The Theatre Evacuation, Movement, and Peace Operations (TEMPO) Model

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Stephen Bocquet graduated from Monash University in 1992 with a Ph.D. in Physics. His thesis was on the magnetic properties of fine particle iron oxides. From 1993 to 1997 he worked in the Maritime Operations Division of the Defence Science and Technology Organisation, doing analysis of naval mine technology in support of the Royal Australian Navy. In 1997 he joined the then Theatre Operations Branch of DSTO, to work on analysis of joint operations with a particular focus on air campaign analysis. In 2001-2002 Dr. Bocquet was attached to Dstl Policy and Capability Studies in Farnborough, UK for 18 months. At Dstl he worked on the Analysis of Defence Capability study, and gained experience with several UK campaign models. During the attachment he participated in the NATO SAS-027 Technical Team on Analysis of Small Scale Contingencies as Australian representative. Dr. Bocquet now works in the Defence Systems Analysis Division of DSTO in Melbourne.

ABSTRACT

The TEMPO simulation model was developed for analytical support to Headquarters Australian Theatre (HQAST). TEMPO provides the analyst with a tool to rapidly compare various concepts of operation for evacuation and other movement operations. It allows modelling of deployment, redeployment, sustainment and transportation operations, and allows the analyst to investigate alternate “what if” cases that vary from a base scenario. Scenario variations can be prepared and analysed on a time-scale of minutes or hours to aid in operational planning. This paper provides an overview of the TEMPO model, and describes how it meets the analysis requirements for the Theatre Planning Group at HQAST, using a scenario based on the evacuation from East Timor in September 1999 as an example.

HQAST THEATRE PLANNING GROUP ANALYSIS REQUIREMENTS

Headquarters Australian Theatre (HQAST) is responsible for planning, conducting and supporting Australian Defence Force (ADF) campaigns and operations at the theatre or operational level. HQAST is composed of branches, which are identified using the United States/NATO standard “J-designator” system. For example, planning branch is referred to as J5; this branch is responsible for planning of future ADF operations.

Within the context of theatre planning, any analysis carried out on behalf of the theatre planners must address the following factors as best as possible:

- *Timeliness:* Simulations and analyses utilised to evaluate a concept of operations must be developed, executed, analysed and have the results presented within a near-real timeframe of hours to, at most, days. Although there is some limited opportunity to gather data ahead of time, most of the analytical work must be achieved within the timeframe of theatre planning meetings.

- *Accuracy and Transparency of Results:* The principles underpinning the analyses must be specified explicitly, with any data used verified and validated as far as possible against that used elsewhere in the courses of action analysis process. Any information gaps would also need to be stated unambiguously, so that the results could be interpreted appropriately in context.

- *Relevance:* The simulation must be able to model and display results at an appropriate level of detail. Results should not only provide relevant performance measures, but it is also important that they be presented in a concise fashion that is compatible and comparable with the findings of other planners.

- *Relative ease of generation and modification:* The system used for analysis should be reasonably simple for the analyst to operate and maintain. If military planners are not directly involved with the generation, execution, analysis and presentation of results of the simulation, this obviates the need for extensive training, documentation and service support. Analytical results are typically obtained from several different simulation runs. It follows that these runs should be appropriately named and identified, so that the appropriate run can be quickly located should subsequent analysis and modification be required. The importance of appropriate identification of analysis results is further increased by the tight time constraints on the planning sessions.

With these requirements in mind, five different approaches were considered for the provision of analytical support to HQAST:

1. <u>Analytical support:</u> Mathematical models, pencil and paper, and expert judgement.

2. <u>Planning support:</u> Visualization tools, visual aids

3. <u>Calculator models:</u> Outputs provided as a relatively simple function of input values.

4. <u>Optimization models:</u> Linear programming and related approaches.

5. Simulation models: Time-stepped or Event-stepped. Geographical, Network, or Process modelling.

Each of these techniques has advantages and drawbacks as far as fulfilling the criteria mentioned above and need not be implemented in isolation. The criterion for timely information, for instance, leads to a need to keep the data requirements for any tool developed to be relatively simple. However, this must be tempered with the need for useful information across a broad theatre level operation. This leads to two types of data requirement with different timescales:

- Background Information (scenario specific – not part of the plan).

- Plan Specific Information.

Furthermore, output to standard briefing format should occur automatically allowing timely presentation of analytical results. Other aspects that affect the modelling approach include the level of aggregation and the importance placed on providing a theatre-level overview of a complete operation. A simulation modelling approach is particularly good for this because it can be used to check the integrity of a complete plan in regards to movement in time and space.

In December 1999, DSTO scientists began developing a geographically based computer simulation to analyse and investigate Evacuation Operations. This software comprises two fundamental components:

1. *Theatre Operations Modelling Environment (TOME)*, a set of JAVA classes that incorporates simulation functions and the display of geographical information in a Graphical User interface format.

2. *Theatre Evacuation, Movements, and Peace Operations (TEMPO),* an additional set of JAVA classes that are used to model the movement of assets from one location to another, and to read input from a Microsoft Access database which holds scenario-specific information.

TOME was developed to provide general geographically based simulation functionality. TEMPO contains higher-level algorithms that are specifically geared towards modelling evacuation and movement operations and relies upon the underlying TOME functionality. Initially, the TEMPO simulation was demonstrated to J5AST, using historical recreations of the evacuation of Australian and Approved Foreign Nationals from East Timor by the ADF in September 1999. Following positive comments from military planners, further extensions and improvements were included, and the software continues to be developed.

THE TEMPO SIMULATION MODEL

One of the key modelling philosophies behind the design of TEMPO was an emphasis on the transparency of model results. An integral part of this philosophy was the desire to reduce the amount of model behaviour that was hard-wired into the code and hence hidden. Instead the model has been structured in a strongly data-centric manner. This data-driven approach to modelling allows the behaviour of the model (such as the standard operating practice) to be database-driven with the model logic defined, in the main, by the analyst in a scenario specific way. This provides for a great deal of flexibility as well as transparency in the model's behaviour.

A second element of the design philosophy that runs somewhat counter to this is the need to keep the data requirements relatively simple, in line with its theatre-level perspective. These two objectives have been achieved in TEMPO using an object-oriented framework. Basic classes describing assets, operational parameters, road networks, transports and crews are provided by the model. These have certain basic data requirements. It is up to the user, however, to define through the database particular objects (e.g. particular transports, or particular assets of interest) to be used in the model and how these should behave. The analyst is thereby free to identify key drivers for a particular scenario and to use the model to track the assets, parameters or other items which are relevant to these drivers. Furthermore the aggregation used by the model can be fully defined by the analyst along with the model logic which specifies the behaviour of these aggregations.

The data requirements of TEMPO can broadly be separated into three distinct categories. These are:

1. Geographical data: data that define the map layers, key locations in the scenario and the route network connecting these.

2. Force Element data: data that define the specific transports, crew, assets and operational parameters available and key parameters relating to the performance of these items.

3. Scenario Concept of Operation: data that define the concept of operation under consideration. This includes user-specified orders or requests with triggering conditions and priority levels. It may also define operational requirements and restrictions on items defined in the force element data (such as consumption rates, resource availability and time restrictions).

A brief description of each data category follows; more details may be found in reference 1. Geographical data is displayed in TEMPO with a map display based on the freeware OpenMap package, a simple GIS. Multiple layers can be displayed, including maps in ESRI shape file format, Digital Terrain Elevation Data (DTED), day/night shading, and icons representing user-defined simulation objects such as ships and aircraft. The display allows the various layers to be turned on and off, or moved to the foreground or background. The map scale and projection can also be changed as required. The simulation uses a node and arc network, which must be defined in the Access database for each scenario. The node coordinates are specified as latitudes and longitudes, and the arcs are specified as linking any two named nodes.

FORCE ELEMENT DATA

In a given scenario there is a requirement for the force elements and assets available to be defined. Much of this data remains static, however, and can be reused in different analysis scenarios. The data required for TEMPO includes: (1). Transports, (2). Crew. (3). Assets, and (4). Parameters.

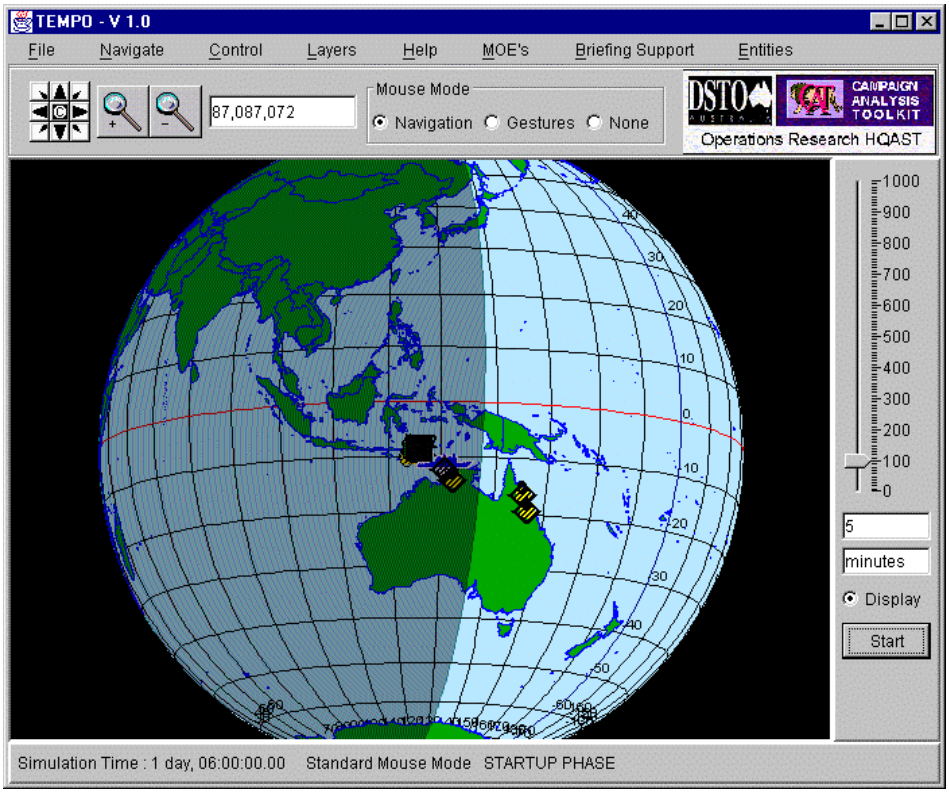

Figure 1: TEMPO display, with day/night shading and the map displayed at large scale in orthographic projection.

TRANSPORTS

Transports can be defined either individually, or grouped collectively with a common name. The basic parameters that define and identify a transport include its name, speed, range, pax, operational capacity, initial ready time and turn-around time. Transports also have a priority value which gives the minimum priority tasks that that transport is available for. If a request is placed with a lower priority the transport may be held as unavailable.

Other items which given transports can carry can also be added, so that each transport has a fixed maximum and minimum carrying capacity, as well as consumption (or production) rates of any number of items. Thus, the database allows the user to define any number of assets or parameters that a transport may carry or have associated with it (for example the asset, “fuel,” or the parameter, “service level”). Transports may be defined as requiring a crew to move, in which case the crews that are able to drive the transport must be defined in turn. Transports may also be given operational restrictions, such as a restriction that it is unable to work during certain hours of the day (e.g. night time flying restrictions on a helicopter) or other restrictions on total time in use.

CREW

Crew, like transports, are defined either individually or grouped. Crew may represent within TEMPO a particular crew or crew-type required to work a transport. The transport or set of transports that a crew is able to run is defined in the database. Alternatively a crew may not specifically drive a transport, but may represent a force element such as a medical crew or even combat forces. As for transports, crews have an operational capacity, initial ready time, re-ready time, and a minimum priority of the tasks on which that particular crew is available to work.

Crew may also have working restrictions placed upon them. These may include a maximum number of hours they are available to work per day, or a maximum number of days available per week. Alternatively, restrictions relating to unavailability during particular hours of the day (e.g. unavailable at night) can be enforced.

ASSETS

Within TEMPO, crew and transports are particular specialised assets that carry with them specialized properties and behaviour discussed above (e.g. maximum range, speed or operational restrictions on transports along with the ability to be used in moving between locations if requested). They also have fixed relations to other aspects of the model, for instance a crew may be required to run a transport.

The analyst is also able to define any number of additional assets within TEMPO for use in a particular scenario. An asset is normally used to describe a physical quantity within the model. Typical examples would be “fuel”, “food” or “evacuees”. Each asset is stored in a conceptual “bucket” at each place it is being used or carried. Valid places where asset “buckets” may be located include physical locations (e.g. fuel at Dili), transports (e.g. AVTUR at C130) and crew (e.g. food at Jervis crew).

The bucket that holds an asset has properties such as the minimum amount and maximum amount of the asset that can be held. They may also be to be “leaky” — meaning that the asset stored in this “bucket” has an intrinsic rate of consumption (or production) per unit time or per unit motion. For instance fuel on a C130 may have a particular rate of consumption per unit motion, a minimum value of zero and a maximum value equal to the fuel capacity of the aircraft. Other asset reserves at a fixed location may have a rate of consumption or production per unit time (rather than per unit motion), allowing the analyst to avoid detailed modelling of a particular asset’s consumption if detailed modelling is not required. Assets also have a minimum priority task on which they may be used, defined by the user.

Asset sources and sinks can also be defined, separate from the asset containers. These can be used to represent things like the arrival of evacuees at an assembly area, or the consumption of fuel at a particular location. The rate of arrival of an asset at a source, or its departure at a sink, may be changed dynamically. For example, at day one of the model run evacuees begin flowing into each Evacuee Assembly Area at an initial rate of 10 per hour, increasing over the course of a week up to 20 per hour.

PARAMETERS

Within TEMPO, the analyst is also free to define an arbitrary number of parameters that may be used in the model. The definition and behaviour of a parameter in TEMPO is very similar to an asset, however conceptually these are somewhat different. While an asset describes a physical quantity within the model, a parameter is used to quantify a concept within the scenario. For example a “threat” parameter may be defined at each of a series of locations or a “morale” parameter may be defined at a crew or transport.

Apart from this conceptual difference, however, parameters are handled in a way that is almost identical to assets. A “bucket” of the parameter at a particular location defines its value, along with its maximum and minimum value and any intrinsic growth or decay behaviour. Parameter sources and sinks provide the user with the ability to control the changing value of the parameter.

For instance, a “threat” parameter may be defined at all locations in East Timor, with initial values of threat in all locations set to zero and a maximum value of one hundred. The threat may then be slowly increased at all locations using one (or more) sources of threat which increase the threat at each location at a particular rate. The actual effect of the “threat” parameter must then be defined by the analyst. This is achieved by setting up orders that are triggered by particular threat values.

SCENARIO CONCEPT OF OPERATION DATA

The final data required by TEMPO is the data that defines the concept of operation under consideration. These include user-specified orders or requests with triggering conditions and priority levels. The user may also define operational requirements and restrictions on items defined in the force element data.

The basic mechanism by which an analyst defines the progress of a scenario is through “requests.” Each request is made up of four main components that provide the flexibility to produce a wide range of behaviour from the model:

1. The trigger or initiator that starts (or restarts) the request.

2. The list of requested items involved in the request. These may be a single unit (such as a transport), or a transport may be requested to carry one or more additional items (such as evacuees). At its most general the requested items may involve a task group of transports of different kinds with various assets, crew, and parameters being sent or travelling with each transport.

3. The locations the request is to occur between. These may be specified explicitly, or by type, region or other grouping. Specific paths may be specified if required, and the mechanism of travel (i.e. travel together or not) may also be set.

4. The (possibly dynamic) priority of the request, and any alternate requests that may be initiated if this request can not be met.

Request initiators are constructed in the database using Boolean logic. For instance, suppose we wish to move evacuees out of an area (i.e. start a movement request) after 5 days have passed, however we would start this movement earlier if the threat is greater than 50 AND the number of evacuees at the location is greater than 10. The initiator for this request would be expressed as:

(Simulation Time ≥ 5 days) OR ((Threat > 50) AND (Number of Evacuees > 10))

Items and locations may be requested in a general way, for example “any air transport,” “any two helicopters,” “any Evacuee Assembly Area” etc. Combined with the Boolean logic in the request initiator, this gives the analyst plenty of freedom to define the concept of operation in the model. The construction of requests in TEMPO is described in more detail in reference.

DATA DISPLAY

TEMPO allows the user to display and modify parameters for a large number of the objects involved in a simulation run. These allow the analyst to investigate “what-if” like conditions for a given scenario and change values during a simulation’s progress. The list of data-displays include displays for fixed items (Figure 2), mobile display (Figure 3) and displays relating to the requested items and initiators (Figure 4). Displays are available for each of the items listed below:

- Locations.
- Transports.
- Crew.
- Assets and Asset sources/sinks.
- Operational Parameters and Parameter sources/sinks.
- Requests.
- Request Items.
- Initiators.
- Mobile objects.

Plotting displays are also available to present data in a graphical form. The value of any asset, or operational parameter over time can be plotted. For instance, in the case of the evacuation of East Timor, we may wish to investigate the number of Evacuees at a particular location (say Baucau) as a function of time. Figure 5 shows a typical plot of this kind.

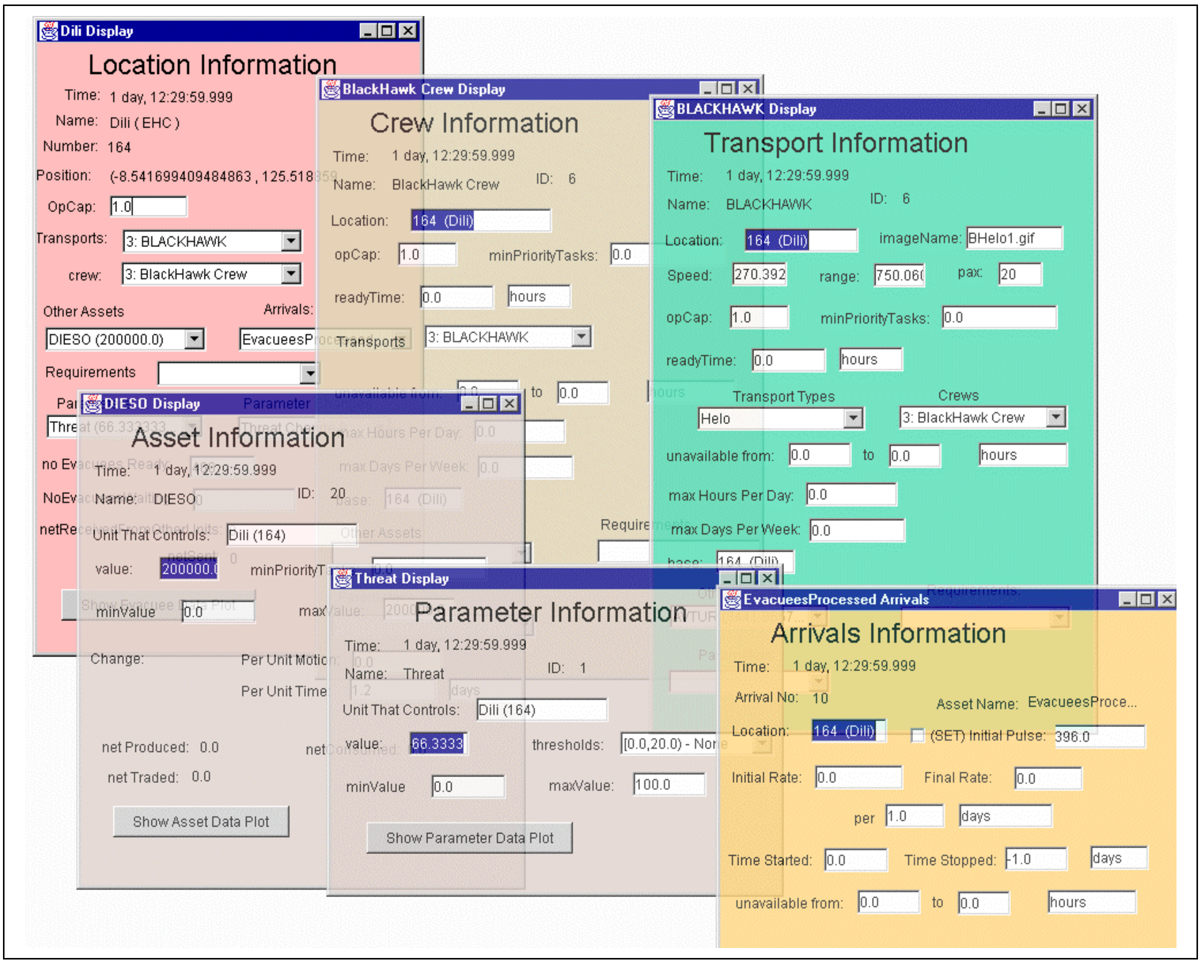

Figure 2: Some of the fixed information displays available in TEMPO.

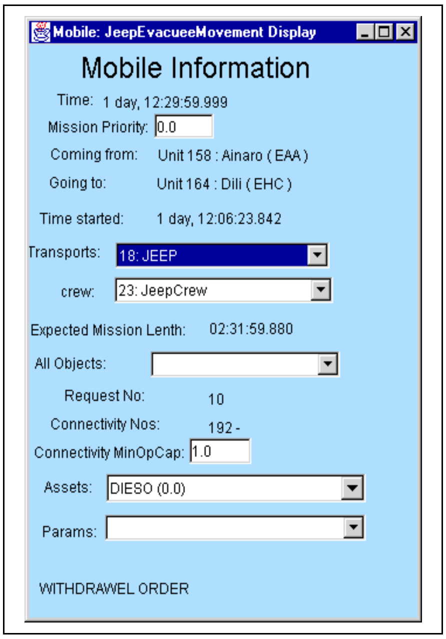

Figure 3: The mobile display showing a request in action.

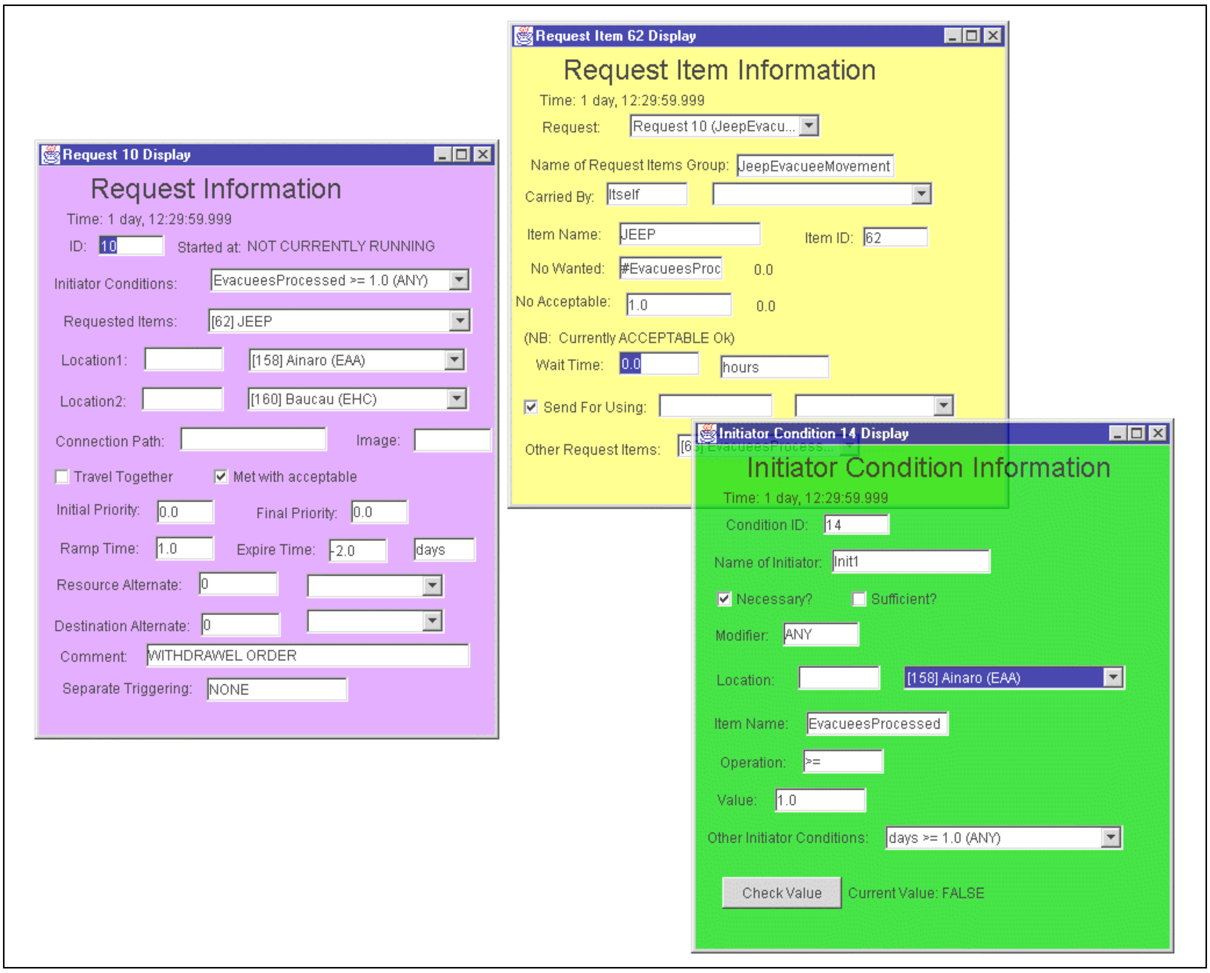

Figure 4: Some displays relating to requests.

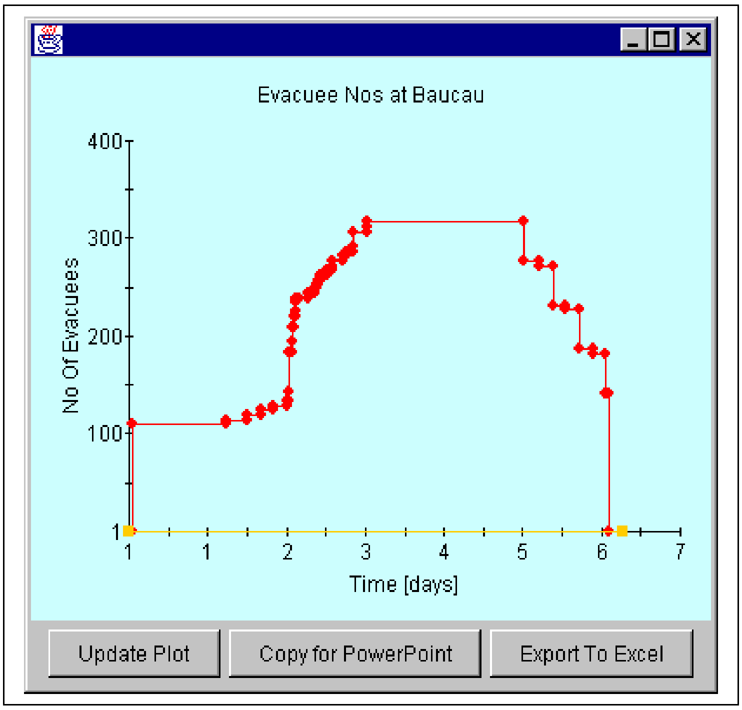

Figure 5: Plot of evacuee numbers at Baucau.

These plots can be copied to Powerpoint™, or the data exported to Excel™ and a new plot generated in Excel™. Other data collected by the model during a run can also be exported to Excel™ for further analysis.

EAST TIMOR EVACUATION SCENARIO

Following the August 1999 independence vote in East Timor, conditions in the territory rapidly deteriorated, with escalating militia violence and destruction. The Australian Defence Force conducted an operation to evacuate Australian and other foreign nationals from East Timor. This historical scenario was used to validate the TEMPO simulation model. The East Timor evacuation scenario provides a simple example of the kind of analysis that may be supported with the use of TEMPO. The data presented here are fictitious and is provided for demonstration only.

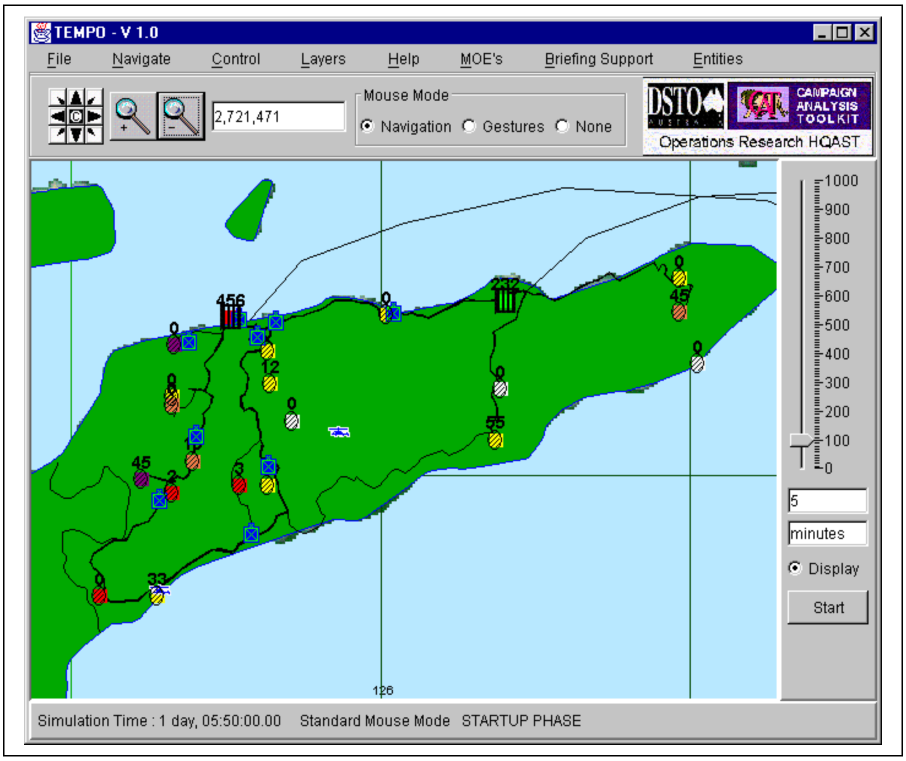

Figure 6: East Timor evacuation scenario. The number of evacuees at each location is shown; colours indicate different levels of threat.

It is incumbent upon military personnel to reduce the timeframe of an evacuation to the shortest duration possible. Extended deployments require extensive logistic support and resupply, thereby greatly increasing the scale of the operation. If a larger scale operation is warranted, then the associated logistics requirements increase significantly, and must be factored into planning. It is therefore imperative that planners have a realistic estimate of the likely duration of the operation as early as possible in the planning process. If analysis indicates that the interval is likely to be prolonged, then further planning will determine what additional resources could either reduce the operation to an acceptable timeframe in the best case, or logistically to support the deployed force beyond its normal viable period of operation in the worst case. Hence the main MOE for the East Timor scenario is the time taken to complete the evacuation.

TEMPO can be used to investigate a number of "what-ifs" in relation to the base scenario. These could include issues relating to:

- Weather effects on routes and transport use.
- Concurrent operations.
- Limited logistics/resources.
- Change of mode of evacuation (for example: Air versus Sea).
- Effects of escalated threat.

The basic methodology for the use of TEMPO is to consider a number of alternate scenarios, such as:

1. Flow interception along a major route (cutting the bridge at Manatuto).
2. Evacuation by sea rather than by air.
3. Scenario with increased population to be removed with the same assets.

Using these three "what-ifs" as a basis we then investigate the effect of varying key parameters for each. Our sample conclusions may then be presented with plots to back them up. For example, our base scenario may take about eleven days to complete the evacuation (Figure 7). In these plots the squares indicate people awaiting evacuation in East Timor, diamonds indicate the number of people evacuated to Darwin, and triangles show evacuees in transit.

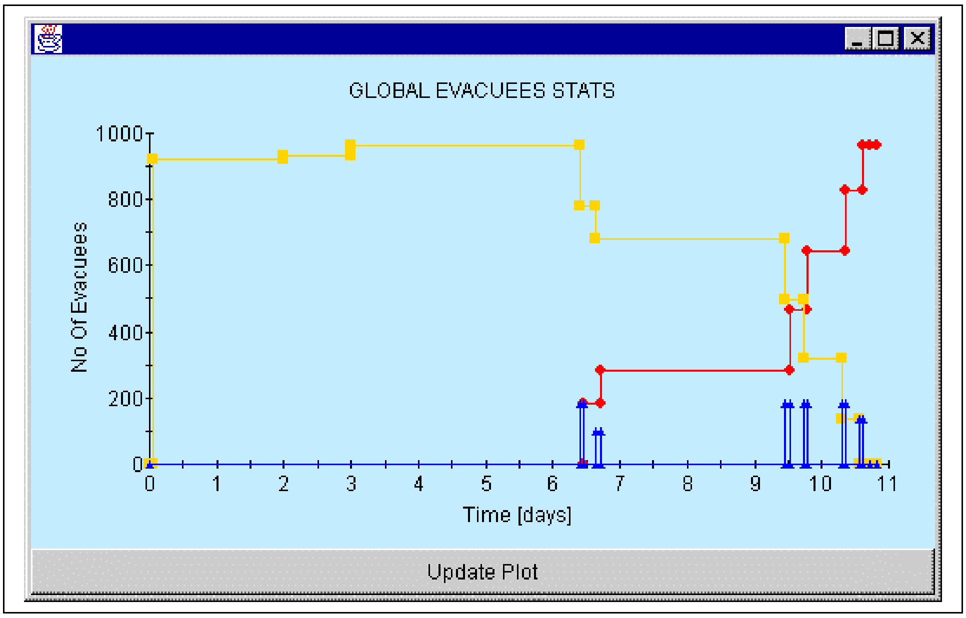

Figure 7: Global Evacuees Data for the base scenario.

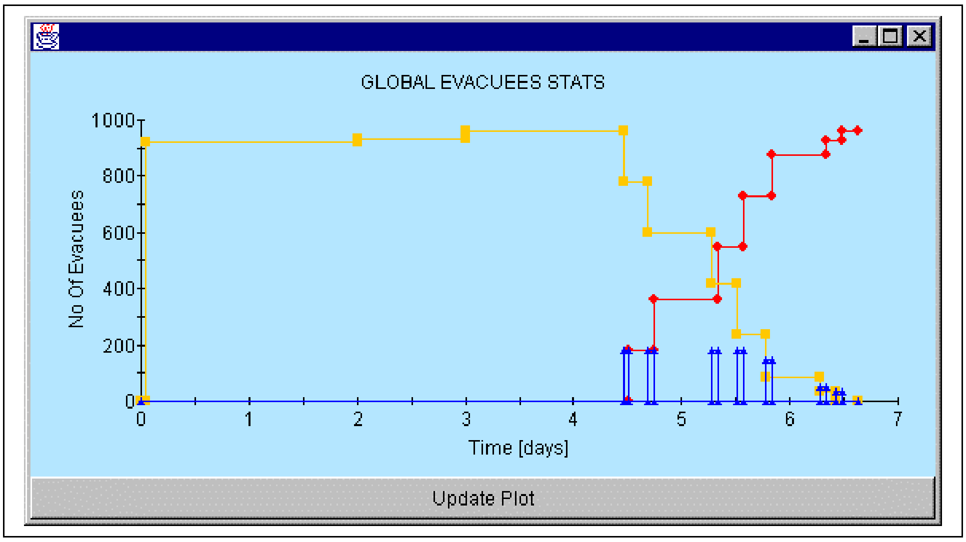

Figure 8: Global Evacuees Data for scenario with the bridge at Manatuto destroyed.

We may then examine alternate scenarios and draw conclusions. Provided there are at least 4 helicopters at Dili and ground escorts provided locally, the loss of the bridge at Manatuto does not lead to the operation exceeding its planned duration (Figure 8). However, loss of available security crews for ground escorts (or reducing this number) may have a large effect (Figure 9).

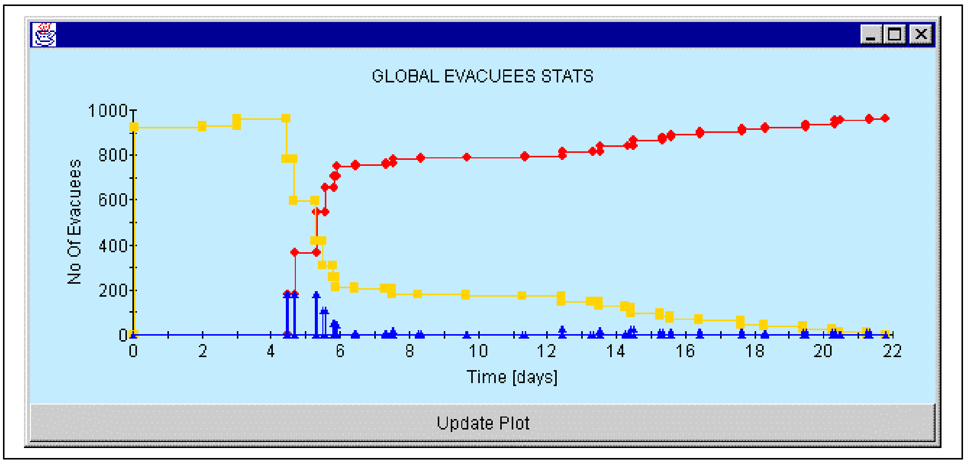

Figure 9: Global Evacuees Data for scenario with reduced numbers of ground escorts.

TEMPO is also designed to investigate the logistics effect of various operations. For instance, we may find that if evacuation by shipping is required, we will note a corresponding requirement for greater fuel supplies at Dili (Figure 10), although the requirement for aviation fuel is less (Figure 11).

The effect of changing the mode of evacuation can also be evaluated (Figure 12). The triangles indicate the number of people in transit between countries. This plot, using sea evacuation, shows a correspondingly longer transit time than for the case of air evacuation.

TEMPO provides a flexible tool for investigating different operational concepts, resource availability and other constraints. The output it provides is in the form of plots and tables of resource use and time taken to achieve various values. In this case we are considering the asset "evacuees" and the time taken to move this from one set of locations (in East Timor) to another set (in Australia). In another scenario the key MOE and the assets and parameters considered could all be quite different.

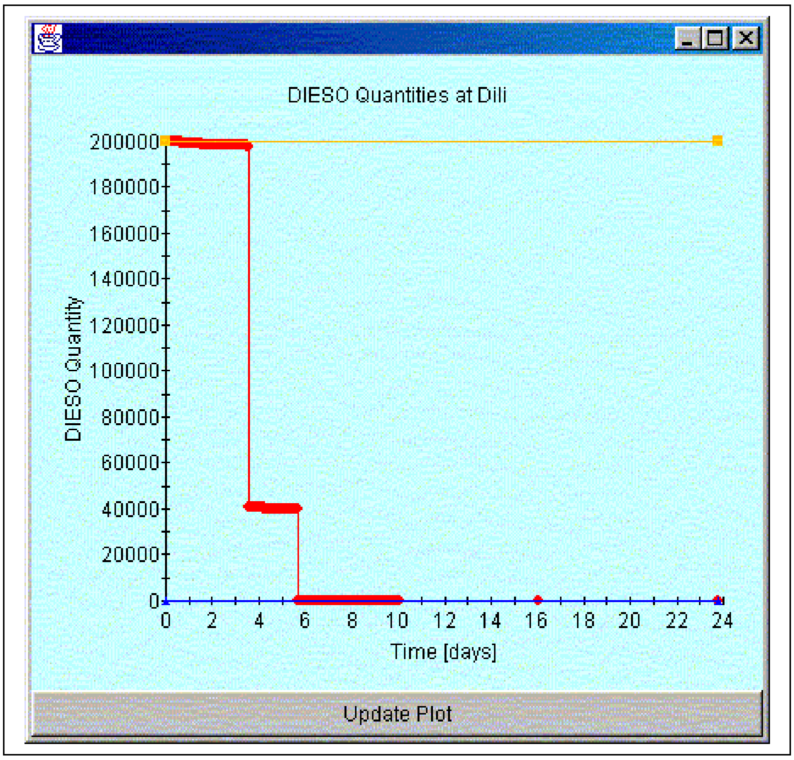

Figure 10: Diesel fuel supply requirements at Dili.

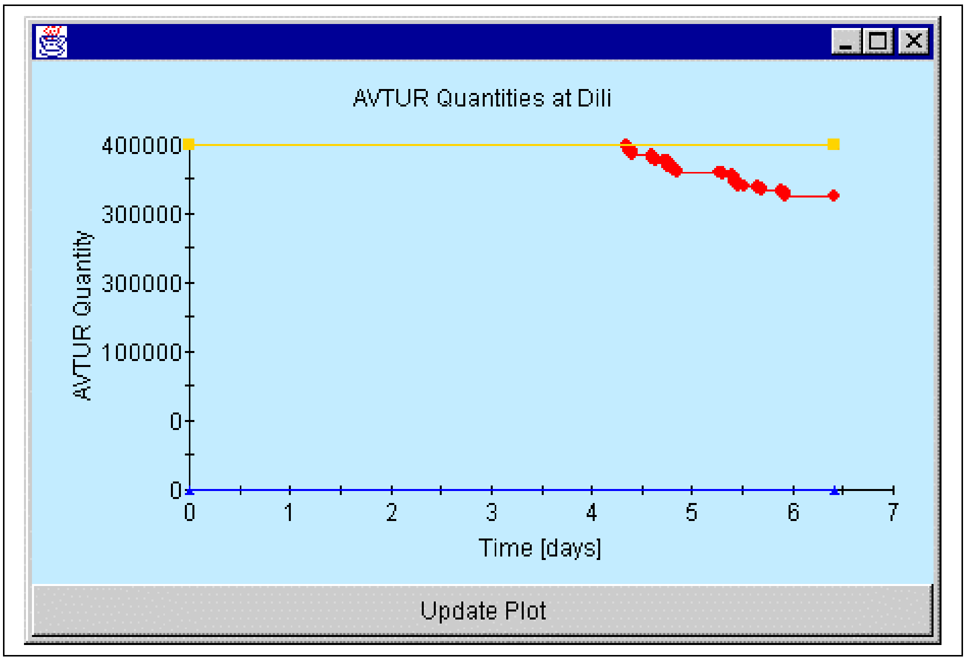

Figure 11: Aviation fuel supply requirements at Dili.

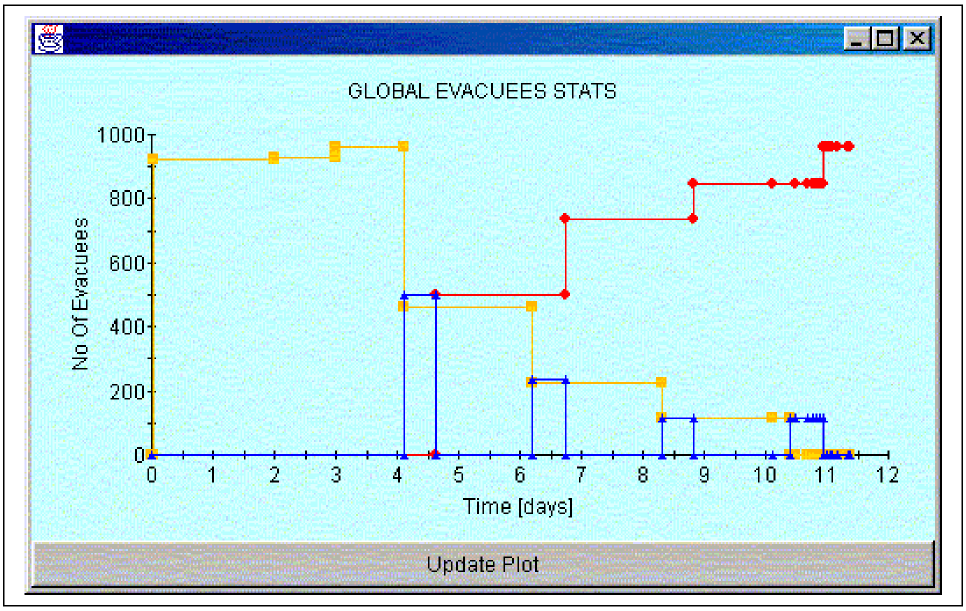

Figure 12: Global Evacuees Data for scenario using evacuation by sea.

ACKNOWLEDGEMENTS

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