HOW FORM AFFECTS FUNCTION: ON THE POSSIBILITY OF AGGREGATING RISK INFORMATION

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ABSTRACT

Geared towards all-hazard and whole-of-society approaches, contemporary disaster risk management is dependent upon exchange and integration of information across societal sectors and administrative borders. We focus on the ability of assessing overall risk in functional or geographical areas based on risk descriptions from multiple stakeholders and seek to establish which characteristics of information that is most conducive to creating such overviews. The paper presents results from an ongoing experimental study where students of risk management are asked to rate how useful different combinations of risk descriptions, pertaining to two fictional municipalities, are as a basis for comprehensive risk assessments and decisions on risk reducing measures. The participants consider quantitative risk descriptions as most constructive for decision-making, whereas descriptions that solely rest on qualitative statements provide most difficulties in this regard. In addition, the findings show that disparities in how descriptions of risk are presented have a negative effect on people's ability to synthesize information from several risk assessments. Thus, from this perspective it is better to use the same type of risk description (e.g. quantitative or qualitative) than mixing different types of descriptions.

Key words: *risk assessment, risk communication, whole-of-society, aggregation of information*

I. INTRODUCTION

The recently adopted Sendai Framework for Disaster Risk Reduction highlights the importance of integrated planning and exchange of information across functional sectors and administrative borders.[1] This emphasis on collaboration and information sharing in disaster risk management (DRM) contexts is not new however. Inter-organizational collaboration is the backbone of whole-of-society and all-hazard approaches to DRM, which were instigated by the end of the cold war and further advocated in the wake of pandemic influenzas in the beginning of the 21st century.[2-5] Along these lines, many countries have issued legislations and established processes to foster an exchange of risk information in support of holistic apprehensions of risks.[6] Being able to aggregate[a] risk information from various sources is vital for decisions on how to allocate limited resources (i.e. for prioritizations between hazards, functional and geographical areas and risk reducing measures) in DRM systems.[b] As such, it is decisive for the ability to reduce losses in terms of lives, property and environment that hazards may bring about.

[a] A general definition of *aggregation* implies the collecting of units or parts into a mass or whole.[18] In this paper aggregating information refers to the processes of collecting pieces of information from various sources as well as making sense of the collected material. The sense-making activity entails assessing relationships between the constitutive parts, which may produce knowledge that would not appear if analyzing the parts in isolation only. As such, our view of aggregating information goes beyond making a compilation or a summary of assembled information.

[b] We use the term disaster risk management system to denote a set of elements (organizational, legal, financial, policy frameworks) established to avoid or to limit the adverse impacts of disasters in a society.

However, attaining holistic apprehensions of risk involves numerous challenges; from identifying what information one needs and where to find it, to acquiring it and later make sense of the collected material. We are interested in the latter, sense-making part of this process and focus on how different ways of describing risk influence the ability of using the information as basis for aggregation and decision-making. In modern DRM systems the involved actors (e.g. local municipalities and national authorities) often need to rely on risk assessments produced by other actors as a basis for their own activities.[c] Sometimes, it entails making decisions based on the assessments and sometimes it involves using them as inputs to produce new risk assessments. A typical situation of the latter is when a regional authority (e.g. a county administrative board in Sweden) uses risk assessments produced by local municipalities as a basis for creating a regional analysis. The present paper describes an experimental study which simulates such a situation. The experiment was designed to investigate how various ways of describing risk influence the possibility of aggregating information from different risk assessments.

II. BACKGROUND

The problem of how to communicate risk has received considerable attention by researchers; see for example reviews in Fischoff,[7] Gurabardhi, Gutteling and Kuttschreuter,[8] and Sheppard, Janoske, and Liu.[9] However, most of the research has been concerned with communication between experts and the public and not so much with expert-to-expert communication.[10,11] As argued by Lin, Abrahamsson and Tehler, expert-to-expert communication of risk is crucial in order for the actors involved in a DRM system to be successful in their collective management of disaster risk.[12] Previous research regarding communication of risk in DRM systems has mostly been descriptive in nature, e.g. Vastveit, Eriksson and Njå[13] and Månsson, Abrahamsson, Hassel and Tehler.[14] However, a few studies have also been focused on investigating how the perceived usefulness of a risk description is influenced by how risk is described.[12,15] The results from those studies show that the way risk is presented in a DRM context will influence the perceived usefulness of the descriptions as a basis for decision-making. Moreover, the results indicate that using quantitative descriptions (e.g. frequencies to describe likelihood and numbers, volumes and areas when describing consequences) rather than qualitative ordinal scales, will increase the usefulness of a risk description. The previous investigations have been focusing on risk descriptions of five types (see below). The five types correspond to the different ways of describing likelihood and consequences that were found after having reviewed more than 120 reports from risk assessments conducted by authorities at all administrative levels (local, regional and national) in Sweden.[14] The five classes are:

1) Not at all (i.e. there is no description of likelihood or consequences)
2) Qualitative (mere descriptions in words, without the use of scales, e.g. unlikely, moderate)
3) Qualitative ordinal scales (a scale containing sequential steps, e.g. low-middle-high)
4) Semi-quantitative ranking scales (similar to qualitative ordinal scales, but where each step is combined with a probability range or an interval indicating the magnitude of consequences, e.g. 1 time between 10 and 100 years or 5-10 casualties)
5) Quantitative scales (implying the use of frequencies, i.e. the number of events per unit of time, and consequences expressed in numeric estimates only, e.g. volumes, areas, numbers)

The studies referred to above have all been concerned with *single* risk descriptions. However, in DRM systems actors often have to rely on several sources of risk information, and the challenge often lies in how to combine them. Therefore, the present study focuses on multiple risk descriptions and their combined usefulness. To this end, we present results from experiments aimed at investigating the perceived usefulness of various combinations of two risk descriptions. Perceived usefulness is here defined as *the degree to which a person believes that the information contained in two or more risk descriptions would enhance the basis for an overall apprehension of risk, and as support of decisions on risk reducing measures*.

Our experiment entails cases where the risk descriptions that need to be aggregated utilize different ways of expressing likelihood and consequences (e.g. one of the risk descriptions may be expressing likelihood and consequences using a qualitative ordinal scale whereas the other could be using frequencies). The purpose of our study is to contribute to the understanding of how different formats of risk information in DRM systems influence the usefulness of the information. Ultimately, such knowledge should be valuable when deciding on

[c] The terms *actor* and *stakeholder* are used interchangeably in this paper to denote organizations and interest groups rather than individuals or cultural artefacts (e.g. documents or systems). Depending on the context, it may imply public authorities with a formal responsibility to cater for societal safety or other parts of society which contribute to or are affected by hazards (e.g. private companies, voluntary groups and the general public).

how professionals need to communicate risk to each other in order to facilitate aggregation and, hence, increase their possibility of appreciating the overall risk in functional or geographical areas.

III. EXPERIMENT

III.A. Overview

The aim of the experiment was to explore which type of risk description that is deemed as most useful when participants had to judge the usefulness of two risk descriptions in combination. Moreover, we set out to investigate whether this ranking coincide with the types of risk descriptions that Lin et al. found to be most useful as bases for decisions on risk reducing measures (i.e. the semi-quantitative and quantitative risk descriptions).[12] Finally, we wanted to compare the perceived usefulness of two risk descriptions of the same type (hereafter termed "pure" combination of risk descriptions) with two risk descriptions of different types (hereafter called "mixed" combination of risk descriptions). Would a mix of two different types of risk descriptions be considered as less, more or as useful as a pure combination of risk descriptions? Thus, given that participants rate a pure combination of two risk descriptions of *type A* as more useful than a pure combination of two risk descriptions of *type B*, will a mix of these two types of risk descriptions be considered as useful as the pure combinations (either *type A* or *type B),* or will the usefulness of such a mix be apprehended as somewhere in the middle of the perceived usefulness of these two options?

III.B. Experimental Design

We wanted the participants to assess the usefulness of the various combinations of risk descriptions in relation to each other. Hence, the experiment was run as a within-subject design, meaning that each participant had to appraise all combinations of risk descriptions. However, including the five types of risk descriptions as presented in the background section would entail 15 combinations to assess. This would require a lot of time and potentially undermine the willingness to take part in the experiment. It would also entail a risk of carry-over effects, where participants' concentration, energy and performance deteriorate along the course of the experiment, making comparisons of the assessments across the different combinations questionable.[16] For these reasons, we chose to delimit the experiment to risk descriptions of classes 2, 3 and 5. That we chose to omit class 1 may be evident as there would be nothing to assess. Exclusion of class 4 requires a motivation however. The studies performed by Lin et al. indicate that people essentially equate the usefulness of semi-quantitative and quantitative risk descriptions as basis for decisions on risk reducing measures.[12,15] As we expected these two types of risk descriptions to also be perceived as equally useful for the purpose of aggregation, we chose to omit one of them. In this case we chose to keep the quantitative risk description. The reason was that it is easier to avoid introducing spurious effects due to different numbers of words in the risk descriptions when using a quantitative risk description compared to a semi-quantitative (see discussion in Lin et al.).[12]

The three types of risk descriptions can be combined in six different ways:

1) Quantitative + quantitative
2) Qualitative ordinal + qualitative ordinal
3) Qualitative + qualitative
4) Quantitative + qualitative ordinal
5) Quantitative + qualitative
6) Qualitative ordinal + qualitative

Each of these combinations represents one experimental condition. Hence, every participant was asked to assess the usefulness of each of these six combinations of risk descriptions in relation to a flood scenario which was held constant for the different conditions (the scenario and the different risk descriptions are provided in the appendix). To avoid response trends we varied and randomized the order with which the combinations of risk descriptions were presented to the participants.

III.C. Participants

In total 27 students participated in the experiment, 15 males and 12 females, aged 22 to30 years (mean 25). All of them study risk management as part of an engineering program at Lund University. They were selected because they were expected to have a preconceived notion of risk and, hence, to comprehend the nuances of the risk descriptions used in the experiments.

III.D. Procedure and Materials

To ensure a high response rate, the experiment was conducted in conjunction with compulsory lectures. The students were handed a document and asked to assume the role of an official at a regional county administrative board. The "official" was about to compare assessments conveyed by two neighboring municipalities on the likelihood and consequences of a flood scenario and assess the overall, regional risk, on this basis. The document contained an introductory page explaining its structure and contents. Hereafter, the participants were asked to provide some background data concerning themselves, including age, gender and previous experience from risk management in the public sector. The following six pages contained the description of the scenario together with one of the six different combinations of risk descriptions as enumerated in Section 3.2. In each case, the participants were asked to use a 7-point Likert type response scale to indicate the extent to which they concurred to a number of statements (1 indicating that they strongly agreed, and 7 that they strongly disagreed). In the present paper we focus on two of these:

1. It is easy to understand which of the municipalities that face the greatest risk

2. The description of the scenario and adhering risk assessments are useful as a basis for decision on risk reducing measures in the area concerned (municipality 1 and 2)

There are many ways to operationalize and investigate the process of aggregating risk information. We used the results from the two statements above to serve as the dependent variables in the experiment. The statements reflect two important, and somewhat overlapping, purposes of aggregation in the present context. The first relates to creating an overview of risk, and judging where it is greatest, based on assessments conducted by others. The situation is similar to that of a county administrative board in Sweden who uses risk assessments produced by the local municipalities in their region as a basis for producing their own risk assessment. The second is related to making decisions based on such material. Although we expected the responses to the two statements to be similar, in practice it is often a significant difference between producing an overview of risk and judging where the risk is greatest and making decisions regarding, for example, which risk reduction alternative one should choose. An overview of risk is certainly helpful to determine *where* limited resources and assistance should be directed but does not provide an answer to which *type* of assistance that would be needed, i.e. what to *do* to reduce the risk.

IV. RESULTS AND ANALYSIS

Table 1 shows how useful the combinations of risk descriptions are perceived to be as support of decision making as well as how easy it is to use them for creating an overview of risk and compare the risk faced by the two municipalities. The table displays the mean values of the participants' responses. "1" means strongly agreeing and "7" strongly disagreeing with a particular statement. Therefore, the lower the mean value, the more the participants perceived a specific combination of risk descriptions to be useful for decision-making or risk overviews and comparisons. The shaded rows represent the "pure" combinations of risk descriptions, i.e. when both risk descriptions belong to the same type. Moreover, when discussing the results below we will refer to the quantitative risk descriptions using the letter "A", the ordinal ones with the letter "B" and the qualitative ones with the letter "C". A combination of risk descriptions will be denoted using the same letters separated by a "+" sign. Thus, (A+A) means a pure combination of two quantitative risk descriptions.

Table I. Mean values of the participants' responses (n = 27).

Experimental condition	Decision-making	Overview of risk
Quantitative + Quantitative (A + A)	2,44	2,93
Ordinal + Ordinal (B + B)	4,41	4,22
Qualitative + Qualitative (C + C)	4,81	4,70
Quantitative + Ordinal (A + B)	4,37	5,59
Quantitative + Qualitative (A + C)	4,59	5,93
Ordinal + Qualitative (B + C)	4,74	5,07

The results indicate the same trend as seen in previous studies, i.e. that quantitative descriptions are perceived as more useful for decision making than qualitative ones. Interestingly, the same trend is present when considering their usefulness for producing risk overviews in order to determine which municipality that faces the greatest risk.

To investigate the effect of combining *different* types of risk descriptions, one needs to analyze the information in table 1 in more detail. More precisely, it is necessary to investigate what happens when one of two risk descriptions in a pure example (e.g. both risk descriptions are quantitative, A+A) is exchanged for another type. Will the perceived usefulness of the combined risk descriptions change and in that case how? Since we have three pure examples (A+A, B+B and C+C), we may compare the mix of two risk descriptions to its pure counterparts in three cases. For example, we can compare the pure (A+A) version to the pure (B+B) version and relate these two combinations to a mixed version (A+B). In figure 1 the three comparisons are illustrated with respect to how useful the combinations of risk descriptions are perceived to be when utilized as support of decision-making. Each column of boxes represents a comparison of two pure combinations (shaded boxes) with their mixed counterparts (white boxes). The boxes are arranged such that the combination representing the experimental condition that were perceived to be most useful for decision-making are placed on top of the ones representing the conditions not perceived to be as useful. Although the mean values presented in the figure indicate a difference between two experimental conditions, it might not be statistically significant. To indicate whether there is a statistically significant difference (using a Wilcoxon signed-rank test with p = 0,05), lines connecting the conditions are used.[17] A line connecting two conditions means that the difference in mean value is *not* statistically significant. Conversely, a lack of a line means that there *is* a statistical significant difference between the corresponding two conditions.

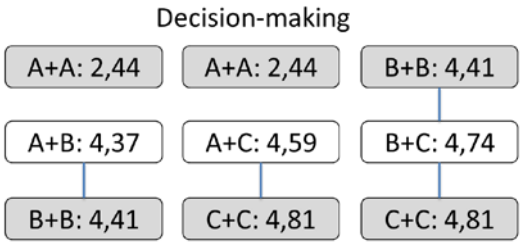

Figure 1 Illustration of the results to highlight the comparison of pure combinations of risk descriptions with their mixed counterparts, focusing on their usefulness as support of decision-making.

From the illustration in figure 1 it is clear that when mixing two types of risk descriptions, one which is considered more useful than the other, the resulting mix is essentially perceived as being *equally* useful as the least useful one. Interestingly, when studying how the participants rated the usefulness of the risk descriptions with respect to how easy it is to create an overview of risk, another pattern can be seen. Figure 2 illustrates these results.

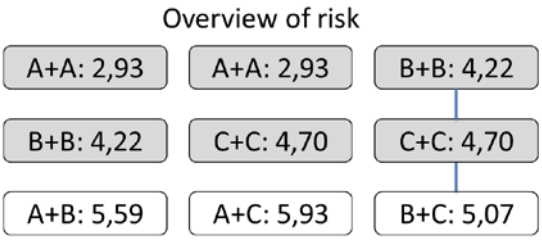

Figure 2 *Illustration of the results to highlight the comparison of pure combinations of risk descriptions with their mixed counterparts, focusing on their usefulness when creating overviews of risk.*

Comparing the results illustrated in figure 1 with those in figure 2, it is clear that there is a difference in terms of how the mixed and the pure combinations of risk descriptions are rated. When focusing on the extent that a combination of two risk descriptions is useful to create an overview of risk, the mixed combinations are considered *less useful* than the least useful of the pure combinations of risk descriptions.

V. DISCUSSION AND CONCLUSIONS

The study shows that descriptions of likelihoods and consequences can have a significant impact on the ability of stakeholders to make well informed decisions as well as on their ability to appreciate overall risk based on multiple risk descriptions. Moreover, the participants in the experiment perceived quantitative risk descriptions as more useful than qualitative ones for both of these purposes. However, the possibility of making quantitative estimates of likelihood and consequences depends on available evidence and this differs between countries as well as types of disasters. It is for instance easier to describe risks in quantitative terms when assessing common scenarios for which there may be ample statistical data (e.g. traffic accidents, fires, floods) than rare, systemic risks, which induce simultaneous and ambiguous consequences across geographical areas and a number of societal sectors. Thus, although our study clearly indicates the value of quantitative estimates, one must realize that using quantitative data is not always a viable option.

Whilst probing the usefulness of the combinations of mixed types of risk descriptions, some interesting observations were made. When used as basis for decision-making, the participants deemed them as *equally* useful as a pure combination of the *least* useful of the types of risk descriptions involved. With regards to aggregation, mixed combinations of risk descriptions were considered as *less* useful than a pure combination of the *least* useful of the involved risk descriptions. These results highlight the difficulties of bringing sense out of dissimilar types of risk descriptions. One must also consider the fact that our experiment only encompassed combinations of two different risk descriptions. In reality, any actor that aspire to attain a comprehensive understanding of risk in geographical or functional areas need to consider input from far more than two stakeholders (aside from risk descriptions conveyed by private players and national authorities, a medium sized county administrative board in Sweden receives input from about 10 different municipalities). If the participants in our experiment have trouble even to aggregate two risk descriptions of different types, one must assume that the difficulties of doing so multiplies by the numbers of disparate risk descriptions involved. Taken together, the results of our experiment suggest that stakeholders, when feasible, should opt for describing risks quantitatively and align their ways of presenting them with regards to e.g. scales and consequence dimensions.

VI. FINAL REMARKS

In the experiment, we intentionally kept the scenario rather brief as we did not want it to become arduous to read, yet provide enough details to be able to assess the usefulness of the risk descriptions. A more thorough account of “background knowledge”, i.e. presumptions and facts that support the estimations on consequences and likelihood, may profoundly affect the perceived usefulness of the risk descriptions. Moreover, we suspect that the numeracy of respondents may influence their views on the usefulness of different risk descriptions, i.e. that more numerate persons tend to focus on and appreciate quantitative evidence, whereas less numerate persons would rely more on qualitative data (e.g. a narrative providing background knowledge). However, if numerate and less numerate persons converge in their opinions on which types of risk descriptions that are most useful for the purpose of decision-making as well as aggregation, it renders a compelling argument for how professionals ought to communicate risk descriptions to each other. Hence, we believe it is valuable to test this

by carrying out a comparative study which involves more varied respondents in terms of numeracy as well as more profound narratives. Such a study is presently being conducted.

APPENDIX

Flood Scenario

There are several rivers that may cause flooding in both municipalities. However, the risk of flooding has been deemed to be greatest along the watercourses with the largest catchment areas, which are located close to the most populated districts in the municipalities. The areas that are threatened by flood are reasonably flat, which means that large parts of the municipalities may be affected if a flood occurs. As a basis for reporting in accordance with the EU Flood Directive (2007/60/EC), the county administrative board has requested that the two municipalities assess the risk adhering to the maximum calculated flow in each of the rivers. This implies that the water level in the watercourses rises 2.5 meters above the normal level, which means that both municipalities will be flooded. There are residential areas as well as several critical infrastructures (e.g. electrical substations, roads and railroads) in these areas.

Table II. Combinations of Risk Descriptions with Varied Ways of Expressing Likelihood and Consequences

Combinations of risk descriptions	**Municipality 1**	**Municipality 2**
1. Quantitative + Quantitative (A + A)	The likelihood of the scenario is assessed to be once every 100 years. If the scenario occurs, the consequences are judged to be: flooding of approximately 2000 residential homes, one water purification plant, 75 hectares of polluted land, two schools, one hospital, one health care center, one highway and one railroad.	The likelihood of the scenario is assessed to be once every 50 years. If the scenario occurs, the consequences are judged to be: flooding of approximately 1000 residential homes, one electrical substation, two schools, one health care center and one highway.
2. Ordinal + Ordinal (B + B)	The likelihood and consequences have been assessed using five-level scales (Very low, Low, Moderate, High, Very high) and (Very limited, Limited, Serious, Very serious, Catastrophic). The likelihood of the scenario is judged to be Low. The consequences of the scenario are judged to be Very serious for residents, and include disturbances in the transportation systems (flooded/damaged roads and railroad) as well as in the supply of electricity.	The likelihood and consequences have been assessed using five-level scales (Very low, Low, Moderate, High, Very high) and (Very limited, Limited, Serious, Very serious, Catastrophic). The likelihood of the scenario is judged to be Moderate. The consequences of the scenario are judged to be Serious for residents, and include disturbances in the transportation systems (flooded/damaged roads) as well as in the supply of electricity.
3. Qualitative + Qualitative (C + C)	The likelihood of the scenario is judged to be low. The consequences are judged to be very serious for residents, and include disturbances in the transportation systems (flooded/damaged roads and railroad) as well as in the supply of electricity and drinking water.	The likelihood of the scenario is judged to be moderate. The consequences are judged to be serious for residents, and include disturbances in the transportation systems (flooded/damaged roads) as well as in the supply of electricity.
4. Quantitative + Ordinal (A + B)	The likelihood of the scenario is assessed to be once every 100 years. If the scenario occurs, the consequences are judged to be: flooding of approximately 2000 residential homes, one water purification plant, 75 hectares of polluted land, two schools, one hospital, one health care	The likelihood and consequences have been assessed using five-level scales (Very low, Low, Moderate, High, Very high) and (Very limited, Limited, Serious, Very serious, Catastrophic). The likelihood of the scenario is judged to

	center, one highway and one railroad.	be Low. The consequences of the scenario are judged to be Very serious for residents, and include disturbances in the transportation systems (flooded/damaged roads and railroad) as well as in the supply of electricity.
5. Quantitative + Qualitative (A + C)	The likelihood of the scenario is assessed to be once every 100 years. If the scenario occurs, the consequences are judged to be: flooding of approximately 2000 residential homes, one water purification plant, 75 hectares of polluted land, two schools, one hospital, one health care center, one highway and one railroad.	The likelihood of the scenario is assessed to be low. The consequences are deemed to be very serious for residents, and include disturbances in the transportation systems (flooded/damaged roads and railroad) as well as in the supply of electricity.
6. Ordinal + Qualitative (B + C)	The likelihood and consequences have been assessed using five-level scales (Very low, Low, Moderate, High, Very high) and (Very limited, Limited, Serious, Very serious, Catastrophic). The likelihood of the scenario is judged to be Low. The consequences of the scenario are judged to be Very serious for residents, and include disturbances in the transportation systems (roads and railroad) as well as in the supply of electricity.	The likelihood of the scenario is assessed to be low. The consequences are deemed to be very serious for residents, and include disturbances in the transportation systems (flooded/damaged roads and railroad) as well as in the supply of electricity.

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