

# Modelling Risk and Identifying Countermeasure in Organizations

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**Abstract.** Modelling and analysing risk is one of the most critical activity in system engineering. However, in literature approaches like Fault Tree Analysis, Event Tree Analysis, Failure Modes and Criticality Analysis focus on the system-to-be without considering the impact of the associated risks to the organization where the system will operate. The Tropos framework has been proved effective in modelling strategic interests of the stakeholders at organizational level. In this paper, we introduce the extended Tropos goal model to analyse risk at organization level and we illustrate a number of different techniques to help the analyst in identifying and enumerating relevant countermeasures for risk mitigation.

**Keywords:** risk analysis, countermeasure identification, goal modelling.

## 1 Introduction

Software systems are more and more part of our life (look how many computers and electronic gadgets are around us), and very often they have a strong influence in our daily life decisions. Considering software systems as integral and active part of the organization introduces the needs of including the software development as part of the organizational development. In this direction, some software engineering methodologies have been proposed (e.g., Tropos [1] and KAOS [2]) to capture relationships between system-to-be and the organizational setting since the early phases of software development. Traditional techniques for modelling and analysing risk, such as Fault Tree Analysis (FTA) [3], Event Tree Analysis (ETA) [3], Failure Mode Effect and Criticality Analysis (FMECA) [4], are commonly used in Reliability and Safety community. Unfortunately, these techniques are not conceived to model risks at organizational level and they focus mainly on risks at the system level.

In this paper we present a modelling and reasoning framework that considers risk (in more general *uncertain event*) at organizational level. Several models have been proposed in literature to represent the intentions of the stakeholders in an organization, such as Tropos/*i*\* [1,5], KAOS [6], GBRM [7], and ERM-COSO [8]. We propose a framework, called Goal-Risk Model, that extends the

Tropos methodology [9,10] with three basic layers (i.e., goal, event, and treatment). The framework introduces also number of techniques to analyse risk and identify countermeasures. The rest of the paper is organised as follows. Section 2 overviews briefly about Goal-Risk framework introducing the London Ambulance Service (LAS) [11,12] case study, then using this framework we define several categories of countermeasures that can be applied as a part of the solution to protect an organization from its risks. We define the guidelines to choose and model them in Section 3 and draw an example in LAS and Vehicle company case study. Finally, we conclude the paper and outline the future work in Section 4.

## 2 Tropos Goal-Risk Framework

Tropos goal model [9,10] proposes a formal framework to do requirement analysis by refining stakeholders' goals and ending up with the elicitation of the requirements. The framework results in a number of goal models represented as graphs  $\langle \mathcal{G}, \mathcal{R} \rangle$ , where  $\mathcal{G}$  are goals and  $\mathcal{R}$  are relations (decomposition or contribution relations). In Tropos, a goal is defined as a strategic interest of a stakeholder that intended to be achieved [1].

Each goal has two attributes SAT-  $Sat(G)$  and DEN-  $Den(G)$ , which quantify the value of evidence for the goal being satisfied and denied, respectively<sup>1</sup>. The values of the attributes are qualitatively divided in the range of *(F)ull*, *(P)artial*, *(N)one*. These attributes can infer the probability of the goal to be satisfied and denied.

Goal analysis in Tropos starts with a number of top goals (i.e., ellipse in Fig. 1) of stakeholders and each of them is refined by decomposition (AND or OR) into subgoals. For example, consider in modelling the strategic objectives of London Ambulance Service (LAS) where an ambulance needs to reach the location of Accident and Emergency (A&E) in time (Fig. 1). The goal reach the location A&E in time can be achieved by distributing ambulance over the area or dispatching the closest ambulance from the A&E location to handle the accident. Moreover, distributing ambulance over area can be achieved either by organizing the movement of ambulance s.t. cover all the area or by building many ambulance pools all over the area. This decomposition and refinements will continue until the goals are considered tangible goals, i.e., when there is an actor that can fulfil the goal.

Moreover, Tropos goal analysis allows the analyst to model the influence of the satisfaction (denial) of a goal to the satisfaction (denial) of other goals. This influence can be positive or negative and is graphically indicated by “+/-” contribution relations. Tropos also has “++” and “--” to express *strong positive contribution* and *strong negative contribution*, respectively. For example, the goal, applying dispatch to the closest ambulance from the A&E location to reach

<sup>1</sup> There is no relation between SAT and DEN, unlike Probability Theory  $P'(x) = 1 - P(x)$ .

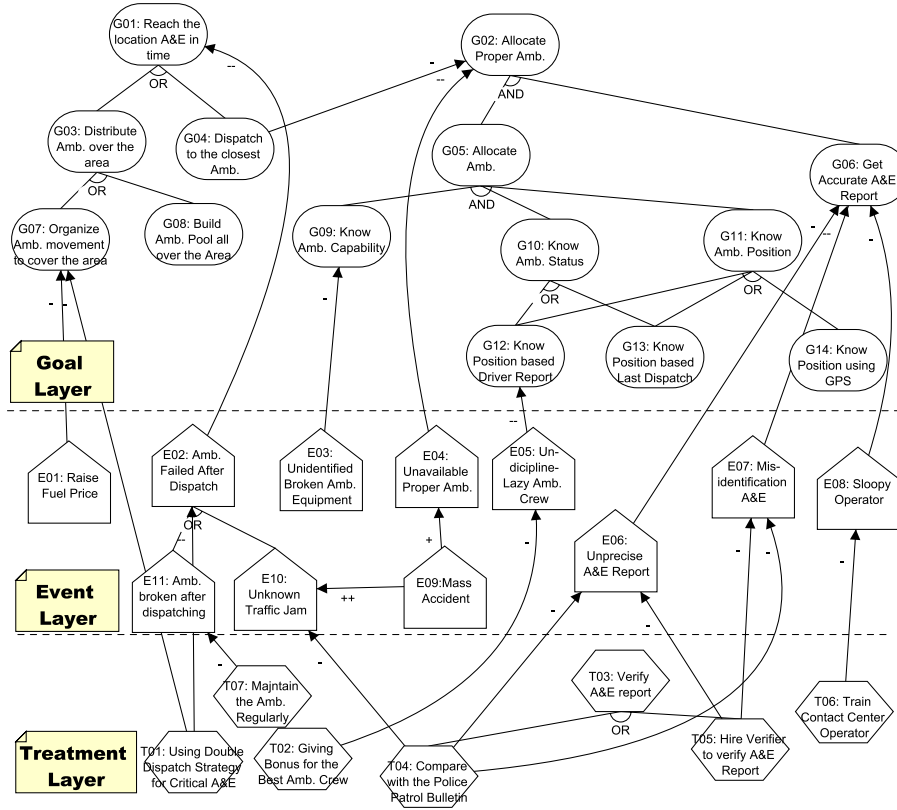


Fig. 1. London Ambulance Services (LAS) Case Study

the location in time, can result the assigned ambulance is not the most appropriate one, indeed the closest ambulance could be not equipped to handle that particular accident (i.e., dispatch to the closest ambulance from the A&E location gives “-” contribution to the achievement of goal allocate the proper ambulance).

We extend the Tropos goal model [9,10] introducing two new entities: event<sup>2</sup> (e.g., risk, opportunity) and treatment (e.g., tasks, countermeasure, and mitigations). This allows for modelling uncertain events, mainly risks, that can influence the fulfilment of one or more goals, and treatments that are needed to manage the effect of risks. Each entity has a separate layer of analysis as shown in Fig. 1: Goal layer, Event layer, and Treatment layer.

The analysis starts identifying a relevant event or an uncertain circumstance, depicted as pentagon in Fig. 1 that can influence the goal fulfilment in the goal layer. Top events are decomposed and related one to another with contribution

<sup>2</sup> A *risk* is defined as an uncertain event with negative impact and an *opportunity* with positive impact.

relations. A top-event is identified applying the approaches proposed in literature, such as obstacle analysis in KAOS [13], taxonomy-base risk identification [14], or Risk in Finance [15]. We represent *likelihood* as the level of evidence that supports or prevents the occurrence of an event (SAT or DEN), and the level of influence or *impact* of an event is encoded as the type of contribution relation between events and goals.

An event can influence more than one goal and one event can be considered as a risk for certain goals and, at the same time, as an opportunity for other goals. For instance, in LAS of Fig. 1 the risk of *failure in contact centre computer system* is a risk that obstructs the achievement of the goal *allocate ambulance properly* because LAS can not know the status of current ambulance. However, the event can also be seen as an opportunity for the goal *having reliable manual standard operating procedure (SOP) for A&E*, because it can give the opportunity to exercise the manual SOP. Events refinement continues until leaf-events are assessable (i.e., we can assess the likelihood of leaf-event) and the analyst ensures that each leaf-event is mutually exclusive. When a risk obstructs a goal, the denial evidence-DEN of being fulfilled is added.

Once the events have been analysed, the analyst identifies and analyses the countermeasures (denoted as hexagon in Fig. 1) to be adopted in order to mitigate the risks. We categorise a countermeasures into five categories: avoidance, prevention, alleviation, detection, and retention (the guidelines for choosing among the categories are presented in the next section). A countermeasure can be realised in two different ways: reducing the *likelihood* or reducing the *impact* [16]. In this work, we concentrate on modelling a countermeasure that reduces the likelihood of risk. Similarly for goals and events, we use SAT and DEN to represent the evidence that supports and prevents a treatment/countermeasure to be successfully executed, called success-rate. A countermeasure effects the event layer, and in particular risks. We represent the *effect* of a countermeasure as a relation, where its strength is expressed by the type of contribution relations. For instance in Fig. 1, the countermeasure *maintaining ambulances regularly* reduces the risk of *having ambulance is broken after receiving A&E dispatch*, which is denoted by “-” contribution. A countermeasure mitigates a risk by adding (propagating) evidence for the risk denial-DEN.

In our model, we also allow for relations between the treatment layer and the goal layer. This is useful to model situations where a countermeasure adopted to mitigate a risk has also a contribution (especially negative effects) to some goals. For instance in Fig. 1, the countermeasure *double-dispatch ambulances for critical A&E* can reduce the likelihood of the risk of *ambulance failed to reach location after dispatch* because there are 2 ambulances that dispatch to handle a critical A&E. This countermeasure leads to the difficulties in achieving the goal *organizing the movement of ambulance s.t. cover all the area*, because the countermeasure needs a greater number of ambulances than in the case of normal strategy.

The idea of model separation into 3 layers makes a flexibility in interchanging the model language in each layer, as far as the model still has the same intuition

(e.g., model for goal layer is to represent the structure of the needs of the stakeholders). This flexibility helps the modeller that has already had prior experience in a particular modelling framework to reduce the learning cost. For instance, reliable engineers have been familiar with FTA [3] s.t. they can use FTA in event layer, or enterprise risk analysts are well train to build COSO-Objective model [8], then they can use that model instead of Tropos goal model. However, a semantic re-definition of relations between layers is needed to be done to adopt those modelling frameworks.

When the model has been fully developed, we start analysing the model and eliciting the most reasonable solution to fulfil the stakeholders' goals and satisfy certain preference (e.g., minimizing the total cost). A solution consists of the leaf-goals that need to be fulfilled, the treatments which need to be employed to manage the risks, and the total cost (leaf goals and treatments). The steps of analysis are the following:

**Find alternative solutions**, Stakeholders define their targets in terms of assignment of SAT values to top-goals. Backward reasoning, as presented in [10], is used to search all the possible SAT/DEN values assignments for leaf-goals that satisfy the stakeholder's targets. These assignments are called alternative solutions.

**Evaluate alternative solutions against relevant risks**, Stakeholders define the acceptable level of risk, in terms of assignment of DEN values to top-goals. Forward reasoning, as presented on [9], is used to propagate the SAT/DEN values of risk on the goal layer. If the level of risk of top-goals are below the acceptable level of risk (namely, if they produce DEN values for top-goals less than the DEN values specified by the stakeholders) then the alternative solution is considered as a candidate solution. Conversely, if the DENs of top-goals are higher than the acceptable level of risk, then we move to the next step.

**Assess countermeasures to mitigate risks**, Combinations of countermeasures are identified to reduce the effects of risk of an alternative solution such that it becomes acceptable for the stakeholders. The alternative solution and the combination of countermeasure are considered as a candidate solution.

After identified "all" the candidate solutions, we evaluate them adopting the "minimal cost" criteria as a preference. The candidate solution with the cheapest cost, in terms of total cost of the leaf-goals and the necessary countermeasures, is the selected solution to be implemented. The complete framework of Tropos Goal-Risk (i.e., semantic definitions, reasoning mechanisms, analysis guidelines) has been defined in [17].

### 3 Countermeasure Identification

As mention before, in this paper we also provide the guidelines to identify countermeasures, in particular countermeasures that reduce the likelihood of risk. There are two ways to manage a risk: one can choose alternative goals with free of risk (avoidance) or trying to anticipate the risk with the countermeasures.

We categorise treatments into 5 categories of measure that can be used to manage the risk: *avoidance*<sup>3</sup>, *prevention*, *alleviation*, *detection*, and *retention*. The order of the categories can also be seen as the steps in eliciting the treatments. First, the analysts try to find the way to *avoid* the risks; if it is not possible then they should try to *prevent* the occurrence of the risks. If the prevention measures are not adequate, then they try to identify the *alleviation* measures. If it is still not adequate, then they have to identify the *detection* measures. Otherwise, the organization should be prepared to *retain* the risk.

In the next sub-section section, we detail the measures by specifying the goal-risk model characteristics that can lead the analyst in choosing the proper category of measure and what are the consequences (advantages and drawbacks) of each category. In the model, goals, events and treatments are characterised as follows:

- Goal (i.e., leaf goal in goal layer): the importance of a goal from the stakeholder point of view and its fulfilment type (i.e., achieve goal, maintain goal, and achieve-maintain goal [18]);
- Event (i.e., top event in event layer): the impacts and the likelihood of the event, the structure of event tree in event layer, and the type of risk (e.g., avoidable, preventable, reducible);
- Treatment (i.e., leaf treatment in treatment layer), the success rate in mitigating the risk, the cost of the treatment, and the probability of cost.

### 3.1 Avoidance

It defines as an activity that tries to achieve the stakeholders' goals by choosing a risk free alternative.

*Characteristics of the model.* The goal fulfilment results being very important for the stakeholder, and most of the time the goal is categorised as a maintain goal or an achieve-maintain goal (i.e., the goal that needs to be fulfilled from certain time until the future). Thus, the analyst has to ensure its fulfilment during the time. For example in Fig. 2, the stakeholder can fulfil the goal knowing ambulance position ( $G_{11}$ ) by means of choosing knowing ambulance position from driver's report ( $G_{12}$ ) or knowing from Global Positioning System (GPS) ( $G_{14}$ ). In this scenario, the modeller chooses  $G_{14}$  instead of  $G_{12}$  because  $G_{11}$  needs to be fulfilled all over the time. However, this category of measure can not always being elicited, while there could exist a circumstance where there are no alternatives to fulfil the goal with risk-free.

*Consequences.* There is no need to introduce any treatment and/or additional cost to use countermeasures. The only possible drawback of this category is that the risk-free alternative could be more costly than the total cost for the risky alternative and relative countermeasures. For instance, the cost of  $G_{14}$  is much higher than the cost  $G_{12}$  and its treatment (e.g.,  $T_2$ ).

<sup>3</sup> Some works do not consider avoidance as a countermeasure.

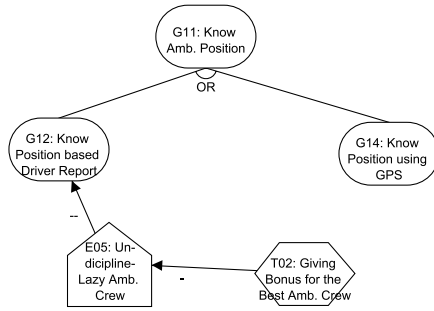


Fig. 2. Avoidance Means

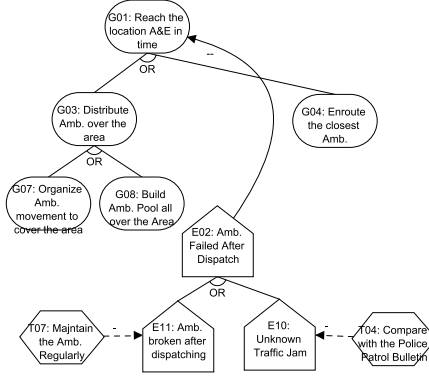


Fig. 3. Prevention Means

### 3.2 Prevention

This category aims at preventing the risk occurrence by employing certain measures. Preventing risk means reducing the risk until an acceptable value for the fulfilment of stakeholders' goals. This measure operates mitigating leaf-events.

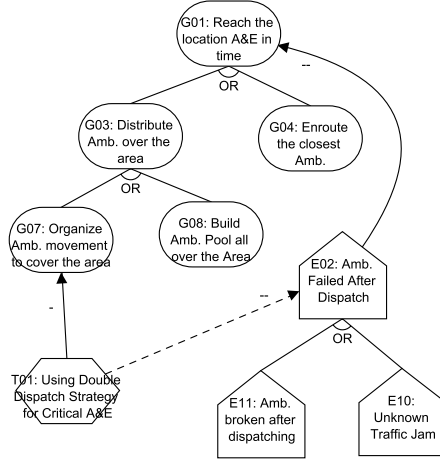
*Characteristics of the model.* The risk obstructs significantly the stakeholders' goals and it results unavoidable. This category of measure is carried on by reducing the likelihood of related leaf-events s.t. the likelihood of the top-event is also reduced. To identify the related leaf-events, we use the same technique that commonly used in defining minimal cut-set in FTA [3]. For instance in Fig. 3,  $T_7$  and  $T_4$  try to prevent  $E_2$  occurrence by mitigating all the leaf-events of  $E_2$  which are  $E_{10}$  and  $E_{11}$ . This category is less efficient while meeting the risk/top-event with many alternative occurrences (or-decomposition), because the risk will be really reduced when we prevent all the leaf-events from risk (as we have seen in the example, we need to prevent two events in order to mitigate an event).

*Consequences.* Differently from avoidance, here it is not possible to guarantee 100% risk-free of the model since there is a chance that the treatment fails to mitigate the risk. This category is not suitable for mitigating the unlikely risk, because it has to be taken before the risk occurs, and frequently, the organization does this measure as part of their daily activity even the likelihood of risk is low.

### 3.3 Alleviation

This measure intends to reduce the risk/top-event by employing a countermeasure over the top-event. This measure does not intend to prevent the risk to be developed (i.e., the occurrence sub-events), it just mitigates top-events that impact directly to the goals fulfilment.

*Characteristics of the model.* The analyst can not find any measures from the previous categories and then introduces a new treatment. For instance in Fig. 4,



**Fig. 4.** Alleviation Means

$E_2$  can be caused by  $E_{10}$  or  $E_{11}$  and the analyst mitigates  $E_2$  introducing  $T_1$ . In this scenario, the analysts can not prevent the occurrence of  $E_{10}$  and  $E_{11}$ , and they argue that it is fine having high-risk at  $E_{10}$  and  $E_{11}$ , and they argue that it is fine having high-risk at  $E_{10}$  and  $E_{11}$  as far as they can contain  $E_2$  on low-risk. This type is suited for circumstances in which there are many leaf-events that need to be mitigated to prevent a top-event and thus the total cost of mitigating risk is not economical as we mention in prevention measure.

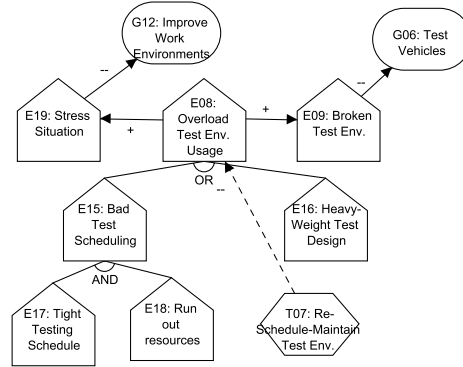
*Consequences.* Once the measure fails to mitigate the top-event than the top-event will impact to the goal layer severely without any mitigation. Unlike, in the prevention category, a failure in a countermeasure can be compensated by the effect of other countermeasures, because prevention measures, typically, are employed as a group. This measure is recommended to be applied when the analyst is really satisfied with the success-rate of the countermeasure in mitigating the risk. The probability of cost follows the likelihood of top-event/risk, which is usually less or equal than the likelihood of its sub-events. The measure is very suitable for the unlikely risks.

### 3.4 Detection

This category mitigates an intermediate event in the event tree so to reduce the risk/top-event. The advantage of applying this category is that there is a chance that several top-events share intermediate-event so mitigating an intermediate event can consequently reduce several risks/top-events at the same time.

*Characteristics of the model.* The event-trees of the risk layer share intermediate-event/sub-tree. Mitigating risks/top-events can be done employing a countermeasure over the shared intermediate-event and consequently, reducing several risks/top-events. Suppose, we are the managers of a vehicle testing plant (Fig. 5) and





**Fig. 5.** Detection Means

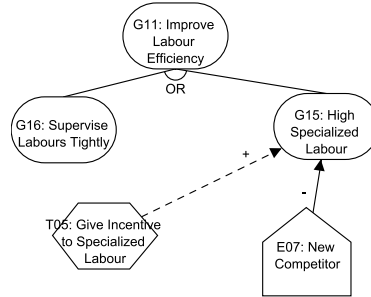
we need to ensure that the plant performs test vehicle ( $G_6$ ) correctly. Moreover, we need to improve the situation of work environments ( $G_{12}$ ) so to maintain quality of employees. As you see in Fig. 5, each goal has own risk, and interestingly there is a common sub-tree from these risks, namely overload test environment usage ( $E_8$ ). By re-schedule and maintain test environment ( $T_7$ ), it will reduce, hopefully, the likelihood of overload test environment usage ( $E_8$ ). Consequently,  $E_8$  reduces the possibility of stress condition ( $E_{19}$ ) for employees, which in turn can obstruct the achievement goal  $G_{12}$ .  $E_8$  also reduces the chance of having broken test environment ( $E_9$ ) that could lead to the denial of goal  $G_6$ .

*Consequences.* Very bad consequences if the measure fails to reduce an intermediate event. Indeed, it results in the obstruction of one or more goals. Therefore, the analyst has to be aware of the final consequences if the countermeasure fails and how much the success rate of the countermeasure is, before choosing this type. The probability of cost of the detection measures follows the likelihood of its intermediate event (i.e., equal or higher than likelihood of top-events, and equal or less than likelihood of leaf-events).

### 3.5 Retention

It is the last alternative to deal with risks, once we can not find any treatments from the previous types.

*Characteristics of the model.* It is used when the organization does not have the capability to mitigate or control the risk (e.g., war, inflation, new competitor, natural disaster). The best thing that the organization can do is predicting the likelihood of risk and work for its consequences. For instance in Fig. 6, the risk of having new competitor ( $E_7$ ) is beyond the control of the company and it could obstruct the goal of having high specialized labour ( $G_{15}$ ) because the competitors can give a better offer to the specialize labour. The only thing that the company can do is trying to give incentive for specialized labour ( $T_5$ ) s.t. the achievement of  $G_{15}$  is maintained. Transferring the risk to an insurance company, restore the



**Fig. 6.** Retention Means

obstructed goals, and design fault tolerance system can be categorised in this type, because they neither reduce the likelihood nor the effects of risks, rather they just repair the consequence of the risk.

*Consequences.* There will be a certain period of time where the goal might be un-satisfied before it is restored. Besides that, this measure can be seen as a mean to fulfil the goal besides as a treatment for the risk.

## 4 Conclusions

In this paper, we have presented a framework to model and reason about risk within the early phase of the system development. We have adopted and extended the Tropos goal modelling framework to analyse, evaluate, and select risk among the alternatives that are able to fulfil the stakeholders' goals and satisfies the preference (e.g., minimizing the total cost). The framework elicits a solution that is not only based on the stakeholders' goals but it also anticipates the existence of malicious events by introducing several treatments to manage their impacts. Therefore, the solution from 3-layers model is more robust compared to the solution that comes from the goal model.

The paper has also presented different categories of measures that typically are used to deal with the existence of risks in organizations. They are categorised as: avoidance, prevention, detection, alleviation, and retention. The analyst must understand the characteristics of the model before choosing them, especially prevention, detection, alleviation, and be aware of their consequences. Differently, an avoidance measure is usually chosen if it is feasible finding risk-free alternative, and a retention measure is the last option if there is no other type of measures which fits with the model.

The framework has been implemented as an extension of the Goal Reasoning Tool<sup>4</sup> (GR-Tool), shown in Fig. 7. The tool is graphical tool in which it is possible to draw the extended goal models and analyse them.

<sup>4</sup> <http://sesa.dit.unitn.it/goaleditor/>

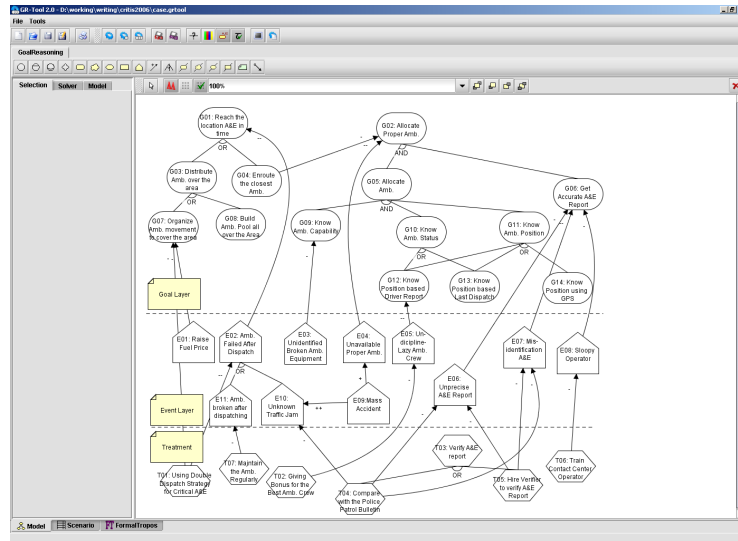


Fig. 7. Extended GR-Tool for Goal-Risk Modelling

Finally, as future work we want to propose also a quantitative reasoning mechanisms where evidence is expressed in term of probability model. The idea is to propose something similar to what have been already developed for the Tropos goal models.

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