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Communicating uncertainty in risk descriptions: the consequences of presenting imprecise probabilities in time critical decision-making situations

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ABSTRACT

One important question concerning a risk description is to what extent it should contain information about the uncertainty surrounding an estimated probability for an event, for example, by using some form of probability range. Presenting a point estimate together with a range can inform the decision-maker about both the best judgement as well as the strength of knowledge regarding the probability in question, so that the decision-maker can take this information into consideration when making decisions. However, communicating uncertainty in risk descriptions may lead to delays in the decision-making process, due to people's general aversion to ambiguity and other forms of uncertainty. This can be devastating in time critical decision-making situations, where delaying decisions leads to substantial costs or losses - as in the case of a military command and control (C2) situation or in crisis response management (CRM). This study investigated how 106 university students handled a fictive time critical military decision-making situation with imprecise probabilities presented in the form of ranges. The purpose was to make a first estimation regarding if presenting uncertainty in risk descriptions could be a problem in these kinds of situations. The results show that almost half of the participants delayed their decisions and that many participants showed little restraint regarding their waiting time. These results indicate that communicating uncertainty in risk descriptions can be a problem in time critical decision-making situations, and that presenting uncertainty in risk descriptions may require decision-makers to be educated in the specific problems associated with decision-making in these types of situations.

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Introduction

A risk description is an essential component in a risk assessment process, generally produced by risk analysts to support decision-making (Aven et al. 2014; Lin et al. 2015; Rausand 2011). One important question concerning a risk description is to what extent it should contain information about the analysts' uncertainty regarding a risk. A study in the domain of

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intelligence forecasting by Dieckmann, Mauro, and Slovic (2010, 987) found that presenting uncertainty in risk descriptions by using imprecise probabilities in the form of ranges 'may have distinct advantages as a way to communicate probability and analytic confidence to decisionmakers'. The main purpose of presenting uncertainty in a risk description in the form of a range is that it can inform the decision-maker about the strength of knowledge, manifested by the width of the range, regarding an estimated probability for an event, so that the decision-maker can take this information into consideration when making decisions. The use of probability ranges as a method for communicating uncertainty is recommended also in other studies in a diversity of domains – such as climate change, weather forecasts and economic investment (e.g. Budescu, Broomell, and Por 2009; Joslyn and LeClerc 2012; Durbach and Stewart 2011; Flage et al. 2014).

A common feature in previous studies, regarding the use of probability ranges in decision-making tasks, is that the decisions made in these studies were made on existing and static information. However, in many decision-making situations it is possible to collect additional information before making a decision, with the objective to reduce uncertainty (Baron 2008). This can be a beneficial strategy in situations where postponing a decision does not lead to any costs. But in *time critical situations*, where delaying decisions leads to costs or losses, this tactic can be devastating – as in the case of a military command and control (C2) situation where, for example, delaying a decision regarding the escort of an emergency transport to humans in distress in a conflict zone may lead to loss of lives. Other similar examples are decisions in crisis response management (CRM) situations where, for instance, delaying a decision regarding how to best coordinate available resources during a forest firefighting situation may lead to significant loss of forest values, or situations where delaying an economic investment decision to obtain more information may lead to loss of profit. As a consequence, due to peoplés general aversion to uncertainty (e.g. Keren and Gerritsen 1999; Visschers 2017), there is a potential downside of adding ranges to probability estimates in situations like these. If the range information leads to unwanted delays in the decision-making process, presenting uncertainty in risk descriptions can turn from an asset to a problem.

The objective of the present study is to explore how decision-makers deal with the trade-off between postponing decisions to receive additional information and avoiding certain losses in a time critical decision-making situation. The overall purpose is to investigate if presenting uncertainty in risk descriptions could be a practical problem in these kinds of situations, and to contribute to the debate on how uncertainty should be communicated to decision-makers. The question we seek to answer is: If one introduces imprecise probabilities in a time critical decision situation, where delaying decisions leads to costs or losses, will the decision-maker react to the uncertainty by postponing the decision and wait for additional information or will he/she try to make a quick decision in order to, for example, avoid certain losses? The article reports a scenario-based survey with 106 participants seeking to investigate and provide a first answer to this question.

The article is organised as follows. The next section contains the background and theoretical framework for the study, including a description of the components in a time critical decision-making situation, and how ambiguity aversion and loss aversion relate to this. This section also includes a brief overview of previous research regarding the representation of uncertainty in risk descriptions and a description of the concept Value of Information (VoI). This section concludes with the three specific research questions for the study and the argument for using a fictitious situation to answer them. Thereafter comes the material and method section, including a description of the text-based scenario used, together with the design and procedure for the study. Next, we present the results and the analysis of these results. This is followed by the discussion, where the results and implications are reviewed and where suggestions for future research are presented. The article ends with the conclusions.

Background and theoretical framework

Time critical decision-making situations

The *time critical decision-making situations* of interest here contain four central components: The first component is *risk*, i.e. it is a situation where something of value is at stake and where the outcome is uncertain (e.g. Aven, Renn, and Rosa 2011). The second component is *ambiguity*. Several different uses of this concept can be found in the literature. In this article, following e.g. Ellsberg (1961), Frisch and Baron (1988), and Trautmann and van de Kuilen (2015), we consider ambiguity to be a situation where the probability judgement for an event to occur is uncertain or unknown. The third component is that the situation evolves over *time* and the fourth component is that this evolution leads to *costs or losses*. These four elements place certain demands on the decision-maker and on the possibility to be successful if waiting for additional information.

To be potentially beneficial, the delaying of a decision in time critical decision-making situations must fulfill two conditions: (1) the delaying time cannot be so long that the expected gain of making a better decision is "eaten up" by the cost of delaying the decision, here called the *time limit condition*, and (2) the information obtained by waiting must have the potential to lead to a *shift of choice*, compared to the choice that would have been made without waiting. Information that only confirms your initial choice does not add anything substantial to the decision-making situation. A complicating factor here is that it is impossible for the decision-maker to calculate a waiting time that is guaranteed to fulfill the time limit condition, and if delaying a decision will actually lead to better information and less uncertainty. As a result, if waiting there is a risk that the two conditions are violated. There is nothing the decision-maker can do about the shift of choice condition, i.e. the decision-maker does not control whether the new information will lead to a shift of choice or not. On the contrary, the decision-maker controls the time limit condition since he/she is the one who ultimately decides when to stop searching for more information and make the decision. However, it is difficult to decide when to stop searching because the same uncertainty that you want to reduce or eliminate by waiting for additional information hinders you from judging the appropriate waiting time. From a practical point of view, it is therefore important to assess how people handle time critical decision-making tasks. Are decision-makers likely to make a quick decision in order to avoid the certain losses that will occur if they wait for information, or are they likely to postpone the decision to reduce some of the uncertainty regarding the situation? Previous research does not give a clear answer to that question.

Ambiguity aversion and loss aversion

On the one hand, presenting uncertainty in these types of decision-making situations may lead to delaying of decisions because even though people normally prefer to be informed about uncertainties they also generally have an *ambiguity aversion*, i.e. people dislike making decisions in situations where probabilities are uncertain or unknown (Ellsberg 1961; Becker and Brownson 1964; Kleindorfer, Kunreuther, and Schoemaker 1993; Einhorn and Hogarth 1985; Curley, Yates, and Abrams 1986; Frisch and Baron 1988; Fox and Tversky 1995; Keren and Gerritsen 1999; Visschers 2017). Furthermore, people have a tendency to postpone decisions when there is uncertainty, while seeking additional information (Lipshitz and Strauss 1997; Van Creveld 1985; Peters et al. 2008; MacCrimmon and Wehrung 1986). Thus, this points us towards the possibility that presenting imprecise probabilities in the form of ranges may lead to delays in the decision-making process.

However, on the other hand, it is established in the literature that people in general have a desire to avoid certain losses in risky situations, i.e. people are risk seeking when there is a possibility that they may lose something (Tversky and Kahneman 1981). According to Prospect theory this behaviour is the consequence of both *loss aversion* and a *convex value function* (Tversky and Kahneman 1986). Loss aversion implies that people's response to losses are usually more significant than the response to a corresponding gain, i.e. losses hurt more than gains feel good, and a convex value function means, for example, that a doubled loss is considered less than twice as bad compared to the original loss. The tendency to avoid situations with certain losses has been confirmed in several domains where choices involve, for example, monetary outcomes (Hershey and Schoemaker 1980) and human lives (Eraker and Sox 1981). Aversion to certain losses points us toward the possibility that people in time critical situations will prefer to make their decisions directly, thus avoiding the certain loss involved when waiting for additional information.

To date it is unknown which of these opposing theoretical predictions best describes people's actions in the kind of decision-making situation of interest here. There are therefore both practical and theoretical reasons for studying how decision-makers handle time critical decision-making tasks when presented with uncertainty in risk descriptions.

Representation of uncertainty in risk descriptions

The traditional way to describe risk, i.e. by specifying consequences and probabilities using *single-values* in some form of risk matrix or risk diagram, is widely used in risk assessment (Cox 2008; Duijm 2015; Goerlandt and Reniers 2016). However, this traditional single-valued based approach has been criticised for being too narrow in scope, especially in situations where it is difficult to determine probabilities (Bjerga and Aven 2015; Veland and Aven 2015; Aven 2013a). To obtain a more adequate risk description for these kinds of situations a broader risk perspective has been proposed, using variables such as background knowledge (Bjerga and Aven 2015; Veland and Aven 2015; Aven 2013b) and tools for representing uncertainty in risk descriptions, such as imprecise probabilities in the form of intervals or ranges, (Flage et al., 2014; Aven et al., 2014; Dieckmann et al., 2010; Dieckmann et al. 2012; Goerlandt and Reniers 2016). In this article we use imprecise probabilities in the form of ranges as the operationalisation of describing this type of uncertainty. These probability ranges express the strength of knowledge regarding the probability of a risky event. A wider probability range around an estimated probability expresses more uncertainty, and thus a lower strength of knowledge, than a narrower probability range.

There are other ways of representing uncertainty regarding an estimated probability in a risk description, than using probability ranges. One alternative is to use *verbal probability phrases*, such as 'certain' or 'reasonably likely', and another way is to use *verbal evaluative labels*, such as 'high' or 'low' (Gregory and Dieckmann 2014). However, in general, verbal phrases are less precise than numerical representation, which can lead to more variability in interpretation between individuals (Lipkus 2007; Gregory and Dieckmann 2014). Because of this variability problem, together with the possibility to present different degrees of uncertainty in a more precise way, in this study we chose probability ranges as the form for communicating uncertainty. Moreover, as shown below, the use of probability ranges has worked in other contexts.

The use of probability ranges to communicate uncertainty has been studied empirically in different decision-making situations in a diversity of domains. In the previously mentioned study by Dieckmann et al. (2010) the decision-making situation was in the context of terrorism-focused intelligence forecasts. The participants in that experimental study were presented with different simulated intelligence forecast warnings, with and without probability ranges, of a possible terrorist attack. The results from three experiments show that the participants were able to use the probability ranges and that 'presenting ranges of probability may be a good approach to communicating probability assessments and analytic confidence' (2010: 997). Moreover, Joslyn and LeClerc (2012) have studied the use of probability ranges in the context of weather-related decisions, focusing on precautionary action for weather events. The results from three experiments demonstrate that 'uncertainty information improved decision quality overall and increased trust in the forecast' (2012: 126). In another experimental study by Dieckmann, Peters, and Gregory (2015), focusing on how lay people interpret numerical uncertainty ranges and the relative likelihood of values in a numerical uncertainty range, the results from three experiments show that presenting a best estimate together with a range contributes to the participants' interpretation of a normal distribution within a range, but that there still is a great variance in interpretation even when point estimates are provided. Furthermore, results from an experimental study by Budescu, Broomell, and Por (2009), in the context of climate change, show that people are sensitive to differential information presented in probability ranges. This result points to the possibility of sensitivity to differential range information also in our study.

However, even though the use of probability ranges has been studied in different decision-making contexts, little or no attention has been paid to the consequences of presenting probability ranges in the kind of decision-making situations of interest here, i.e. time critical decision-making situations where delaying decisions leads to cost or losses. This study is the first in a series of three, aiming to contribute to filling this gap. Before reporting the results we will focus on how long it is reasonable to wait for more information and the concept Value of Information (VoI).

Value of information (VoI)

A time critical decision-making situation can be very demanding for a decision-maker. The four conditions described above (risk, ambiguity, time, and losses) make it necessary for the decision-maker to consider the value of the information that could be obtained by waiting and compare it to the losses during the waiting time. There are different ways of estimating the Value of Information (VoI) (e.g. Heath, Manolopoulou, and Baio 2017) and we will go into more details in the result and analysis section. Here it suffices to note that waiting for more information is reasonable only if both the *time limit conditions* and the *shift of choice conditions* are fulfilled. Both conditions are explained below.

First, to be potentially beneficial the waiting time cannot be so long that the expected value of making a better decision is "eaten up" by the cost of delaying the decision. A fictive example involving a forest fire is used here to illustrate this *time limit condition*. Imagine a fire chief faced with two options, A and B, for extinguishing a forest fire. The best alternative without additional information is option A with an expected loss of 125 acres of the forest, and the expected loss with option B is 150 acres. The fire chief is leaning towards option A, but both expected values are surrounded by ambiguity and the fire chief therefore considers waiting for better information. However, for every minute 2.5 acres of forest are lost in the fire. Therefore, the longer he/she chooses to wait for new information, the more valuable it needs to be to compensate for the lost forest. Thus, there is a limit to how long it is feasible to wait. Beyond a certain point, the value of the new information cannot outweigh the certain losses.

Second, to be an asset the information obtained by waiting must have the potential to lead to a *shift of choice*, compared to the choice that would have been made without waiting. For example: If the decision without waiting for additional information would be to choose option A, the new information must have the potential to shift the best option to B since information that only confirms your initial choice does not add anything substantial to the decision-making situation.

Both of these conditions must be fulfilled simultaneously for a waiting strategy to be sensible, and this must be achieved in a situation where it is often very hard for a decision-maker to judge how long it is appropriate to wait and to know if delaying a decision will actually lead to better information and less uncertainty. Thus, if looking at the decision-making situation in the light of these two conditions, the difficulties to be successful with a waiting strategy emerge.

The specific questions for the study and the use of a fictitious situation

How people handle time critical decision-making situations has been broken down into three specific questions:

1. To what extent do decision-makers use the uncertainty information in the ranges to make their decision?
2. To what extent do decision-makers make their decision directly and to what extent do they wait for additional information, and what are the reasons for these decisions?
3. If some decision-makers choose to wait with their decision, do they show restraint regarding how long they wait, and what determines their waiting time?

The answer to the questions might depend on the context in which time critical decisions are made, and it is not realistic to expect the present study to deliver conclusive answers to them. Such answers would require more detailed studies of the possible contexts in which time critical decision-making is relevant, e.g. firefighting, emergency medicine, or humanitarian emergencies. Although such a study might have provided insight into the effects of variation in terms of practical contexts, it would have been practically difficult to interfere, manipulate and control the decision-making situation, and it would therefore be difficult to discern the effects of how uncertainty was presented from the effects of other contextual factors. Instead, our approach is to focus on the important aspects of time critical decisions, i.e. risk, ambiguity, time and losses, and design a fictitious situation based on them. The aim is to capture some salient features of real decision situations, while at the same time increase our ability to control variables compared to field studies. We thus sacrifice some realism, compared to a field study, in order to gain greater control of variables. Moreover, in order to create a meaningful fictitious situation, we needed to choose a relevant context. To that end we used a military scenario. However, it did not require military expertise to understand.

Materials and methods

Participants

Participants were 106 university students. 74 were students of political science at the Swedish Defence University (27 women and 17 men) and at Mälardalen University (19 women and 11 men). 32 participants were at the beginning of their first semester at the Officers' Programme at the Swedish Defence University (12 women and 20 men). The participants' mean age was 24 (min = 18, max = 51, SD = 5.3). They were recruited on a voluntary basis via e-mail and they were given two movie tickets each for participating.

Scenario

The following description of the scenario is based on the instructions that were given to the participants (see Appendix for the full text-based scenario). Before we used the scenario it was reviewed by military experts.

The participants were acting as commanders of a military force. They were informed that the task was to escort a transport of necessities from the port, located in the north-western part of the country, to a region in the east with approximately 100.000 people in distress (Figure 1). The participants were also informed that for every hour, 20 people die in the region due to starvation, disease and other hardships.

To reach the region, there were only two possible navigable roads, COA 1 and COA 2. Both of these roads were about 100 km and passed through areas where the two hostile groupings

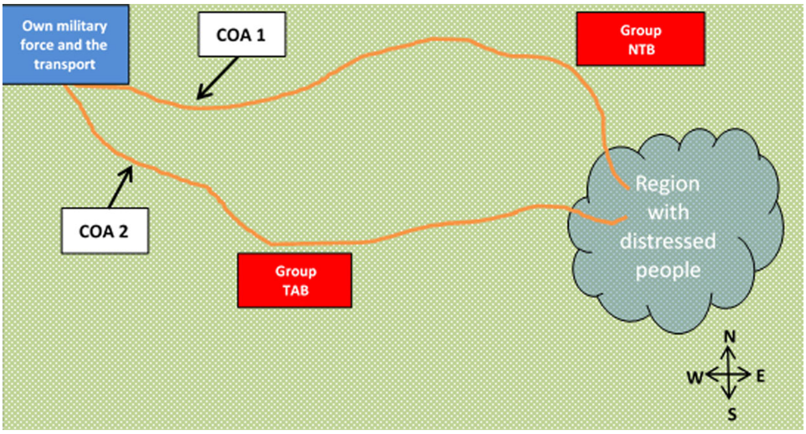

Figure 1. The map.

Intelligence report

Bad intelligence situation. There is uncertainty regarding the priorities of the groupings.

Difficult to estimate the correct probability of an attack along both COA 1 and COA 2.

COA	Estimated probability for an attack	Uncertainty range
COA 1	50%	40% – 70%
COA 2	60%	45% – 65%

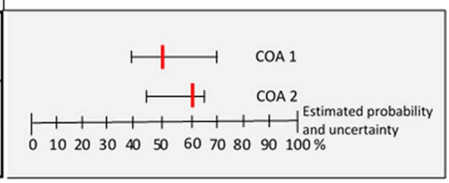

Figure 2. The risk description.

"Northern Togan Liberation Front" (NTB) and "Togan Autonomous Population" (TAB) operated. The participants were informed that both of these groups wanted to appropriate the necessities transported, so regardless if COA 1 or COA 2 was selected there was a risk of an attack on the transport. Such an attack would not have stopped the transport, but the consequence of an attack would have been the death of 1000 people due to delays and missed deliveries of food and medicine.

The participants were also informed that the risk analysts had made the following risk assessment: The estimated probability of an attack along COA 1 was 50%. However, there was uncertainty regarding this estimation. The correct probability for an attack along COA 1 was somewhere in the range of 40%-70%, i.e. the probability for an attack could be as low as 40% or as high as 70% or somewhere in between. The estimated probability for an attack along COA 2 was 60%. However, there was also uncertainty regarding this estimation. The correct probability for an attack along COA 2 was somewhere in the range of 45%-65%. Thus, the estimated probability for an attack along COA 1 was somewhat *lower* than the estimated probability for an attack along COA 2, but the uncertainty about the probability along COA 1 was slightly *greater* than the uncertainty regarding COA 2. The risk assessment was summarised in a risk description (Figure 2).

Intelligence gathering was ongoing in the area, with the objective to determine the real priorities of the groupings to attack the transport.

The first thing that had to be decided by the participants was whether they should make a decision directly about the route based on the information currently available OR if they should choose to wait for further intelligence instead. More information could provide a better picture regarding the risk of an attack, but waiting for additional information had the cost of 20 people dying every hour during the wait.

Design and procedure

The study was designed as a one-group post-test study (e.g. Shadish, Cook, and Campbell 2002), with two different levels of uncertainty regarding the estimated probabilities. The reason for not using a no-treatment control group, without uncertainty regarding the probabilities in the risk description, is related to the main question for the study, i.e. will a decision-maker react to the uncertainty by postponing the decision and wait for additional information or will he/she make a quick decision? It is hard to imagine that a decision-maker would choose to wait for additional information in a time critical decision-making situation where there is no uncertainty regarding a probability. Therefore, no control group was used. The purpose of using two different levels of uncertainty was to get an indicator of whether the participants take into account the uncertainty information. If so, this is manifested by the decision to (1) choose COA 2, because it is reasonable to assume that without any uncertainty regarding the probability a decision-maker would choose the alternative with the lowest estimated probability (i.e. COA 1), or to (2) choose COA 1 with reference to its lowest range value between the two alternatives. Moreover, it should also be noted that the study was designed so as to make the alternative to wait for more information a relatively poor option. More precisely, the potential benefits the participants could hope to gain by waiting for more information is quickly outweighed by the loss of lives due to a delayed operation.

First, the participants signed an informed consent. They then read the text-based scenario including the risk assessment. Thereafter, they answered a survey including the following five questions:

1. In current circumstances – how many hours are you willing to wait for additional information before you instead decide to make a decision directly on the information currently available? (If you want to make a decision directly, write 0 hours)
2. Write a brief motivation regarding your answer to Question 1.
3. Imaging that you just learned that there will be no additional information, and that you have to make a decision regarding the route on available information. Which route would you choose?
4. How confident do you feel about your route selection? Distribute 100 points between the two options COA 1 and COA 2 (e.g. 60 on one and 40 on the other).
5. Write a brief motivation regarding why you chose this route

The text-based scenario and the questions were written in Swedish, and most participants completed the study in less than 30 minutes.

Data analysis

The five questions answered by the participants generated two different kinds of data. Question (1), (3), and (4) generated numerical data in a direct way. Regarding this data, we calculated frequencies, percentage distributions and conducted a t-test. Question (2) and (5) generated free-text data. To analyse and synthesise this data we first read the motivations made by the participants, in order to identify main categories regarding the reasons for making a direct decision or waiting for additional information, and the reasons for choosing COA 1 or COA 2. We then coded each motivation to one or more of those categories. Before calculating frequencies and percentage distributions regarding the free-text data, we double-checked the coding. The presentation of the free-text data in the results and analysis section should be seen as a complement to the primary data, which consists of the directly generated numerical data.

Results and analysis

Our first research question was: *To what extent do decision-makers use the uncertainty information in the ranges to make their decision?* To answer this question we will first look at how many of the participants chose COA 2. Because, as mentioned above, we can assume that without any uncertainty regarding the probability for a risky event a decision-maker would choose the alternative with the lowest estimated probability, i.e. COA 1. The results show that 35% (n = 37) of the participants selected COA 2 and that 87% (n = 32) of these participants motivated this decision by referring to the smaller probability range. Furthermore, 13% (n = 14) of the participants pointed to the *lowest possible value* between the alternatives, as a motive for choosing COA 1. Hence, the uncertainty presented in the risk description influenced the choice for at least 48% (n = 51) of the participants, replicating the results from earlier studies about the value of using probability ranges to communicate uncertainty to decision-makers (Dieckmann et al., 2010; Joslyn and LeClerc 2012; Budescu et al., 2009).

The second question was: *To what extent do decision-makers make their decision directly and to what extent do they wait for additional information, and what are the reasons for these decisions?* The results show that 51% (n = 54) of the participants decided to make a direct decision, and thus, that 49% (n = 52) decided to wait. Since it is difficult to be successful with a waiting strategy, it is not possible to dismiss that it may be troublesome that almost half of the participants in the study decided to wait for additional information. This result points to the possibility that presenting uncertainty in risk descriptions could be a problem in some time critical decision-making situations.

So, what were the reasons for making a direct decision or waiting for additional information? A first thing to notice is that no one in the direct group referred to the time limit condition in their motivation, and only one person touched upon the shift of choice condition. Additionally, only three participants expressed a reason that could be clearly classified as loss aversion, i.e. that they preferred a "risky gamble" with the chance of zero losses in favour of certain losses, and only two more motivations could possibly be categorised as loss aversion. Instead, 93% (n = 50) in the direct group expressed some form of distrust regarding *the value of more information gathering relative to the cost of waiting* for making a direct decision (Table 1).[1] In addition, 15% (n = 8) expressed *remaining uncertainty regarding an attack* as a reason, regardless if more information is gathered or not.

Thus, the reason for making a direct decision seems not to have been *loss aversion*, but rather that the "gamble" of a direct decision was considered more attractive than the "gamble" of waiting.

In the waiting group, the motivations were somewhat different. It is not to any surprise that the participants in this group wanted better information, and the results show that 79% (n = 41) motivated their decision to wait with a reason related to *minimising the risk with a better operational picture* (Table 1). The results also show that 27% (n = 14) in the waiting group pointed out that it was *acceptable to take a cost for additional information*. Thus, the reasons for waiting can be summed up as an opinion of the participants in the waiting group that it was worth the cost to have a chance of obtaining better information.

Moreover, no one motivated their direct decision with the reason that he/she felt satisfied with the information situation. Hence, in this respect there seems to be no differences between the groups. This is also supported by the result showing that there was no difference between the groups regarding how confident they felt in their choice of COA. An independent-samples t-test was conducted to compare the *feeling of confidence* regarding the selection of COA. There

Table 1. Percentage distribution of verbal motivations for making a direct decision or waiting for additional information.

	Direct group (n = 54)	Waiting group (n = 52)
Distrust in information gathering relative to the cost of waiting	0.93	–
Remaining uncertainty regarding an attack	0.15	–
Minimizing the risk with a better operational picture	–	0.79
Acceptable to take a cost for additional information	–	0.27
Other reasons	0.30	0.12

was not a significant difference in the scores for the direct group ($M = 66.91$, $SD = 13.11$) and the waiting group ($M = 67.62$, $SD = 12.67$); $t\ (104) = -0.28$, $p = 0.78$ regarding the participants' feeling of confidence.

Our third question was: *If some decision-makers choose to wait with their decision, do they show restraint regarding how long they wait, and what determines their waiting time?* In this case it is impossible to calculate the guaranteed accurate value of information. Despite this, to come up with a reasonable restraint time limit we argued as follows, based on the reasoning within the concept Value of Information (VoI) (Heat, et al., 2017).[2] In the absence of additional information, the best alternative is COA 1 with an expected loss of 500 people (0.5*1000). The most optimistic expected losses, given perfect information about the probability for an attack on both COA 1 and COA 2, is 400 people for COA 1 (0.4*1000). The difference between these two losses is 100 people (500-400), and because the cost of waiting for additional information is 20 people per hour, this gives a maximum waiting time of 5 hours ((500-400)/20). Hence, waiting 5 hours or more for the information makes no sense from the perspective of VoI, since the value of the information then is 0. Moreover, it must be underscored that the 5 hour limit represents the maximum reasonable waiting time if the alternative with least expected loss after receiving the perfect information is 400 people. If the perfect information should reveal that the expected loss of the best alternative is 650 people the waiting time limit is zero. Thus, waiting for more information in this case is probably not a very good strategy. Nevertheless, Table 2 shows that 34 of the 52 participants (65%) who waited for information were willing to wait 5 hours or more, and that 22 of these were even willing to wait 10 hours or more for additional information.

So, what was it that determined the waiting time? 30 participants in the waiting group stated a reason for their waiting time in their verbal motivations. Almost all of these participants related their waiting time to *the cost of an attack*, i.e. the death of 1000 people if an attack were conducted. In addition, eight participants related their waiting time to some paraphrase of an "attack" or to "rescue more people", which can be related to the cost of an attack as the basis of the waiting time. Only one participant mentioned the time limit condition, and no one referred to the shift of choice condition in their motivations. Thus, the waiting time was for the most part not related to the expected value of information, but instead to some appropriate proportion of the cost of an attack.

Discussion

The results in this study show that 51% of the participants made a direct decision and that 49% decided to wait for additional information. Most of those who decided to wait showed little restraint regarding their waiting time.

From a practical point of view these results indicate that presenting uncertainty to decision-makers by using imprecise probabilities in the form of ranges could be a problem in time critical situations, i.e. leading to delays that are not motivated by the value of the information that might be obtained. Also Durbach and Stewart (2011) have found that presenting uncertainty to decision-makers can be problematic and lead to poor choices, but in their study the poor choices were related to the use of a histogram for presenting the uncertainty in a non-time critical economic investment situation. Nevertheless, just as in Dieckmann et al. (2010), Joslyn and

Table 2. Distribution of waiting hours in the waiting group.

Waiting hours	Number of participants (n = 52)
<5	18
5–9	12
10–14	10
15–19	0
20–24	10
>24	2

LeClerc (2012) and Budescu et al. (2009), many of the participants in this study were able to use the uncertainty information presented in the probability ranges - in this case to choose a perceived "safer" course of action.

From a theoretical point of view the results do not support the view that decision-makers in this type of decision-making situation are loss averse. Of those who took a direct decision only a few referred to unwillingness to take a certain loss as an explanation. Instead, most of the participants in the study were dissatisfied with the information situation in the scenario and they expressed a willingness to improve this situation. This is in line with earlier findings, that decision-makers in general dislike ambiguity and other forms of uncertainty when making decisions (e.g. Ellsberg 1961; Becker and Brownson 1964; Kleindorfer et al. 1993; Einhorn and Hogarth 1985; Curley et al. 1986; Frisch and Baron 1988; Fox and Tversky 1995; Keren and Gerritsen 1999; Visschers 2017; Lipshitz and Strauss 1997).

A possible practical implication from the results in this study is that it may be problematic to, without some form of requirement, present uncertainty in risk descriptions in time critical decision-making situations, since this can lead to unwanted delays in the decision-making process. Nevertheless, because the uncertainty information was found to be useful for many of the participants it may be the best alternative to present it anyway, but with the requirement that those who receive the information must be able to handle it. How could we achieve this? One possible way could be to encourage decision-makers to not wait for additional information in these kinds of decision-making situations. However, sometimes new and better information could be available shortly. Thus, urging people to make direct decisions in such situations could be counterproductive. Furthermore, none of the participants mentioned the *time limit condition* in their verbal reports, and only one referred to the *shift of choice condition*. This could mean that most of the participants were unaware of these conditions. This, suggests that making decision-makers aware of the nature of the task may be a better prerequisite for success. Consequently, educating decision-makers to make them aware of the *time limit condition* and the *shift of choice condition* could be a way forward.

The results in this study indicate that presenting uncertainty in risk descriptions may lead to delays in time critical decision-making situations, and that these delays can be problematic. Thus, the results are not conclusive with respect to whether presenting uncertainty in time critical decision-making situations actually poses a serious practical problem. Nevertheless, the results warrant further attention and more studies of the presentation of uncertainty in such situations. Therefore, before taking actions to handle this problem it may be a good strategy to determine the severity of it. The next two studies in this series concentrate on this severity problem. The first of these studies focuses on the degree of ambiguity, i.e. the width of the probability range. According to Becker, and Brownson (1964) and Larson (1980), a higher degree of ambiguity may lead to higher ambiguity aversion. If that is the case, would higher degrees of ambiguity than those used in this study lead to more people waiting? The first of the next two studies aims to investigate this question.

The second study investigates if the results obtained in the present study are also valid for people who handle time critical decision-making situation in real life, in contrast to the more inexperienced university students who participated here. According to Heath, and Tversky (1991) people's beliefs regarding their general knowledge or understanding of a relevant context affects their attitude toward ambiguous situations. The fact that almost half of the participants in the present study chose to wait with their decision can be seen as problematic, but is it better or worse for the category of decision-makers that faces time critical decision-making situations in their profession? The second study aims to address this question.

Conclusions

In the present study we investigated the consequences of presenting imprecise probabilities in risk descriptions in time critical decision-making situations, where delaying decisions leads to costs or losses. The aim was to make a first estimation regarding if presenting uncertainty in risk descriptions, by using imprecise probabilities in the form of ranges, could be a practical problem in these kinds of decision-making situations.

The results show that 49% of the participants in the study decided to delay their decision and wait for additional information despite the relatively low potential value of the new information. Most of those who decided to wait showed little restraint regarding their waiting time. These results indicate that presenting uncertainty to decision-makers by using imprecise probabilities could be a problem in time critical decision-making situations. Since such situations can be quite common in professional domains where the potential consequences of the decision might be significant, e.g. in military or crisis management contexts, the problem warrants further attention.

Notes

1. In the direct group, 63% of the participants gave more than one reason for their direct decision and in the waiting group 17% gave more than one reason for delaying their decision. That is why the percentage distribution amounts to more than 100% for each group.
2. It is important to note that our calculations assumes a risk-neutral decision-maker and since we use a subjective interpretation of probability, the expected losses in our calculations do not necessarily correspond to the actual losses that would occur, on average, if the situation was repeated a large number of times. Instead, the expected losses should only be seen as a way of evaluating an uncertain situation on behalf of the decision-maker.

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Appendix. The text-based fictive military scenario (Figures 3–6)

Instruction

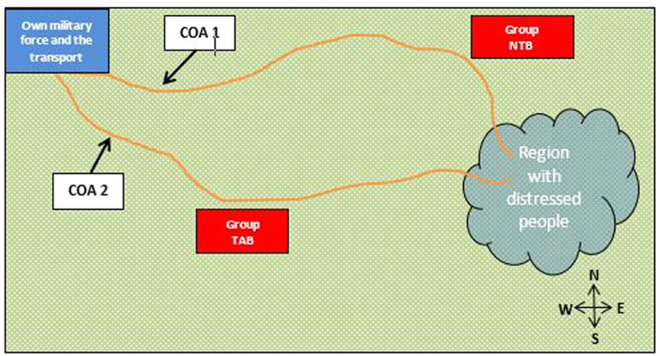
Read the fictional **Scenario** below and the sections describing **Your task and prerequisites** as well as the **Risk assessment** and then answer the succeeding **Questions**.

Scenario:

In TOGALAND, there has been a conflict for several years between two ethnic groups, both of whom consider themselves entitled to the same area of the country. The two conflicting groupings are: "Northern Togan Liberation Front" (NTB) and "Togan Autonomous Population" (TAB). As a result of the ongoing conflict between these groups, there is a great lack of food, medicines and other necessities in most parts of the country. In the eastern part of the country (see map below) there is a demarcated region with approximately 100,000 distressed people from the Madogos population, who are in urgent need of both food and medicine. Every hour 20 Madogos die in the region due to starvation, diseases and other hardships. Since a week the Red Cross, together with the United Nations, has been ready to send a transport to the region consisting 20 large trucks with trailers, containing food and other supplies lasting for about two weeks. But because of the conflict in the area, the transport needs escort by military units in order to reach the distressed region.

Your task and prerequisites:

As the commander of a military force consisting of 10 armored vehicles and 5 light terrain vehicles, your task is to escort the transport from the port, located in the northwestern part of the country, to the distressed region in the east. To reach this region, there are only two possible navigable roads (**COA 1** and **COA 2**). Both of these roads are about 100 km and pass through the areas where the two hostile groupings NTB and TAB operates. These groups are assumed wanting to usurp the necessities of the transport, so regardless if COA 1 or COA 2 are selected there is a risk for the transportation, while at the same time an incorrect decision in route selection may cost many lives due to lack of help. In order to carry out the escort efficiently, the transport requires cohesion along one of the roads.



1

Figure 3. Instructions for participants, page 1.

Risk assessment:

The military staff's risk analysts has made the following risk assessment based on the information currently available:

Alongside **COA 1** operates the group **"Northern Togan Liberation Front" (NTB)**. Choosing COA 1 as the transport route thus poses a risk that the transport will be attacked by this group. Such an attack would not stop the transport, but an attack would mean that 1,000 distressed people die "unnecessary", due to delays and partly missing deliveries of food and medicine, compared to whether the transport would arrive undisturbed. The estimated probability for an attack along COA 1 is **50%**. However, there is uncertainty regarding this estimation. The uncertainty is primarily about NTB's priorities between attacking the transport and trying to achieve other goals, such as defending land-based terrain against TAB. Depending on what is NTB's real priority, the correct probability of an attack along COA 1 is somewhere in the range of **40% -70%**, i.e. the probability of an attack can be as low as 40% or as high as 70%.

Alongside **COA 2** operates the group **"Togan Autonomous Population" (TAB)**. Choosing COA 2 as the transport route thus poses a risk that the transport will be attacked by this group, which would cause as much damage to the transport as an attack along COA 1, i.e. that 1,000 distressed people die "unnecessary" due to delays and partly missing deliveries of food and medicines. The estimated probability for an attack along COA 2 is **60%**. However, there is uncertainty regarding this estimation. The uncertainty is primarily about TAB's priorities between attacking the transport and trying to achieve other goals, such as defending land-based terrain against NTB. Depending on what is TAB's real priority, the correct probability of an attack along COA 1 is somewhere in the range of **45% -65%**, i.e. the probability of an attack can be as low as 45% or as high as 65%.

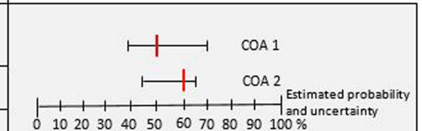
In summary, the estimated probability for an attack along COA 1 is somewhat **lower** than the probability of an attack along COA 2, but the uncertainty about the probability along COA 1 is slightly **greater** than the uncertainty regarding COA 2. Current risk assessment is summarized as follows:

Intelligence report

Bad intelligence situation. There is uncertainty regarding the priorities of the groupings.

Difficult to estimate the correct probability of an attack along both COA 1 and COA 2.

COA	Estimated probability for an attack	Uncertainty range
COA 1	50%	40% – 70%
COA 2	60%	45% – 65%



2

Figure 4. Instructions for participants, page 2.

Intelligence gathering is ongoing in the area, with the objective to determine the real priorities of the groupings to attack the transport, which hopefully will provide new and more accurate estimations regarding the risks of choosing COA 1 or COA 2 as a route.

The first thing that has to be decided is whether you shall make a decision directly about the route on the information currently available OR if you instead shall choose to wait for further intelligence. More information may provide a better picture of the true risk of an attack for respective COA, thus helping to better determine whether the two COA is different and, if so, which COA has the lowest risk for an attack (as stated above , an attack means that 1,000 people in distress die "unnecessary"). Waiting for additional information, however, has a cost in the form of the death of 20 distressed people every hour during the waiting period.

Questions:

1) During current circumstances – how many hours are you willing to wait for additional information before you instead decide to make a decision directly on the information currently available? (If you want to make a decision directly, write 0 hours)

Number of hours: ....

2) Write a brief motivation regarding your answer to Question 1.

3

Figure 5. Instructions for participants, page 3.

3) Imaging that you just learned that there will be no additional information, and that you have to make a decision regarding the route on available information. Which route would do you choose?

I choose:

☐ COA 1

☐ COA 2

4) How confident do you feel about your route selection? Distribute 100 points between the two options COA 1 and COA 2 (e.g. 60 on one and 40 on the other).

COA 1: ....

COA 2: ....

5) Write a brief motivation regarding why you chose this route

4

Figure 6. Instructions for participants, page 4.