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Assessment of Effects Based Operations Using Temporal Logic[*]

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Abstract

This paper presents an application of temporal logic for assessment and analysis of courses of action (COA) in a Timed Influence Net (TIN) model for conducting Effects-Based Operations (EBO). The current practice in courses of action analysis looks at the impacts of actions on the likelihood of the desired effects over a period of time. The impact of time, however, is not studied explicitly. This paper illustrates the use of a point-interval temporal logic (PITL) for evaluating a COA's impact on desired objectives and undesired consequences both in terms of causal influences and timing of actions. The temporal formalism is also shown to run a what-if analysis for a better understanding of the temporal relationships between certain actions that may result in a desired effect at a particular time instant. The analysis, therefore, can be used for *fine-tuning* selected COAs for generating better plans. We return to the analysis of COAs that was reported in the 6th ICCRTS (Wagenhals, et al., 2001) to illustrate the use of this new technology. The hypothetical scenario that involves coalition operations to support Humanitarian Assistance to Indonesia is used for this illustration.

1. Introduction

Timed Influence Nets (TINs) have been used experimentally in the area of Effects-Based Operations (EBO) (Wagenhals and Levis 2002, Wagenhals et al. 2001 & 2003, Wentz and Wagenhals, 2004). They are used as a decision aid for modeling and analyzing uncertainties involved in a complex dynamic situation. Once a Timed Influence Net (TIN) model is constructed, it allows a system modeler to evaluate the performance of different courses of action in terms of their impacts on the likelihood of achieving some desired effect(s). The TIN formalism originates from a general class of probabilistic reasoning framework, known as Bayesian Networks, with the

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distinction that it integrates the notion of uncertainty and time into a single formalism (Wagenhals et al., 1998).

Temporal logic is a term used broadly to include approaches for the representation of temporal information within a logical and/or algebraic framework. A temporal logic can be defined as a language for encoding temporal knowledge about an application system and as a tool for reasoning about temporal relations among the system entities. Many different schemes have been suggested to represent time in the AI literature for both a qualitative and a quantitative treatment of time. A recent paper by Haider et al. (2005) explores the use of point-interval temporal logic PITL (Zaidi and Levis, 2001) for TIN models in analyzing the temporal impact of a certain course of action on variables of interest, i.e., objectives and/or undesired consequences. The inference mechanism of PITL is used to find, at a particular time instant, the source of a change, in terms of the actionable event, in the likelihood of a variable of interest. The PITL inference engine achieves this task by analyzing the relationships that exist between actionable events and the variable of interest. The analysis helps a system modeler in developing a better understating of the temporal relationships that must exist, at a particular time instant, between certain actions required to achieve a desired effect. This knowledge, in turn, can be used to sequence the actionable events on a time line so as to maximize the likelihood of the desired outcome.

This paper provides a brief background on TIN modeling and PITL's approach to temporal knowledge representation and reasoning. The paper then illustrates the use of the proposed temporal analysis of TIN models and the advantages it offers for the problem of planning, executing and assessing Effects-Based Operations (EBO). The potential of the analysis is examined and tested on some of the prototype systems presented earlier at Command and Control Research and Technology Symposia (Wagenhals and Levis 2002, Wagenhals et al. 2003, Wentz and Wagenhals, 2004).

The rest of the paper is organized as follows. Section 2 gives a brief definition of Time Influence Nets (TIN). A temporal language and a graph based representation for modeling it are presented in Section 3. Section 4 describes the temporal analysis of a TIN model that uses approach in Section 3. Section 5 illustrates the use of this new technology by applying it to a hypothetical, but realistic scenario. Section 6 provides conclusions.

2. Timed Influence Net

Timed Influence Nets (TIN) are used to model causal relationships between some desired effects and the set of actions that might impact their occurrence in the form of an acyclic graph. The actionable events in a TIN are drawn as root nodes (nodes without incoming edges). A desired effect, or an objective in which a decision maker is interested, is modeled as a leaf node (node without outgoing edges). Typically, the root nodes are drawn as rectangles while the non-root nodes are drawn as rounded rectangles. Figure 1 shows a partially specified TIN. Nodes B and E represent the actionable events (root nodes) while node C represents the objective node (leaf node). The directed edge with an arrowhead between two nodes shows the parent node promoting the chances of a child node being true, while the roundhead edge shows the parent node inhibiting the chances of a child node being true. The first two elements in the inscription associated with each arc quantify the corresponding strengths of the influence of a parent node's state as being either true or false on its child node. The third element in the inscription depicts the time delay it takes for a parent node to influence a child node. For instance, event B, in Figure 1, influences the occurrence of event A after 5 time units.

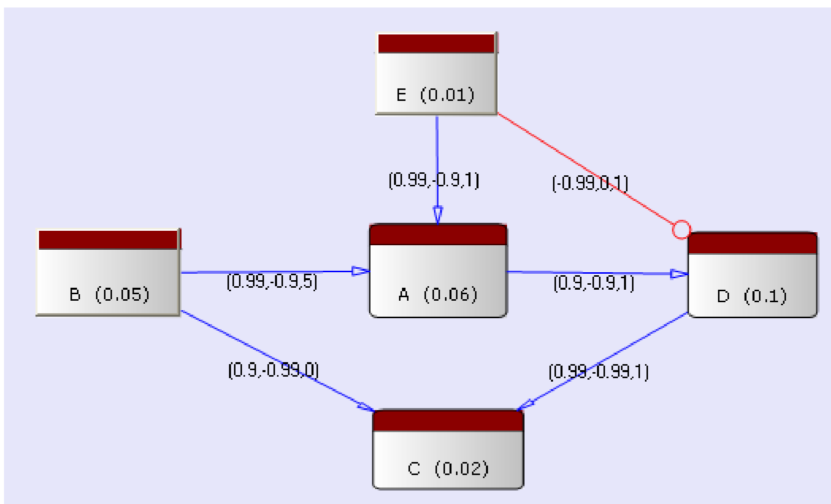


Figure 1. An Example Timed Influence Net (TIN)

The purpose of building a TIN is to evaluate and compare the performance of alternative courses of actions. The impact of a selected course of action on the desired effect is analyzed with the help of a *probability profile*. Consider the TIN shown in Figure 1. Suppose the following *input scenario* is decided: actions B and E are taken at times 1 and 7, respectively. Because of the propagation delay associated with each arc, the influences of these actions impact event C over a period of time. As a result, the probability of C changes at different time instants. A probability profile draws these probabilities against the corresponding time line. The probability profile of event C is shown in Figure 2.

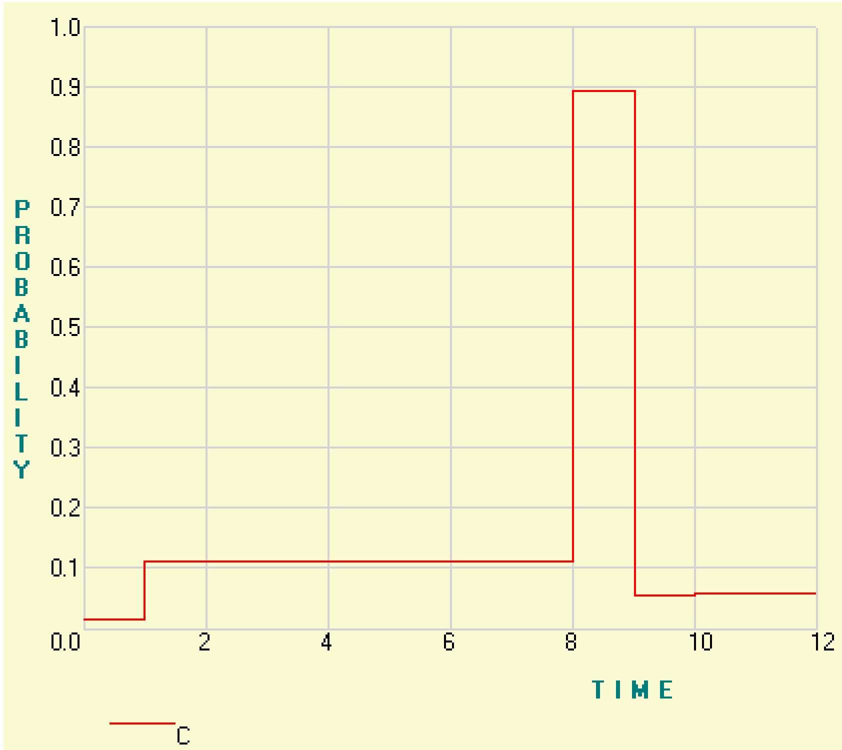


Figure 2. Probability Profile for Node C

The following items characterize a TIN:

1. A set of random variables that makes up the nodes of a TIN. All the variables in the TIN have binary states.
2. A set of directed links that connect pairs of nodes.
3. Each link has associated with it a pair of parameters that shows the causal strength of the link (usually denoted as g and h values). In Figure 1, the two parameters are the first two elements of the tuple associated with each arc as an inscription.
4. Each non-root node has an associated baseline probability, while a prior probability is associated with each root node (node without incoming edges). The baseline and the prior probabilities are shown as node inscriptions in Figure 1 right next to the node labels.
5. Each link has a corresponding delay d (where $d \geq 0$) that represents the communication delay. In Figure 1, the node delays are the third elements on arc inscriptions.
6. Each node has a corresponding delay e (where $e \geq 0$) that represents the information processing delay.
7. A pair (p, t) for each root node, where p is a list of real numbers representing probability values. For each probability value, a corresponding time interval is defined in t. In general, (p, t) is defined as:

$([p_1, p_2, \ldots, p_n], [[t_{11}, t_{12}], [t_{21}, t_{22}], \ldots, [t_{n1}, t_{n2}]])$,

where $t_{i1} < t_{i2}$ and $t_{ij} > 0 \ \forall\ i = 1, 2, \ldots, n$ and $j = 1, 2$

The set of all of the pairs of type defined in item #7, above, is referred to as input scenario, or sometimes (informally) as course of action. Analytically, a TIN can be described as:

A TIN is a tuple $(V, E, C, B, D_E, D_V, A)$ where

V: set of Nodes,

E: set of Edges,

C represents causal strengths: $E \rightarrow \{ (h, g)$ such that $-1 < h, g < 1 \}$,

B represents Baseline / Prior probability: $V \rightarrow [0, 1]$,

D_E represents Delays on Edges: $E \rightarrow Z^+$ (set of positive integers)

D_V represents Delays on Nodes: $V \rightarrow Z^+$ (set of positive integers), and

A: Input scenario. It represents the probabilities associated with the state of actions and the time associated with them.

A: $R \rightarrow \{([p_1, p_2, \ldots, p_n],[[t_{11},t_{12}], [t_{21},t_{22}], \ldots,[t_{n1},t_{n2}]])$, s.t. $p_i \in [0, 1]$, $t_{ij} \rightarrow Z^*$ and $t_{i1} < t_{i2}$, $\forall\ i = 1, 2, \ldots, n$ and $j = 1, 2 \}$

Where Z^* is the set of nonzero positive integers and R ($\subset$ V) represents the set of root nodes (actionable events).

3. Temporal Information and Point Graphs

A graph formalism called Point Graph (PG) is used in (Zaidi and Levis, 2001) to model temporal information. The approach is similar to *Precedence Graphs* with the added provision for quantitative temporal information. A node in a PG represents a time point and a directed arc between two nodes represents the temporal relation *Before* between the two time points. Formally, a Point Graph is defined as follows:

A Point Graph, PG (V, E_A, D, T) is a directed graph with:

V: Set of vertices with each node or vertex $v \in V$ representing a point on the real number line. Two points pX and pY are represented as a composite point [pX;pY] if both are mapped to a single point on the line.

E_A: Union of two sets of edges: $E_A = E \cup E_{\leq}$, where

E (LT edges): Set of edges with each edge $e_{12} \in E$, between two vertices v1 and v2, also denoted as (v1, v2), representing a relation '<' between the two vertices—(v1 < v2);

$E_{\leq}$ (LE edges): Set of edges with each edge $e_{12} \in E_{\leq}$, between two vertices v1 and v2, also denoted as (v1, v2), representing a relation '≤' between the two vertices—(v1 ≤ v2).

D (Length): Edge-length function (possibly partial):

$E \rightarrow Z^+$

T (Stamp): Vertex-stamp function (possibly partial):

$V \rightarrow Z^*$

The following temporal language can be used to describe temporal aspects/requirements of a system either already represented as a PG, or to be input to the PG representation.

The lexicon consists of the following primitive symbols:

Points (Event): A point X is represented as [pX, pX] or simply [pX]. Several labels p1, p2, …, pn, representing a single point are represented as a composite point [p1;p2;…;pn].

Intervals: An interval X is represented as [sX, eX], where ‘sX’ and ‘eX’ are the two end points of the interval, denoting the ‘start’ and ‘end’ of the interval, s.t. sX < eX.

Point Relations: These are the relations that can exist between two points. The set of relations R_P is given as: R_P = {Before, Equals, Procedes}

Functions: Interval length function that assigns a non-zero positive integer to a system interval, e.g.,

Length X = d, where X = [sX, eX], $d \in Z^+$

The stamp function assigns an integer number to a system point, e.g., Stamp p1 = t, $t \in Z$

A temporal statement in this language either takes the form of a function statement, or ‘X Ri Y’ where X and Y are points and $Ri \in R_P$.

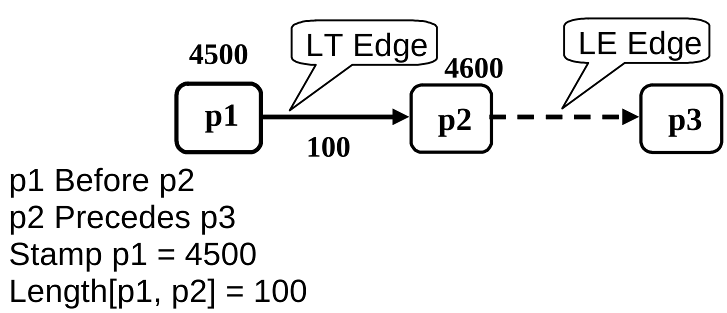


Figure 3. Point Graph and Corresponding Temporal Statements

The temporal relation ‘Before’ corresponds to the ‘<’ edge in the PG definition. Similarly, the relation ‘Precedes’ corresponds to a ‘≤’ edge, and the temporal relation ‘Equals’ results in a composite point (vertex) in the PG representation. The two functions for the quantitative information directly map to the identically named functions in the PG definition. Figure 3 shows the correspondence

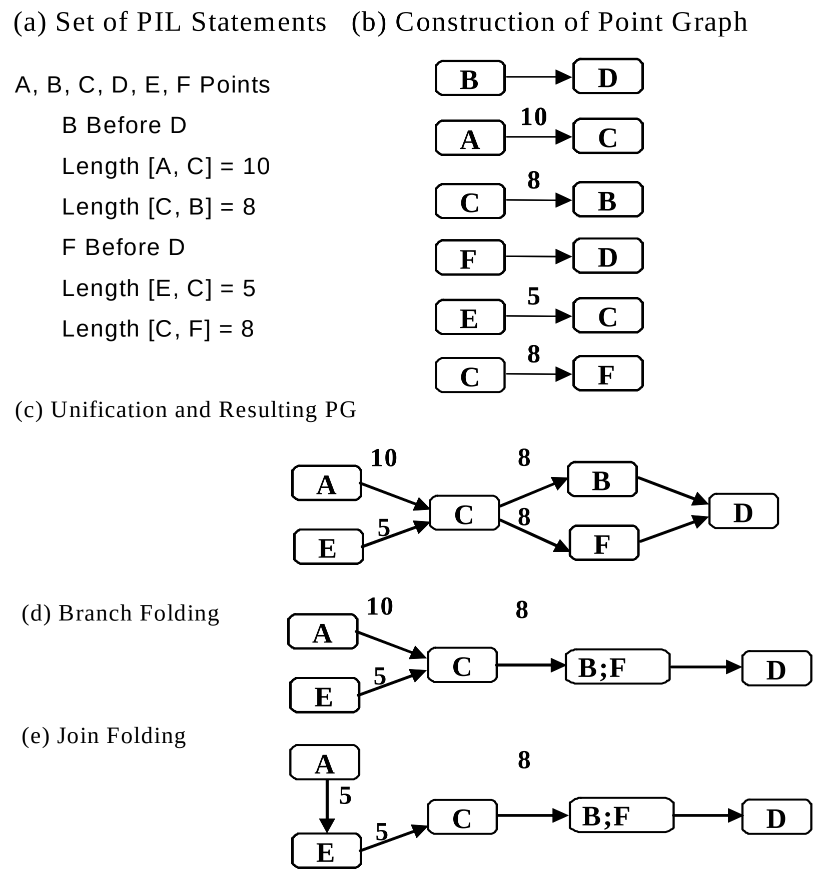


Figure 4. Steps in PG Construction

A set of PITL statements can now be represented as a set of PGs where each PG corresponds to a single statement in the temporal system. A consolidated PG for the entire temporal system can be constructed by *unifying* and *folding* the individual PGs (Zaidi and Wagenhals, 2004). The unification looks at the nodes of a set of PGs and merges the nodes with identical node labels or the ones with equality relation between them. The folding process, on the other hand, looks at the quantitative information on nodes, and edges, of a PG and folds the edges based on the available information. The process establishes new relations among system points, inferred through the quantitative analysis of the known relations specified by interval lengths and stamps. Figure 4 illustrates the process of constructing a PG for a set of PITL statements with the help of an example. An inference algorithm only needs to establish the presence or absence of paths between a pair of points to establish a temporal relation between the two. The lengths on the path help establish the exact, minimum, or maximum distance between two points in a query. For instance, in Figure 4, the processing of the PG results in an edge between points A and E with a length of 5. The relation 'A Before E' with 'Length [A, E] = 5' is, therefore, the inferred temporal information.

A polynomial-time *path-consistency* algorithm is presented in Zaidi and Wagenhals (2004) for deciding the consistency of temporal information in the PG representation.

4. Temporal Analysis of Timed Influence Nets

Haider et al. (2005) present an approach for extracting the temporal information in a TIN and model it using the PG representation. The following is a brief description of the process of constructing a PG from temporal information in a TIN. Once a PG is constructed, the PITL approach is shown to help analyze temporal relationships among system variables in a complex uncertain situation. The results of this analysis can aid a system modeler in gaining a better insight of the impact of a selected course of action on desired effect(s). The PG representation of a corresponding TIN answers queries regarding certain temporal characteristics of an effect's probability profile. The PG also aids a system modeler by explaining what needs to be done for achieving a certain effect at a specific time instant. If the requirements for achieving effects at certain time instants are not temporally consistent, then the PG helps in understanding the reasons for inconsistencies.

4.1. Creating a Point Graph from a Timed Influence Net

The steps involved in generating a PG from a corresponding TIN are presented in Table 1. (Haider et al., 2005) The example TIN in Figure 1 is considered for an illustration of the algorithm. For this example case, R = {B, E}, F = {C}, and the input scenario is given as: 'B occurs at time 1 and E occurs at 7.' The following are the PITL statements that are extracted for the TIN as part of Step 2 of the algorithm.

Length [B1, A1] = 5	Length [A1, D1] = 1
Length [D1, C1] = 1	Length [E3, A3] = 1
Length [A3, D3] = 1	Length [D3, C3] = 1
Length [E4, D4] = 1	Length [D4, C4] = 1
B2 Equals C2	B1 Equals B2
E3 Equals E4	

The following PITL statements model the input scenario:

Stamp B1 = 1	Stamp E3 = 7

The PGs obtained as a result of Steps 2-5, in the algorithm, are shown in Figure 5.

Table 1. PG Construction from a TIN

Given a TIN

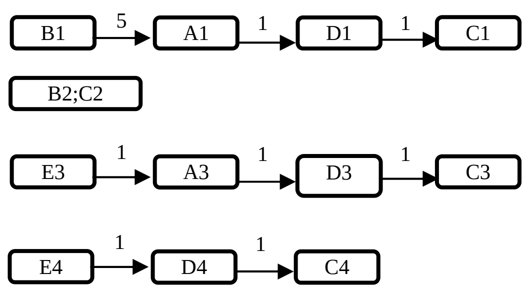
R: Set of Root Nodes (Actionable Events; nodes without incoming edges.)

F: Set of Leaf Nodes (Desired Effects; nodes without outgoing edges.)

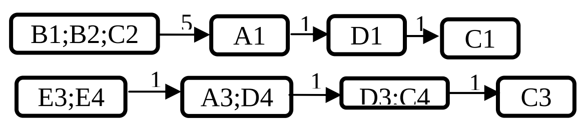
1. For each $r \in R$ find all the paths leading to an $f \in F$. Apply this step to all $f \in F$.
2. Add a unique subscript to each node label in an individual path obtained in Step 1.
3. Represent each path as a PG where a node in the path becomes a vertex and a delay d (d >0) on an arc between two vertices v1, v2 becomes Length [v1,v2] = d in the PG.
4. For each set of vertices in PG that represent a root node in TIN, add a temporal equality relation 'Equal' among its elements.

The following step is executed once an input scenario is provided:

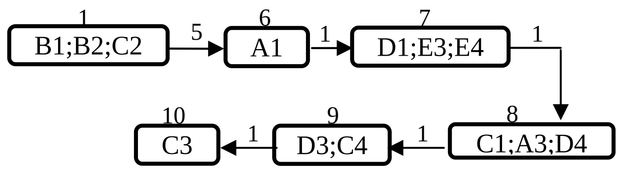
5. Based on the input scenario, assign time stamps to vertices representing root nodes.
6. Construct aggregate PG using temporal statements provided in Steps 3-5 after applying the unification and folding operations.



(a) PGs Corresponding to Paths in the TIN



(b) Folded PGs



(c) Final Folded and Unified PG with Input Scenario

Figure 5. Steps in Constructing the PG Representation for the TIN in Figure 1

4.2 Temporal Queries

Once a PG is obtained from a TIN, it can then be used to explain certain temporal characteristics of a probability profile. Consider the profile shown in Figure 2. Suppose a system modeler is interested in knowing what causes a change in the probability of event C at time 8. The algorithm that answers this and similar queries is presented in Table 2. Figure 6 shows the temporal query interface of *Pythia*[*]. The figure shows the query and the response obtained by the system while performing an inference on the underlying PG representation, shown in Figure 5. The response, as shown in the figure, states that the change in the profile of C at time 8 is because of action B occurring at time 1. Furthermore, if multiple paths exist between an action node and a desired effect, in a TIN, the algorithm of Table 2 can be used to identify the path through which the action has impacted the effect node. For the example under consideration, the path through which B impacted C at time 8 is: B – A – D – C. The Pythia interface is designed to highlight such paths for a visual check on the influences and their impacts on intermediate and end nodes.

Table 2: Answering Temporal Queries using a PG

Given a PG, a TIN, v: variable of interest, t: time of interest, C: list of Causes
1. Initialize C to null.
2. Determine the subscripts of v at time t. Let S = [s1, s2, …, sn] be the list of subscripts.
3. For each element s in S:
(i) Starting from the root of the PG, search the PG until the first variable with the subscript s is identified. Let x be such a variable.
(ii) Let m be the time stamp associated with x.
(ii) Add (x, m) to C.
4. Report the list C.

4.3 What-If Analysis

The PG obtained in Section 4.1 (Figure 5b) can also aid in performing what-if analyses. Suppose after observing the probability profile of Figure 2, the system modeler is interested in knowing what needs to be done, in order to combine the impact that reach C at time 8 with the impact that reach at time 9. Such a requirement may arise from a desire to cancel out the rise in probability at time 8 with the fall in probability at time 9, thus avoiding a potential window of high likelihood of the effect C in the interval from times 8 thru 9. The algorithm that accomplishes this task is presented in

[*] Pythia is a software application developed at the System Architectures Lab for constructing TIN models for planning and assessment of Effects-Based Operations. It is an advanced version of an earlier tool called CAESAR II/EB.

Table 3. Figure 7 shows the user interface for processing the What-If condition. The figure also shows the result obtained by the system with the help of PG in Figure 8. Since the length between points representing events B and E is 5 time units, to combine the impacts that affect node C at times 8 and 9, B must be executed 5 time units before E. This is, therefore, a necessary condition for the effect to materialize; however it might not be sufficient. The result of the analysis can be used to construct an input scenario that can then be tested on the TIN model to check if it really produces the desired effect. For the example under consideration, a possible input scenario suggested by the What-if condition can be described as: 'B occurs at time 1 and E occurs at 6.' As PITL statements, the scenario will be: Stamp B1 = 1 and Stamp E3 = 6. The resulting probability profile for node C is shown in Figure 9. The profile shows that the new scenario has successfully purged the high probability window present in the profile of Figure 2. The example illustrates how a system user can use the temporal analysis to acquire a better understanding of the impacts of actionable events on effects and then run a What-if analysis to identify temporal sequencing of these events to get the desired effects.

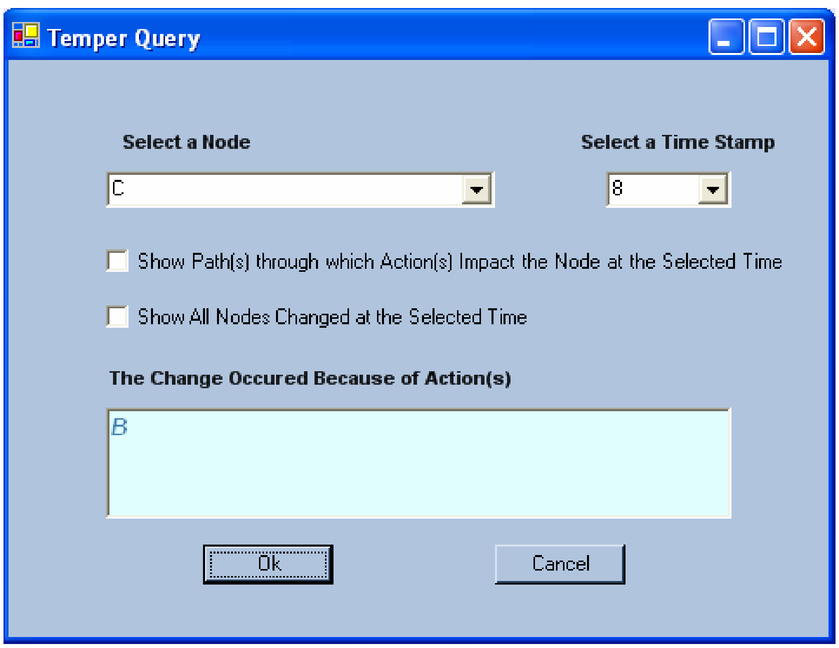


Figure 6. Query Processor Interface

The what-if analysis not only identifies the temporal relationships that should exist between two actionable events for achieving a desired impact at a certain time instant, but it also tells a system modeler if a given set of requirements are temporally inconsistent/infeasible.

Table 3. What-If Analysis Using a PG

Given a TIN, a PG G1

R: Set of Root nodes (Actionable Events) F: Set of Leaf nodes (Desired Effects)

V: List of variables of interest T: List of times of interest

S: List of variables with equal time stamp

1. For each $r \in R$ find all the paths leading to an $f \in F$. Apply this step for all $f \in F$.
2. Add a unique subscript to each node in an individual path obtained in Step 1.
3. Represent each path as a PG where a node in the path becomes a vertex and a delay d (d >0) on an arc between two vertices v1, v2 becomes Length(v1,v2)=d in the PG.
4. For each set of vertices in PG that represent a root node in TIN, add a temporal equality constraint 'Equal' among its elements.
5. For each element v in V,

   (i) Find its subscript at the corresponding time t ($t \in T$) in G1. Let s be the subscript.

   (ii) Add variable v with subscript s to S.
6. Add temporal equality relation 'Equals' among the elements of list S.
7. Construct aggregate PG G2 using temporal statements provided in Steps 3-6.

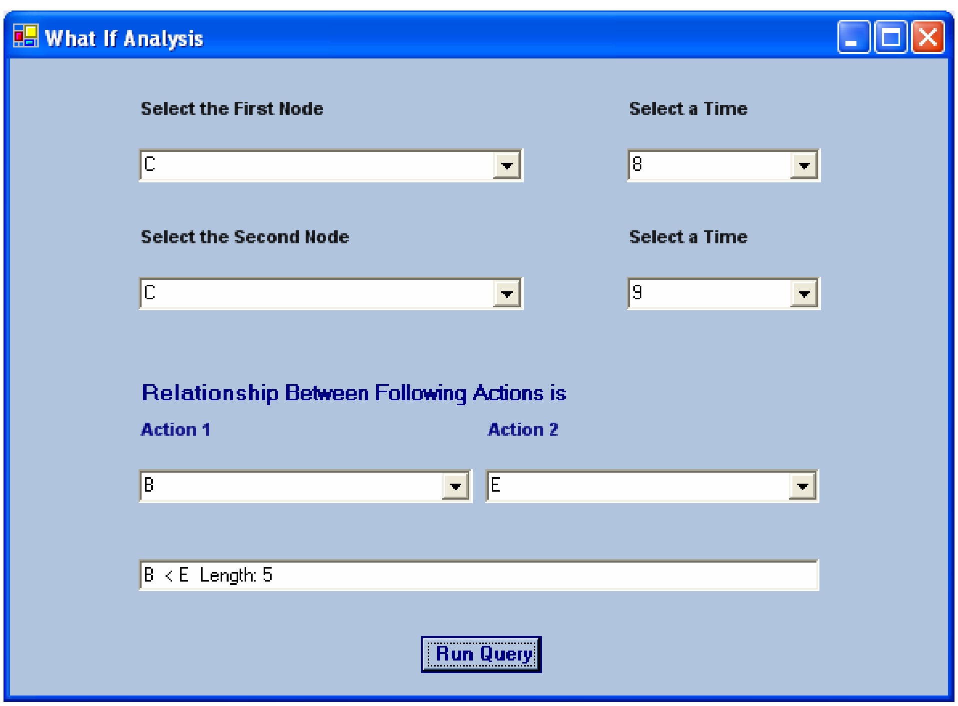


Figure 7. Illustration of What-If Analysis

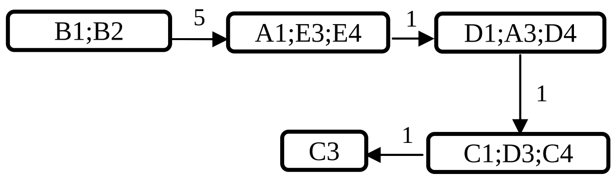


Figure 8. PG Used for What-If Analysis

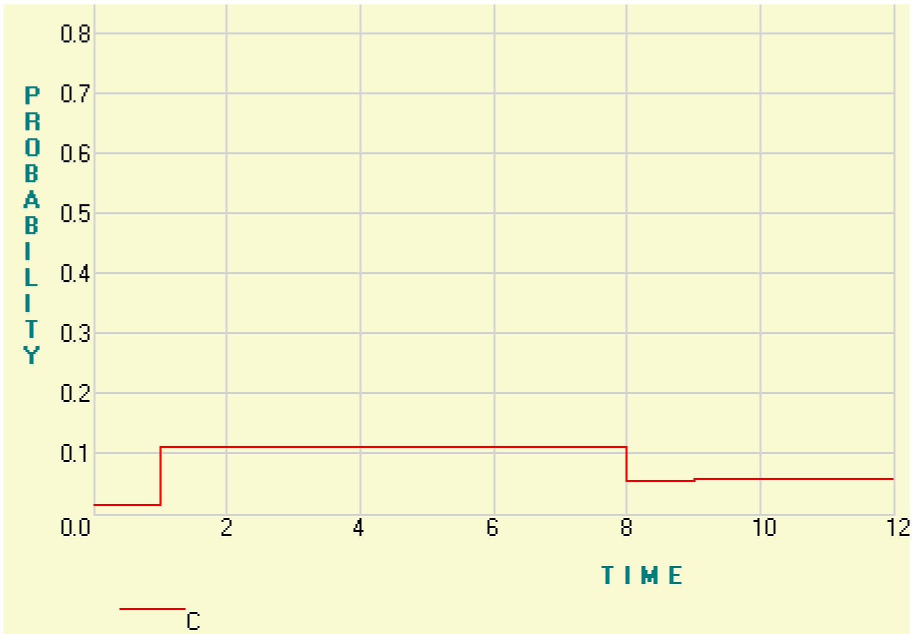


Figure 9. Probability Profile for New Scenario

5. Application

A scenario that was plausible but fictitious was developed for the purpose of demonstrating the potential use of the TIN and PITL combined capabilities for COA analysis. The scenario is the same one that was presented in the 6th ICCRTS (Wagenhals, et al., 2001). In the scenario, internal political instabilities in Indonesia have deteriorated and ethnic tensions between the multiple groups that comprise Indonesia have increased. Religion has been a major factor in these conflicts. Members of one of the minority (2%) religious groups have banded together to combat disenfranchisement.

These members have formed a rebel militia group. Armed conflict recently occurred between these rebels and the Indonesian military. The rebels fled to eastern Java where they have secured an enclave of land. This has resulted in a large number of Indonesian citizens (estimates of about 10,000) who are within the rebel-secured territory. Many of these people are unsympathetic to the rebels and are considered to be at risk. It is feared that they may be used as hostages if ongoing negotiations break down with the Indonesian government. The food and water supply and sanitation facilities are very limited within the rebel-secured territory.

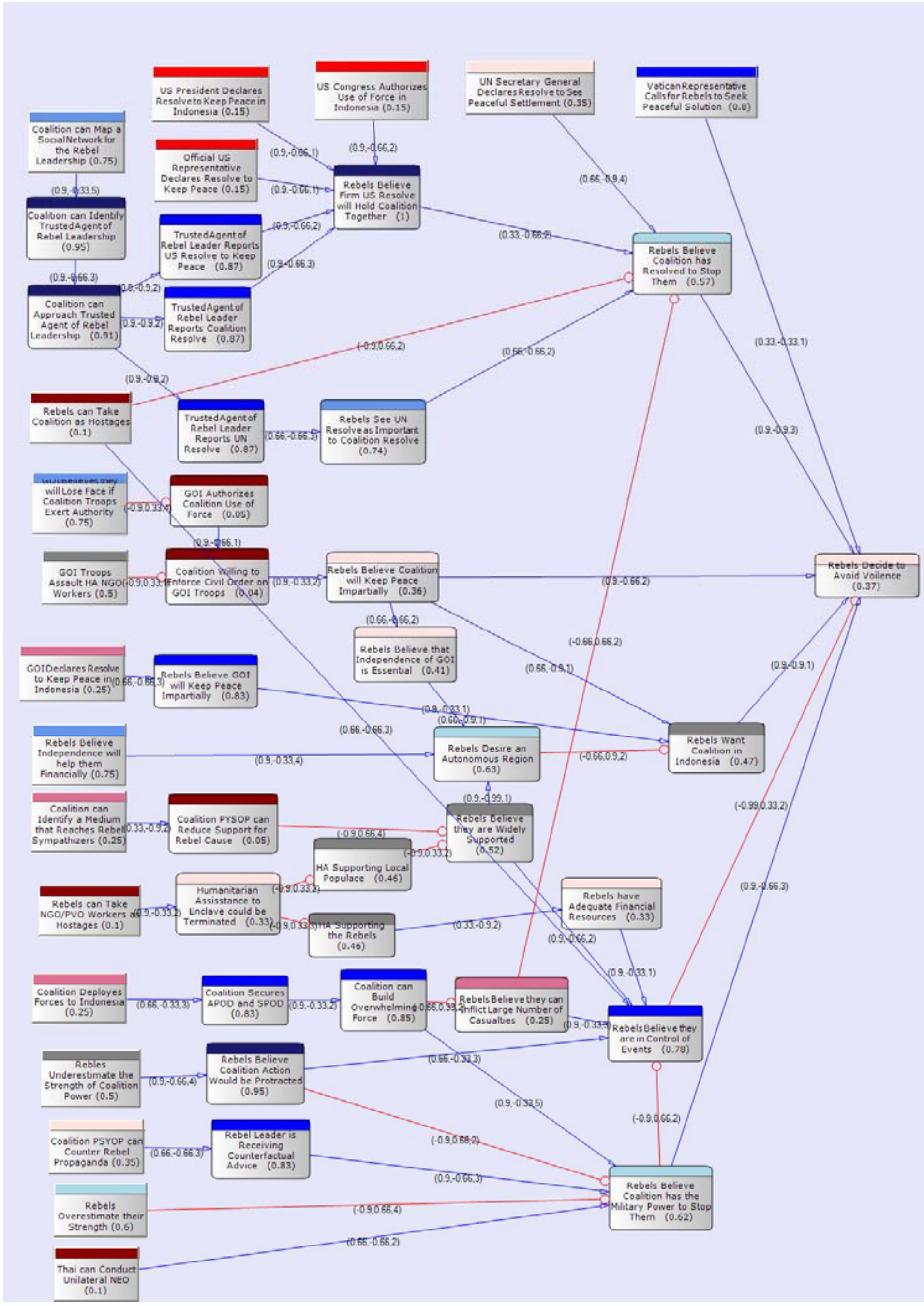


Figure 10. Timed Influence Net of East Timor Situation

Several humanitarian assistance (HA) organizations are on the island, having been involved with food distribution and the delivery of public health services to the urban poor for several years. So far, the rebels have not prevented HA personnel from entering the territory to take supplies to the citizens. The U.S. and Australian embassies in Jakarta are closely monitoring the situation for any indications of increasing rebel activity. In addition, Thailand, which has sent several hundred citizens to staff numerous capital investment projects on Java, is known to be closely monitoring the situation.

A TIN has been created that reflects the situation and can be used to analyze potential COAs (see Figure 10).

The TIN models the causal and influencing relationships from actionable events (on the left side and along the top of the model in Figure 10) and the overall effect of concern which is the single node with no parents on the right-hand side of the model. In this case, the effect is “Rebels decide to avoid violence”.

The actionable events in this model include a combination of potential coalition, UN, and rebel actions. The coalition actions include actions by the US government, its military instrument of national power, actions by the Government of Indonesia, and actions by Thailand.

For purposes of illustration, we have created a proposed course of action that contains potential actions by the coalition, UN, and the Rebels along with the timing of those actions. The TIN model was executed with that COA (COA #1) and the probability profile for the overall effect was generated as shown in Figure 11.

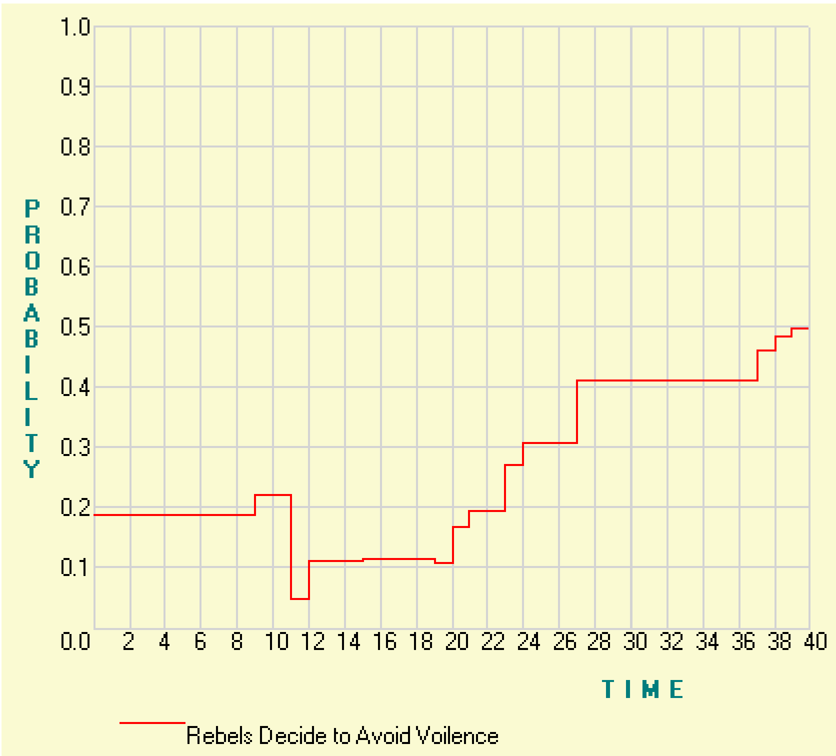


Figure 11. Probability Profile for Initial COA (COA #1)

It is noted that initially it is unlikely that the rebels will decide to avoid violence. In fact the projection is that matters will get worse before they start to improve. Of particular concern is the drop in the probability profile at time 11 with a rise at time 12. The goal is to see if changing the COA can eliminate the "dip" shown between time 11 and 12. The question is what are the actions that are causing the changes in the probability profile and can the timing of those actions be changed to positively affect the probability profile.

To do this analysis the TIN is converted to a point graph and the temporal query function is used to address the cause for the decrease in the probability profile at time 11 and the increase at time 12. The two Pythia generated temporal query windows are shown in Figure 12.

The algorithm, presented in Section 4.2, shows that there are two actions that cause the downward change in the probability profile at time 11 ("Government of Indonesia Troops Assault Humanitarian Assistance Workers" and "Rebels take Hostages") and one action ("UN Secretary General Declares Resolve to See Peaceful Resolution") that causes the increase at time 12.

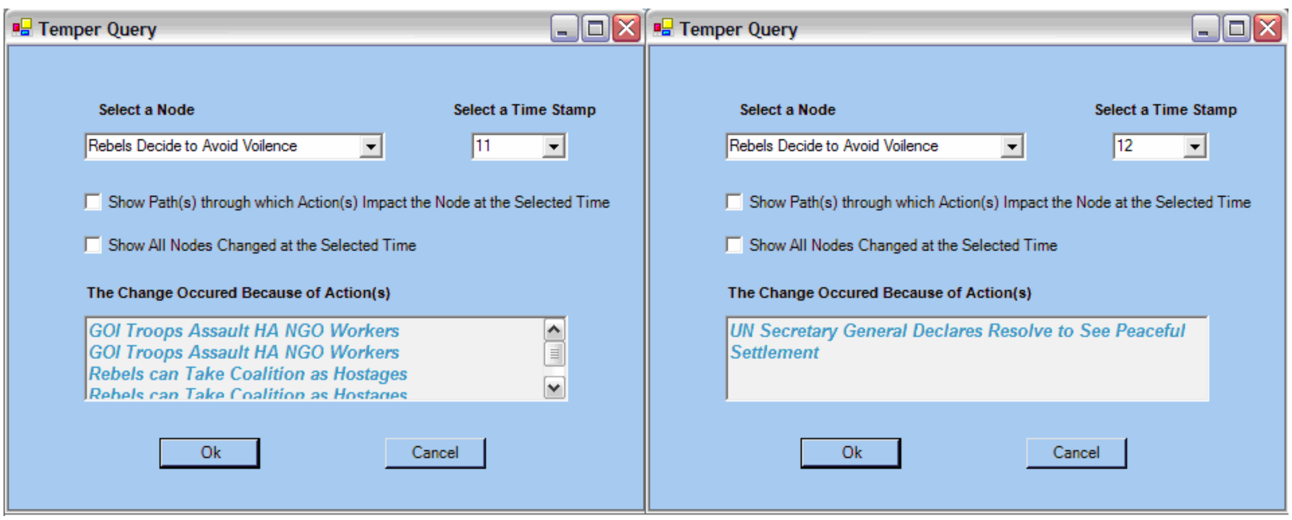


Figure 12. Temporal Queries on Actions that Cause the Change in the Probability Profile

It is believed that Rebels may take the Hostages at time 6, so a "What if" temporal query is made to see if asking the UN Secretary General to make his declaration at a different time can positively impact the assessment. The query is shown in Figure 13. In this query, we are looking at the same effect node (Rebels decide to avoid violence) at two different times (11 and 12) and seeing what the temporal relationship needs to be between the two actions under consideration to cause the changes at times 11 and 12 to occur at the same time. The assumption is that by making them occur at the same time, the positive change will counter the negative change. The result of the query says that the UN Secretary's action must occur at least two time units before the Rebel action. Since intelligence believes that the Rebel action might occur at time 6, the COA is changed to have the

UN Secretary make his declaration at time 4. The new COA is termed COA #2. A new probability profile is generated and compared to the original probability profile as shown in Figure 14.

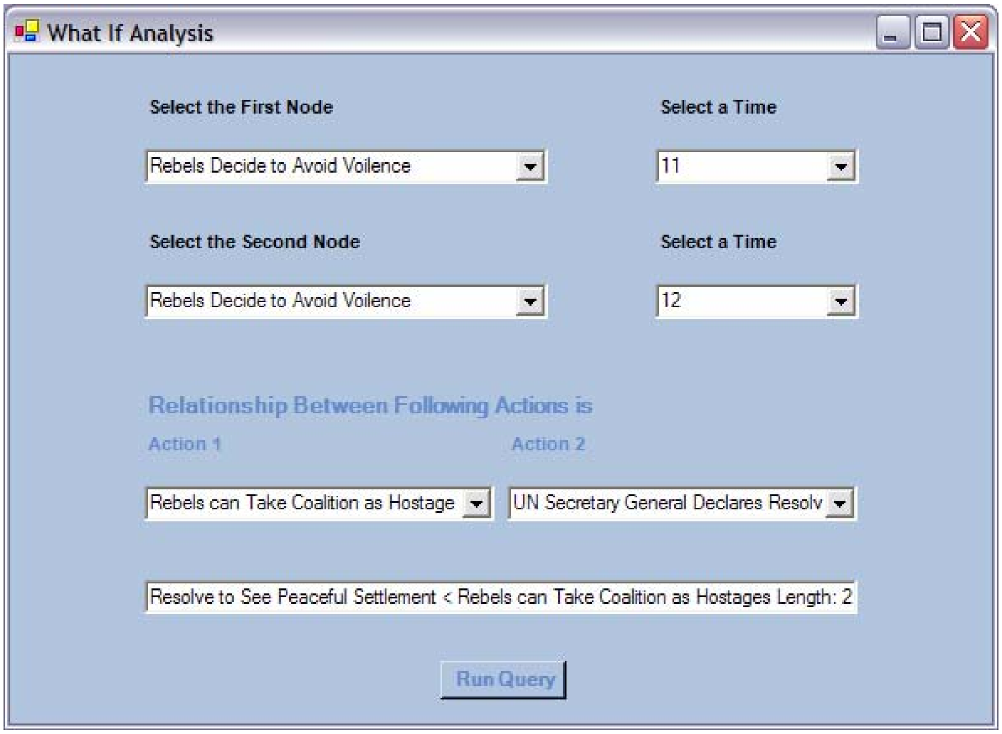


Figure 13. What if Analysis Query

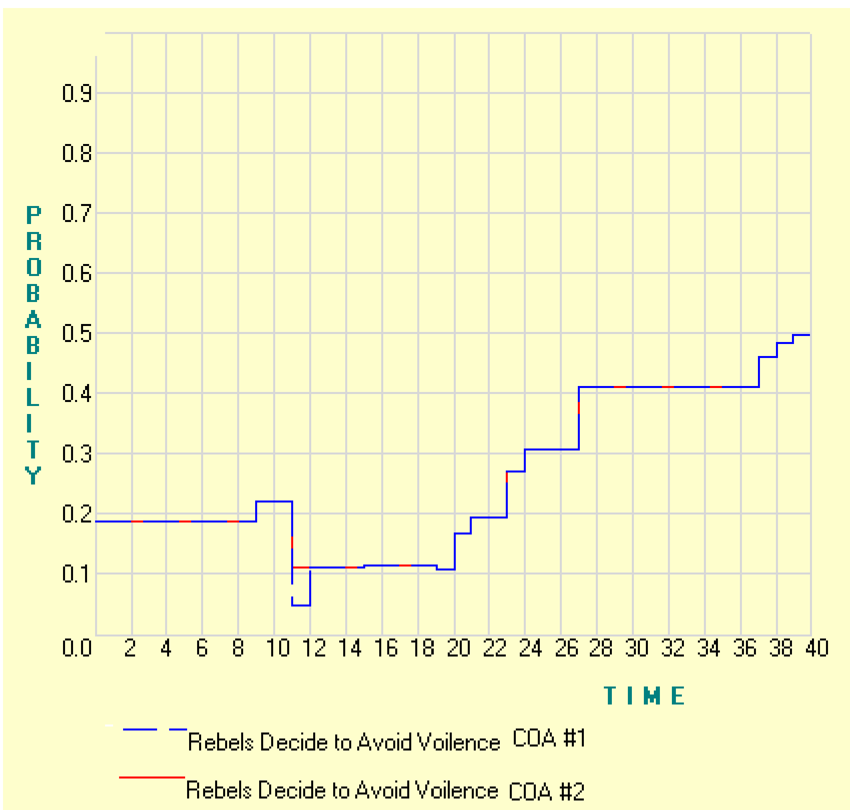


Figure 14. Probability Profile Comparison Based on Change in UN Secretary's Action

The comparison of the profiles shows that the proposed action eliminates the "dip" in the probability profile between time 11 and 12.

We also note that the Government of Indonesia (GOI) assault actions also have a negative impact on the probability from the first temporal query of Figure 12. The TIN analysis shows that eliminating this action results in a further improvement in the probability profile as shown in Figure 15. The new scenario is shown as COA #3.

This analysis could provide the rationale to persuade both the UN and the GOI to modify their plans.

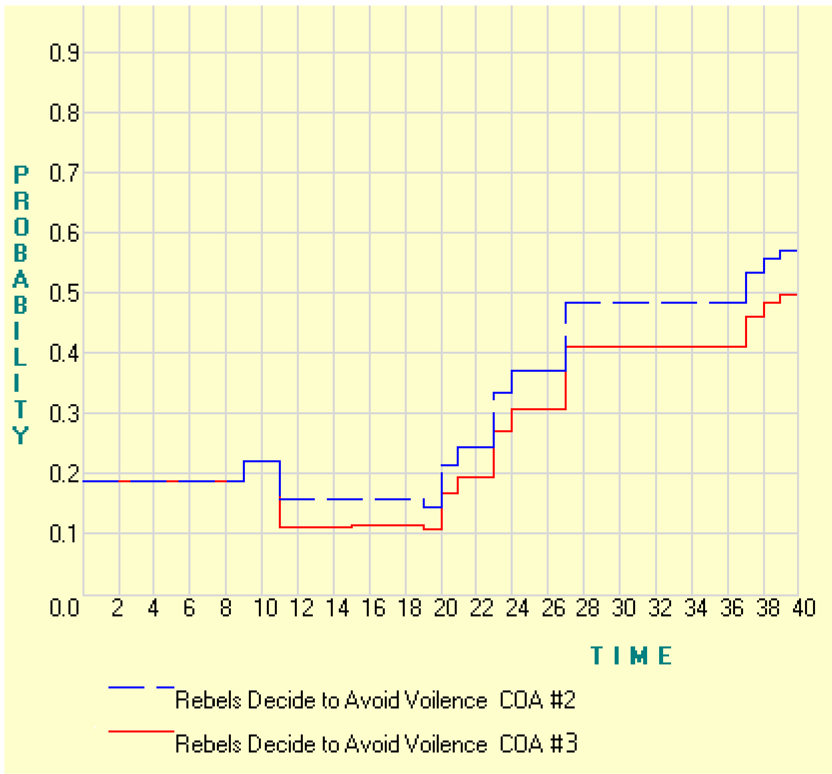


Figure 15. Improvement in Probability Profile if GOI Does Not Assault

6. Conclusions

Previous experience with building effects based TIN models has shown that the analysis of the COAs was very time consuming and difficult. This was in part because there was no easy way to determine which actions were causing changes in the probability profile or any way to determine the temporal relationships between actions and the changes in the probability profiles other than by trial and error. By combining the rigor of the point-interval temporal logic with the TIN representation, it has been shown that it is possible to provide this capability to the COA analyst. Of course, the new capability still requires the analyst to determine which queries to make and requires the analyst to determine how the COA might be adjusted based on those queries. In the future it may be possible to provide a more automated algorithm that makes use of the PITL capability and the features of the probability profile to assist the analyst in adjusting the COAs to improve the projections on achieving effects. This is a topic of on-going research.

References

Haider, S., Zaidi, A. K., and Levis, A. H. 2005. On Temporal Analysis of Timed Influence Nets using Point Graphs, *In proceedings of The 18th International FLAIRS Conference*, FL. (In Press.)

Wagenhals, L. M., Shin, I., and Levis, A. H. 1998. Creating Executable Models of Influence Nets with Colored Petri Nets. *Int. J. STTT*, No. 2, 168-181.

Wagenhals, L. W., T. J. Reid, R. J. Smillie, & A. H. Levis 2001. Course of Action Analysis for Coalition Operations. Proc. 6th International Command and Control Research and Technology Symposium, Annapolis, MD.

Wagenhals, L. W. and Levis, A. H. 2002. Modeling Support of Effect-Based Operations in War Games. *In Proceedings of the Command and Control Research and Technology Symposium*, Monterey, CA.

Wagenhals, L. W., Levis, A. H., and McCrabb, M. B. 2003. Effects-Based Operations: A Historical Perspective of a Way Ahead. *In Proceedings of the Eighth International Command and Control Research and Technology Symposium*, Washington DC.

Wentz, L. K. and Wagenhals, L. W. 2004. Effects Based Operations for Transnational Terrorist Organizations: Assessing Alternative Courses of Action to Mitigate Terrorist Threats. *In Proceedings of the Command and Control Research and Technology Symposium,* San Diego, CA.

Zaidi, A. K. and Levis, A. H. 2001. TEMPER: A Temporal Programmer For Time-Sensitive Control Of Discrete Event Systems. *IEEE Transactions on Systems, Man and Cybernetics, Part A*, 31(6), 485-496.