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Risk Assessment Techniques as Decision Support Tools for Military Operations

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Abstract.

The major objective of this paper is to analyze the most widely used techniques for risk assessment and to discuss their applicability as decision support tools for military operations. These are the qualitative and the quantitative risk analyses, which are commonly used for handling uncertainty in project management. Initially, the main processes for the implementation of each method are presented highlighting the most critical issues that should be taken into account by project analysts. Further, it is discussed how these processes can be used by military operations analysts as decision support tools during the planning phase of a military operation. In particular, the main steps that should be followed by operations analysts are analyzed and the limitations as well as the benefits of the specific techniques are also discussed. Finally, in order to demonstrate that these methods can be effectively applied as decision support tools to military operations, the paper presents two illustrative examples with the application of the qualitative and quantitative risk analysis.

Keywords: Qualitative risk analysis, quantitative risk analysis, Monte Carlo simulation, risk matrix, military operations, random variables

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1. Introduction

The development of decision support models for military operations (MOPs) is one of the most widely topics examined. Since the World War II, a traditional research topic in the operations research field has been focused on developing tools and methods to help decision makers with tactical decisions over MOPs (Jaiswal, 1997). Moreover, the management of the positive or negative effect of uncertainty on a project or program's objectives (ISO, 2009), includes specific approaches, which are the identification, assessment and prioritization of risks. According to Kaplan and Garrick (1981), Haimes (1991) and Haimes (2002), the risk assessment analysts attempt to answer some formal questions, which are: what can go wrong; what is the likelihood that it would go wrong; and what are the consequences. Answers to these questions help decision makers to identify measure, quantify and evaluate the risks as well as their consequences and impacts. In most cases, a MOP's objectives are influenced by tactical risks which are the hazards associated with the enemy as well as by accident risks that include all operational risk considerations other than tactical risk, e.g. terrain and weather (MCI, 2002).

The major objective of this paper is the presentation of the risk assessment approach in a MOPs context. Initially, the paper presents two specific approaches of the most widely used risk assessment methods, which are the qualitative and quantitative risk analysis (RA) techniques, and further discusses the strengths and weaknesses of these techniques as decision support (DS) tools in MOPs. Table 1 presents all the abbreviations used throughout the paper, the rest of which is organized as follows. Section 2 presents the basic methods of the qualitative and quantitative risk analyses. Section 3 presents the application of the main RA techniques in two illustrative examples. Section 4 discusses the strengths and weaknesses of these techniques as DS tools for MOPs. Finally, section 5 summarizes the main conclusions.

RA	Risk Analysis
MOPs	Military Operations
DS	Decision Support
CDF	Cumulative Distribution Function
MC	Monte Carlo

Table 1. List of notations

2 Methods

This section presents the most widely used methods for risk assessment. In the literature, risk assessment is defined as a collection of models and methods for analyzing the probability of an event and its consequences to the project objectives (Hull, 1990). It is divided in two main categories which are the qualitative and quantitative RA. According to Arena et al. (2006), the main difference between these types is that quantitative methods attempt to assign numerical values to a single index and to the probability that those values may occur. In contrast, qualitative methods divide both consequences and probability into a small number (2 to 10) of broad categories that are then characterized by phrases (e.g., “rare”, “possible”, etc).

2.1 Qualitative Risk Analysis

In most cases, a qualitative RA is implemented following a simple process, which is illustrated in Figure 1. As can be seen, this process consists of 5 basic steps that are following presented. In the first step, the analysts develop a $n \times m$ matrix $[S]_{n \times m}$, in which the n rows denoted by i represent the likelihoods, the m columns denoted by j represent the consequences and the elements denoted by S_{ij} represent the scores. Rather than provide a detailed discussion of the different risk matrices that can be developed, we briefly present an example and we refer readers to MIL-STD 882C (1993) and to Cox (2008) for different examples of risk matrices as well as for a detailed discussion of their limitations.

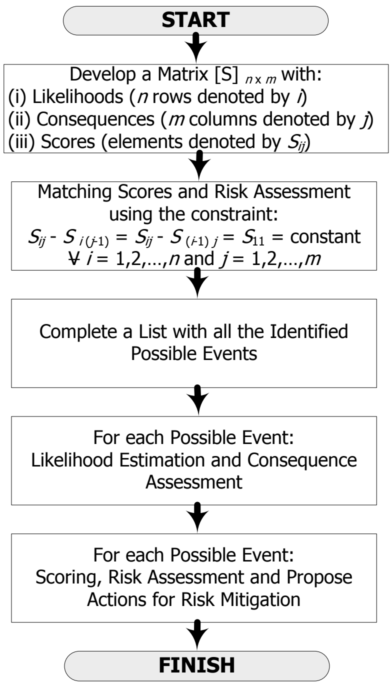

Figure 1. Qualitative risk analysis process

Table 2 illustrates a formal risk matrix (in this case $n = m = 5$, that is: $[S]_{5\times 5}$). In the second step, the analysts match the scores and risk assessment, in order to assess the impact of a risk. Specifically, the scores in this symmetric matrix are developed using the following constraint:

$$S_{ij}\text{-}S_{i(j\text{-}1)}=S_{ij}\text{-}S_{(i\text{-}1)j}=S_{11}>0, \qquad \forall i=1,2,...,n, \quad \forall j=1,2,...,m, \quad (1)$$

where the S_{11} is a positive constant serving as the desired scale. In the example presented in Table 2, the scores are gradually increasing from the "insignificant – rare" that is the element $S_{11} = 1$ representing the desired scale, to the "severe-almost certain" that is the element S_{nm} = $S_{55} = 9$.

Likelihood	Consequence: Insignificant	Minor	Moderate	Major	Severe
Rare	S_{11}= 1	S_{12}= 2	S_{13}= 3	S_{14}= 4	S_{15}= 5
Unlikely	S_{21}= 2	S_{22}= 3	S_{23}= 4	S_{24}= 5	S_{25}= 6
Possible	S_{31}= 3	S_{32}= 4	S_{33}= 5	S_{34}= 6	S_{35}= 7
Likely	S_{41}= 4	S_{42}= 5	S_{43}= 6	S_{44}= 7	S_{45}= 8
Almost Certain	S_{51}= 5	S_{52}= 6	S_{53}= 7	S_{54}= 8	S_{55}= 9

Table 2. A risk rating matrix

In this step, the analysts can classify further the risks by selecting different ranges. For instance, as can be seen in Table 2, the risks are classified in four categories using different colors:

(i) Low risk: blue color, score range 1 to 3,
(ii) Medium risk: green color, score range 4 to 5
(iii) High risk: yellow color, score range 6 to 7, and
(iv) Extreme risk: red color, score range 8 to 9.

In the third, fourth and fifth steps, the analysts identify all the possible events that may impact the operation objectives developing a list; for each possible event, they estimate the likelihood to happen and they assess its consequence. That is, with the use of the risk matrix they complete the list with all possible events by scoring and assessing the risk for each event. Finally, according to the risk assessment for each possible event, the analysts propose actions for risk mitigation.

2.2 Quantitative Risk Analysis

The qualitative RA is usually followed by a quantitative RA, which supports the total military operation plan, simply by analyzing those risks that have been assessed as crucial. As happens with the qualitative, a simple process can be followed for the implementation of the quantitative RA.

Figure 2 illustrates a basic process, which can be used for those risks that are formulated within a simple index, e.g. duration of a task (in hours, days, etc) or cost of a task (in $, €, etc). Initially, the analysts identify all appropriate parameters, which are included in the computation of the index examined and thus their variations have a positive or negative impact on the project's performance. For instance, if a task consists of independent sub-tasks and its duration is computed through the sum of the different sub-tasks (activities), then the duration of each activity is considered as a specific variable. In this first step, the analysts run a sensitivity analysis by giving different values separately to each variable, in order to estimate the impact that each variable has on the index examined (USACE, 2010; Karmperis et al, 2012a). Moreover, the probability distribution of the variables' range around the best estimate value is used (Rentizelas et. al, 2007; Karmperis et al., 2012b), in order to assess their overall impact on the index examined. Specifically, the analysts select the appropriate distribution (e.g. normal, lognormal, triangular, uniform, see DoA, 2008) and the range values for each variable developing a Monte Carlo (MC) simulation model, in which all project's variables are defined as inputs and the index is defined as output (Karmperis et al., 2012c).

The simulation is performed using random values of the inputs e.g. 1,000, 2,000, 5,000, or 10,000 runs (Rezaie et. al, 2007). Through the simulation, the overall impact of the variables is taken into account and the possible range of the index's values is calculated, graphically expressed as the Cumulative Distribution Function (CDF). In the fourth and fifth steps, the analysts assess the acceptable levels of risk and propose actions for risk prevention.

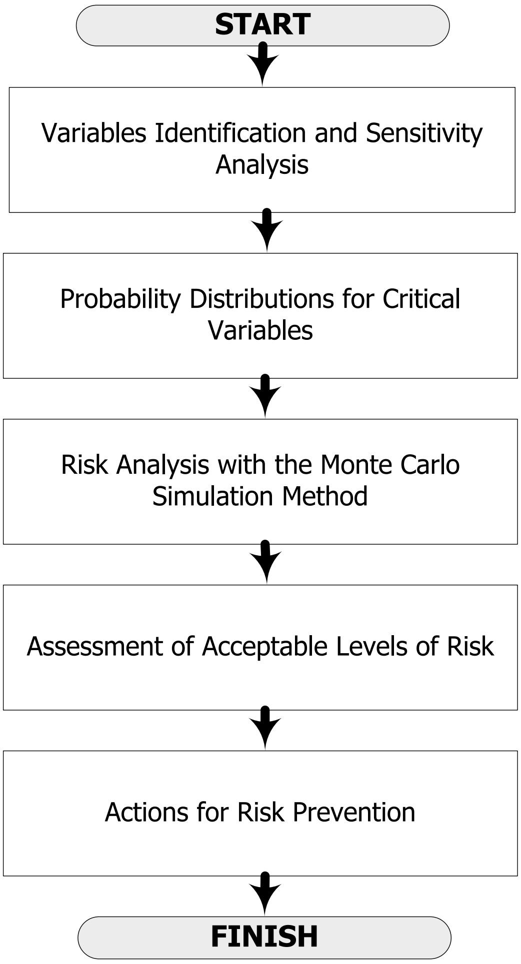

Figure 2. Quantitative risk analysis process

3 Applications

The illustrative example is presented here not to expose a real MOP situation but rather to guide the reader how to implement the proposed RA processes. The case is regarded to be the preparation of a military Unit consisting of 3 Sub-Units for transportation from a specific area to the fight area. It is assumed that there are no enemy forces or other civilians around this area and there is a supply network as well as an intelligence network with supervisors. Moreover, it is assumed that there is no lack of personnel or vehicles and the Unit has been warned that the transportation to the fight area should be implemented within 4 hours (240 minutes) after a task assignment by supervisors.

By following the proposed qualitative RA process that is presented in figure 1, the analysts develop a risk assessment list. More specifically, they identify all the possible events that may impact the transportation from one area to another and further they estimate the likelihood as well as the consequence of each event. By using the risk matrix that is presented in Table 2, they score and perform the assessment of the risks, as illustrated in Table 3. As can be seen, there are 10 operational risks, in which 2 are assessed as low (blue color), 4 as medium (green color), 3 as high (yellow color), and for each risk there is a specific action proposed to the Commander (decision maker). However, there is a specific risk, namely the “delay in the transportation to the fight area”, which is assessed as extreme (red color) and the action proposed is to perform a quantitative RA, in order to estimate with accuracy the duration needed from the task assignment to the transportation of the Unit to the fight area.

That is, a quantitative RA is performed using the process illustrated in Figure 2. Initially, the analysts develop a Gant chart identifying the necessary tasks, i.e. to load vehicles with fuel, ammunition and equipment, as well as the base case value for the duration of the sub-tasks implemented by the 3 Sub-Units. Further, they run a sensitivity analysis, in order to prioritize the sub-tasks’ duration (variables, denoted by: V_k , $k = 1,2,\dots,16$), with the highest impact on the total duration. The result of the sensitivity analysis is the tornado graph that is illustrated in Figure 4. As can be seen in this Figure, there are 8 variables (included in the critical path of the Gantt chart), which have an impact on the total duration through their variation in the range ± 20% form the base case value. Further, the analysts develop a MC simulation model, in which they assign a specific probability distribution in each of the 8 critical variables (inputs) as presented in Table 4, and they define the total “Task duration” as the output. The simulation is performed with 10,000 iterations and the resulting CDF is illustrated in Figure 5. Through the analysis of the CDF, the expected value of the total task’s duration is estimated at 193 minutes. Furthermore, it is almost certain (99.83% probability) that the task’s duration will be greater than 2 hours (120 min.) and also there is: 100.00-89.26=10.74% probability for this duration to be greater than 4 hours. That is, the analysts can propose specific actions to the commander, in order to maximize the probability of the Task to be implemented within 4 hours, as defined by the supervisors.

Description	Risk Assessment				Actions proposed
	Likelihood	**Consequences**	**Score**	**Assessment**	
Lack of food and water in the following days	*Possible*	*Moderate*	**5**	**Medium**	Supply of canned food and bottles of water
Lack of communication with supervisors	*Likely*	*Moderate*	**6**	**High**	Check communication equipment
Lack of tents for personnel	*Unlikely*	*Major*	**5**	**Medium**	Supply of tents from supply network
Road damage in the main route	*Possible*	*Severe*	**7**	**High**	Reconnaissance of the route and of alternative routes
Lack of fuel for vehicles in the following days	*Possible*	*Major*	**6**	**High**	Load a tank truck
Weather conditions (moderate visibility)	*Rare*	*Minor*	**2**	**Low**	Order vehicle drives for limited speed
Lack of operational intelligence	*Unlikely*	*Major*	**5**	**Medium**	Communicate with supervisors and update intelligence
Lack of ammunition in the following days	*Possible*	*Minor*	**4**	**Medium**	Check ammunition store and supply extra from network
Delay in the transportation to the fight area	*Likely*	*Severe*	**8**	**Extreme**	Perform a quantitative risk analysis
Weather conditions (rain)	*Possible*	*Insignificant*	**3**	**Low**	Check the waterproof suits of personnel

Table 3. Qualitative risk analysis

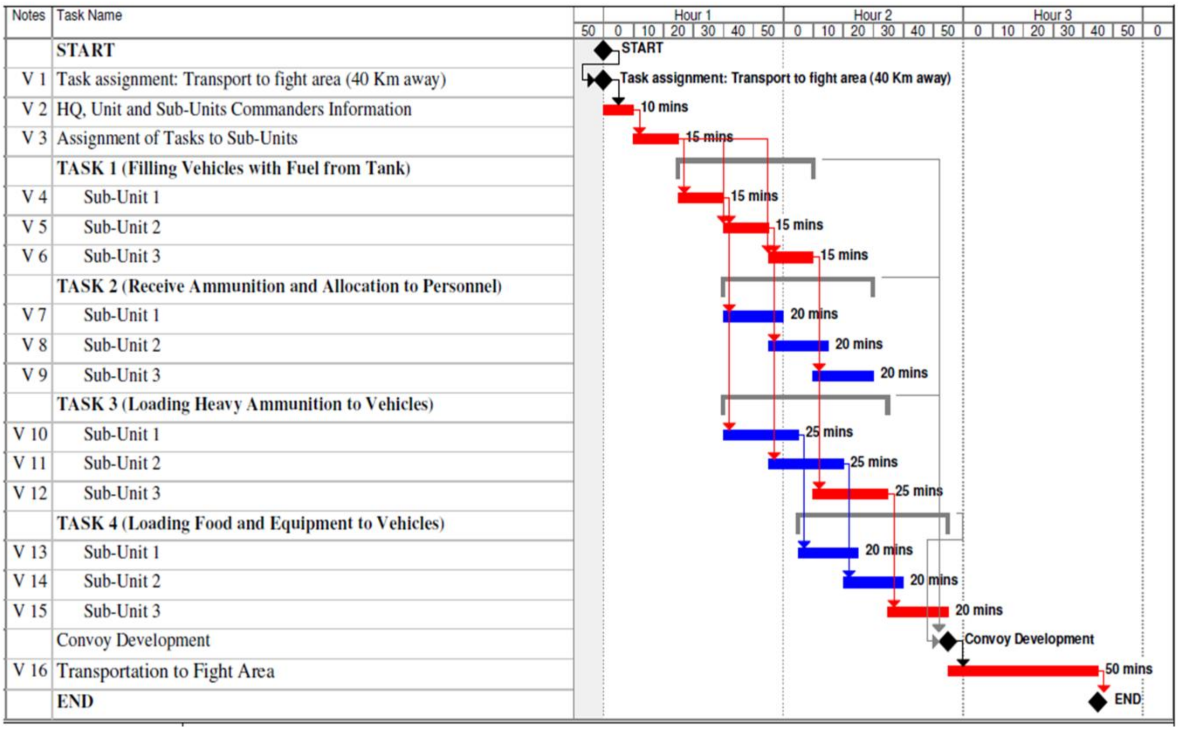

Figure 3. Gantt chart of the Task

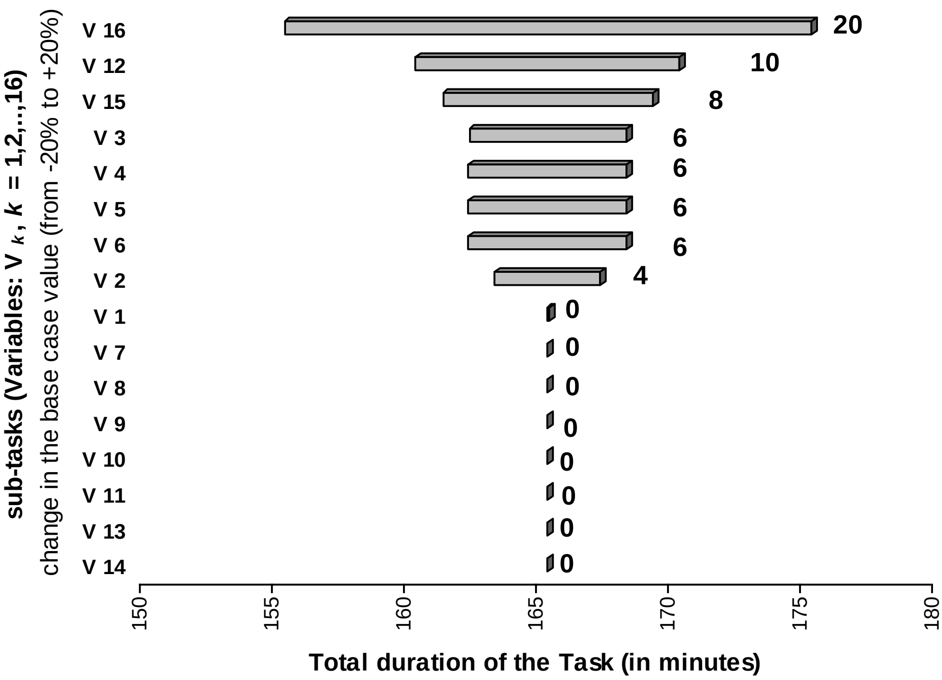

Figure 4. Tornado graph of the variables

Variables	Distribution	Values			Standard Deviation
		Minimum	Mean	Maximum	
V_2	PERT	5.0	10.0	20.0	-
V_3	Lognormal	-	10.0	-	5.0
V_4	Triangular	12.0	15.0	25.5	-
V_5	Triangular	12.0	15.0	25.5	-
V_6	Triangular	12.0	15.0	25.5	-
V_{12}	Normal	-	25.0	-	15.0
V_{15}	PERT	18.0	20.0	28.0	-
V_{16}	Lognormal	-	50.0	-	40.0

Table 4. Probability distribution of the critical variables

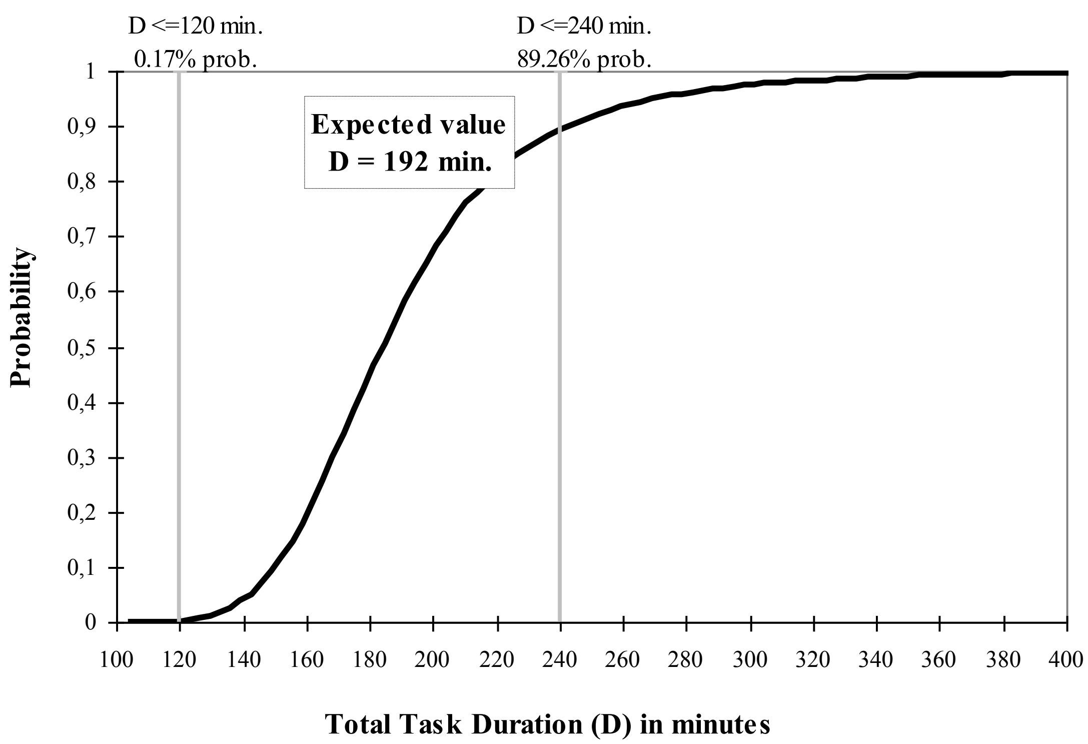

Figure 5. Cumulative distribution function of the Task's duration

For instance, the proposed action/s can be: before the task assignment, to filling vehicles with fuel and/or to loading heavy ammunition and/or food and equipment to vehicles, in order to restrict the necessary sub-tasks of the total task and thus to minimize the risks associated with its duration.

4 Discussion

As mentioned above, the qualitative and quantitative RA techniques can be used by decision makers as DS tools for MOPs. Their main strength is that especially during the planning phase of a MOP, these techniques can handle with efficiency the worldwide phenomenon that is called “optimism bias”. Specifically, according to HM Treasury (2003), there is a demonstrated, systematic, tendency for project appraisers to be overly optimistic. Moreover, similarly with project appraisers, most decision makers in MOPs have the tendency to be over optimistic, i.e. to underestimate the potential losses from a specific operation and/or overestimate the potential benefits (McLennan et al, 2003; Parajon, 2009).

Another common strength of the qualitative and quantitative RA is that both approaches satisfy the axiom of rational behavior, i.e. the decision makers make choices that result in the most optimal level of benefit or utility (von Neumann and Morgenstern, 1944). Most RA models included in the literature satisfy the axiom of rationality, e.g. the probabilistic model of terrorist threats by Paté-Cornell and Guikema (2002) and the probabilistic framework for the assessment of the risks from technological systems by Apostolakis (1990). However, it is mentioned that especially in MOPs it should be better to use the term “bounded rationality” (Simon, 1955; 1957), since the rationality of decision makers is limited by the available information, the cognitive limitations of their minds, and the finite amount of time they have to make a decision.

However, a common weakness of these techniques is that the assumptions used by analysts can be highly subjective. Specifically, since two analysts may select different likelihood/consequence terms and score assignment within the qualitative RA (Korombel and Tworek, 2010), as well as different probability distributions within the quantitative RA, it is concluded that in both approaches the results can be different among two analysts.

Some particular advantages of the qualitative RA technique when compared with the quantitative RA can be stated as:

- It saves time, effort and it is easier to perform, since it does not require software or computer expertise (Rainer et al, 1991).
- Decision makers can have a comparable view of the different risks, in order to prioritize them for further analysis or for risk mitigation actions.
- It allows the assessment of different types of risks as it is not limited on a single index.

On the other hand, the advantages of the quantitative over the qualitative RA approach can be recognized in the following:

- It provides more accurate results
- It allows the comparison of the net effects of different threats (both in terms of probabilities and consequences) and the combination of dependent factors (Paté-Cornell and Guikema, 2002)
- It considers the overall impact of different risks into a specific index

Conclusively, it is difficult to distinguish one RA technique as the most suitable for all MOPs planning cases. Since all MOPs are examined in a case by case basis, it is crucial to identify the level of analysis that is defined by the risk assessment process and to select the RA approach that fits best in the objectives. Therefore, it is clear that the selection of the qualitative or the quantitative RA technique or the combination of both techniques (Haimes, 2002), should be based on the scope of evaluation

5 Conclusions

Since the last century, a traditional research topic in the military field has been focused on developing tools and methods to help commanders with tactical decisions over MOPs. This paper presents two specific processes for the implementation of the qualitative and the quantitative RA techniques, which can be used as decision support tools for MOPs. In particular, these processes can be followed by the MOPs analysts, in order to assess an operation's risks and to propose specific actions for management and mitigation of these risks. Moreover, the paper presents a case study with the application of the qualitative and quantitative RA techniques to an illustrative MOP and analyzes their strengths, weaknesses and possible combinations. In conclusion, the qualitative and quantitative RA techniques can be effectively applied as DS tools to MOPs. However, it should be mentioned that these methods can be used as supplementary tools to the basic tactics, since they do not inhibit the commander's flexibility and initiative as well as they do not remove the necessity for standard drills and procedures.

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