability for that target using the currently selected plan (as is). Pop-up meters can be used to display the kill

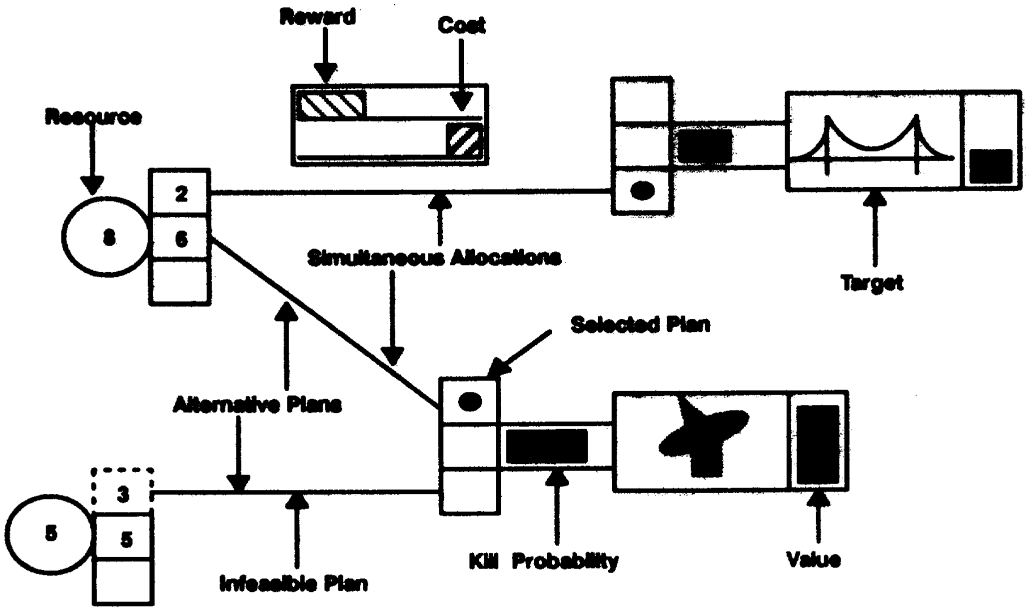

Figure 2. Resource Allocation Network

probabilities for alternative (unselected) plans for that target.

A line from a resource box to a target box indicates the number of units of that resource which could be allocated to that target. Since time is represented along the horizontal axis of the network, the horizontal projection of the line from the resource to the target indicates the duration of the mission. A resource icon can be indexed with a time value and replicated to the right of its allocated target, in order to indicate the time at which the resource becomes available for reuse.

The output ports of a resource box are connected to all the targets against which it is technically feasible to deploy that resource. For a given deployment, there is a cost, which is the sum of the cost of using that resource, and the risk-weighted cost of losing that resource. The value which results from deploying a particular resource is the product of the kill probability for that mission and the intrinsic strategic value of the target of that mission. The rewards for a mission M can be augmented by the values arising from missions which depend on the success of M. We associate a pop-up *risk reward meter* (RRM) with each output port of a resource. An RRM can be used to determine whether a given resource is being used to the best advantage, consistent with the given constraints of the planning task.

3.2 Managing Conflicting Resource Needs

A resource allocation network can be used for the following tasks:

- To view feasible alternative weapon and aircraft (W&A) combinations which can be used against a desired target, as well as the kill probabilities associated with each option. The input ports of a target box define all the weapon and aircraft alternatives which are technically feasible. The edges coming into the input ports of a target can be traced backwards to determine whether the desired W&A option is feasible in terms of the current deployments of W&A to various missions.
- To transform an infeasible allocation into a feasible allocation (if one exists), by tracing through successive edges in the network and modifying their end points. If all the W&A options for a target *A* are infeasible on account of the current deployments of resources, then we select one (technically feasible) input resource port *R* of *A* and determine another mission *B* such that *R* is deployed for *B*. We then determine if any other feasible W&A option can be deployed for *B*,

deallocate R from B, and deploy R for A. Thus we see that redeploying resources in order to make more missions feasible simply involves tracing through *paths* (consisting of connected sequences of nodes and edges) in the resource allocation network.

- To view alternative uses for a selected resource, and the risks and rewards associated with those options. The planner can use this information to optimize the risk-weighted value of deploying resources, over all the planned missions.
- To view dependencies between missions which are dictated by the reuse of resources. Additionally, a tactical dependency between a pair (A, B) of missions can be visualized by connecting a dummy resource after the end of mission A and connecting the dummy resource to the mission B, which is the successor of A in the given tactical dependency.

3.3 Impact of Weather on Planned Missions

The risk reward meter associated with each mission can be augmented with additional values to account for the effects of unfavorable weather. For example, a given mission may have a predicted kill probability if the weather is clear, another if it rains, and yet another if it snows. The meter would now show the three reward values for the three different kill probabilities.

The user can interactively sketch out the extent, path, and timing for a predicted weather phenomenon such as a snowstorm. The extent and path can be specified in an obvious manner as an overlay on the map of the gaming area. The timings can be specified by using a clock face,or by means of a pop-up dialog box, located at the start of the trajectory of the weather phenomenon, as well as at desired intermediate points along the path.

The system can simulate / animate the progress of the predicted weather phenomena (such as snowstorms or rain). It can also simulate the progress of the planned missions. The simultaneous weather and mission simulations can be used to determine which missions are unfavorably impacted by the predicted weather phenomena. This results in an updated display of the risks and rewards associated with each mission represented by the resource allocation network.

4 Coordinating Missions

At the force level planning stage, a mission is typically specified by the end points of its trajectory and its start and end time windows. Also given are a partially specified set of *waypoints* along the trajectory of each mission, which are typically used for coordinating with other missions or offensive / defensive activities. Additional constraints on individual missions are defined by specifying nearness / minimum separation with respect to friendly / hostile positions, by topographic constraints placed on feasible flying routes, and by the performance constraints of the aircraft. We are required to generate a set of coordinated mission plans (including high level flying routes and times), such that the missions individually and collectively satisfy the given constraints.

A mission can be viewed abstractly as a sequence of events, each of which is specified by its location and time. The constraints specify how near or how far apart two events can be. The pair of events thus constrained may be chosen from the same mission or from two distinct missions. The central problem is the ability to visualize a sequence of *events*, each of which is specified simultaneously by its *location* and *time of occurrence*. Given several missions, each of which is a sequence of events, we are required to relate two events from the same mission or from different missions.

We have developed an interactive graphical technique for visualizing and modifying *spatial and temporal coordination constraints* among a set of inter-dependent missions. Using our technique, the user can interactively sketch the spatial trajectories of the desired missions on a displayed map of the gaming area, and also define desired constraints in the *locations and timings* of a subset of the events which constitute the given missions. The novelty of our technique is the ability to visualize and interactively satisfy the spatial and temporal constraints on the given set of missions.

4.1 Constraint-Based Mission Planning

The user initiates coordinated mission planning by bringing up a map of the gaming area on the screen, which displays labelled icons representing the targets, bases, and other natural and cultural features of interest. The user can interactively sketch

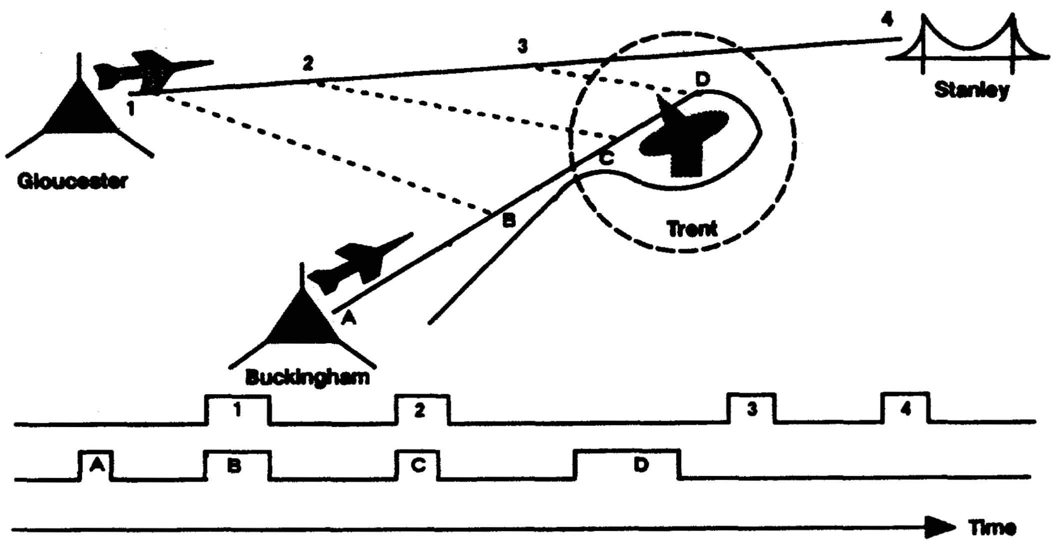

Figure 3. Coordinated Mission

out the locations or trajectories of planned events / missions. For a multi-event mission, intermediate events of interest can also be identified with labels. Events at distinct locations can be identified as occurring at the same time by linking a pair of such events with a line, or enclosing a set of events with a closed line.

Figure 3 shows an example of the usage of our technique for coordinating a refuelling mission with a two step bombing mission. A fighter plane starts out from the base at Buckingham (A) along the lower trajectory, passes through locations (B, C), bombs the radar site at Trent (D), and returns to its base. A fighter takes off from the base at Gloucester (1) along the upper trajectory, passes through locations (2, 3), and then bombs the bridge at Stanley (4). The dotted lines identify the pairs {(1, B), (2, C), (3, D)} of events which are pair-wise simultaneous. The circle around the radar signifies its range, and defines a constraint that the fighter from Gloucester may not pass within its range while it is still operational. The two lines at the bottom show the time lines of each mission, with time increasing to the right. The peaks in the time lines correspond to labelled events, and the width of each peak defines the permissible slack in the time of occurrence of the event.

The location of an event need not be a point, but could also be defined as an enclosed region of the map. Additional spatial or temporal inequality constraints between selected pairs of events may be defined interactively by the user. Some constraints on the locations of events or flight paths may be predefined by means of generic constraints relating to the underlying terrain or cultural features or the current status of the *line of control*. Similarly, a time constraint between any two locations of a flight path can be automatically introduced by referring to the performance constraints of the aircraft.

4.2 Using a Constraint Based Planner

Once the constraints have been defined, an underlying constraint solver attempts to solve for the locations and time of occurrence of each event based upon the given initial values and the given set of constraints. Violated constraints are highlighted and brought to the user's attention. At this point the user can interactively modify the location and/or time of occurrence of selected events and see the impact on the satisfiability of the complete set of constraints. As an example, a selected flight segment may require the aircraft to fly faster than its maximum velocity, and this would result in that flight segment being highlighted (possibly by changing its color). Then the user could drag either end of a constraint line relating to either end of that segment, and thus cause a change in the defined time or location of one of the offending events. After a sequence of visual iterations, the user can derive a feasible set of missions which satisfies all the given constraints. After the mission planning stage, animation can be used to visualize the progress of the planned missions over simulated time.

5 Conclusions

In this paper we have described several novel graphical techniques which can assist an Air Force planner to visualize the dependencies among the set of planning tasks and also to interactively derive a set of missions which are consistent with the predefined goals. We list below the specific steps of the planning process where our interactive graphical techniques can provide support to the planner.

- The user can schedule missions by using *tot sliders*. The related techniques also enable the user to specify and visualize tactical precedence constraints among several missions and to determine how sensitive the missions are with respect to slippages in their schedules.
- The planner can use *resource allocation networks* to allocate the available resources among the set of desired missions to maximize the number of feasible missions. The planner can also perform a cost-benefit analysis of the planned missions by using the *risk reward meters* to determine whether the resources are being deployed for a maximum benefit.
- If several missions are dependent on each other, the planner can coordinate their plans interactively by using the *coordinated mission maps*. This technique permits the explicit representation, visualization, and manipulation of the geographic and temporal constraints present among a set of interdependent missions.

The most fundamental aspect of force level planning is that it is an iterative process, during each cycle of which it is important to be able to visualize the inter-dependence among the decision variables, and to be able to gauge the impact of modifying specific decisions. Traditional text based techniques deny the user the power of the interactive graphical medium for visualizing these dependencies, and for gauging the impact of proposed changes. In contrast, our techniques help the planner to understand arbitrary fragments of the current state of the mission plans, and incrementally improve them to achieve tactical objectives. We believe that our techniques can be easily generalized to support other planning tasks.

Bibliography

1. JS Bradshaw - *A Pilot's Planning Aid for Route Selection and Threat Analysis in a Tactical Environment*, MS thesis, Air Force Inst. Tech., 1986.
2. L Charny, ME Hornsby & TB Sheridan - *An Interactive Multi-Objective Decision Aiding System for Tactical Mission Planning*, Proc. Human Factors Soc. Ann. Mtg., pp 432-436, 1987.
3. DB Chamberlain & CR Kirklen - *Advanced Mission Planning System (AMPS) Employing Terrain and Intelligence Database Support*, Proc. Natl. Aerospace & Electr. Conf., pp 1145-1151, IEEE, 1988.
4. AN Steinberg - *A Planner for Threat Assessment and Response*, Proc. Natl. Aerospace & Electr. Conf., pp 1121-1127, IEEE, 1988.
5. JD Foley, A van Dam, SK Feiner & JF Hughes - *Computer Graphics: Principles and Practice*, Addison Wesley, 1990.
6. RS Pressman - *Software Engineering: a Practitioner's Approach*, McGraw Hill, 1987.
7. J Wiest & F Levey - *A Management Guide to PERT / CPM*, Prentice Hall, 1977.