Chapter 13

Variability of Natural Hazard Risk in the European Alps: Evidence from Damage Potential Exposed to Snow Avalanches

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CONTENTS

Abstract In recent years, risk analyses emerged as the appropriate method to assess natural hazards in the European Alps. The methodology is comparatively reliable in determining the hazard potential and the related probability of occurrence of defined design events, even if modeling approaches differ. So far, little attention has been given to the damage potential affected by those design events, especially concerning temporal changes. The damage potential, particularly the tangible asset, is subject to long-term changes due to the socioeconomic development of mountain regions since the outgoing nineteenth century. These long-term changes lead to variations in the resulting risk, dependent on the dimension of the individual hazard impact. Because of seasonal and diurnal variability of intangibles, short-term changes of damage potential interfere with those long-term developments. As intangibles form an essential part of damage potential, significant differences in the values at risk could be observed. In this study, long-term as well as short-term shifts in the values at risk are presented for different study areas and on different scales. A conceptual framework for the consideration of those changes in risk analyses is developed, and possible explanations for different trends in different study areas are discussed. The spatial sensitivity of the results is highlighted.

Introduction

The historical shift of a traditionally agricultural society to a service industry- and leisure-oriented society led to socioeconomic development in mountain environments and foreland regions. This shift is reflected by an increasing use of those areas for settlement, industry, and recreation. On the other hand, areas suitable for land development are relatively scarce in the Inner Alpine valleys, e.g., in Austria, only about 20 percent of the whole area is appropriate for development activities [1]. Moreover, those areas are located line-shaped along the valley bottoms. Consequently, a conflict between human requirements on the one hand and naturally determined conditions on the other hand results. Due to an increasing concentration of tangible and intangible assets and to an increasing number of persons exposed to natural processes, which in the case of harm to human life or property are considered as natural hazards, there is an emerging need for the consideration of risk in land-use development.

Dealing with natural hazard processes has a long tradition in European Alpine countries. Early attempts in dealing with natural hazards include the establishment of official authorities in the second half of the nineteenth century, e.g., in Switzerland in the late 1870s [2] and in Austria in 1884 [3]. For more than half a century, technical mitigation measures were developed and implemented. These active measures, which represent the human reaction to hazard processes, appeared to be the appropriate way to cope with this challenge. There was little impetus toward an integrative dealing with natural hazards before the 1950s and 1960s, when extreme avalanche events occurred over wide areas of the Alps. Extraordinary governmental expenditures involved with the technical coping strategies resulting from those extreme events made traditional reactive measures increasingly obsolete. Consequently, ideas of complementary passive protection measures emerged, such as hazard mapping and land-use restrictions.*

Only recently, the responsible authorities in most of the European mountain countries developed theoretical models of integrated risk management, which follow mainly the engineering approach to express risk as a product of hazard and values at risk [5–7] (see Equation 13.1). The development of these models is strongly connected to the considerable amount of damage in the Alps due to natural hazards in recent years [8].

$$R = p_{Si} \cdot A_{Oj} \cdot p_{Oj,\,Si} \cdot v_{Oj,\,Si} \tag{13.1}$$

where

R is risk

p_{Si} is probability of scenario i

A_{Oj} is value at risk of object j

$p_{Oj,\,Si}$ is probability of exposure of object j to scenario i

$v_{Oj,\,Si}$ is vulnerability of object j, dependent on scenario i

* To identify hazard zones, defined design events are used to estimate the range and pressure distribution of the hazard processes. The methodologies applied therefore differ slightly between the Alpine countries, but the principle for drawing up hazard maps is similar, the listing describes the delimitation for snow avalanches in Switzerland [4] and Austria [5]. Inside areas marked with red color, the construction of new buildings is legally forbidden. In blue and yellow areas, particular regulations have to be considered with respect to the expected avalanche pressure, such as the reinforcement of walls at the hillside of a building.

- In Switzerland, red color indicates areas where pressure from avalanches with recurrence intervals T between 30 and 300 years exceeds a lower limit that ranges from 3 kPa for $T = 30$ years to 30 kPa at $T = 300$ years. The entire area affected by (dense flow) avalanches with $T < 30$ years is also marked in red. Blue indicates areas where pressure from avalanches with recurrence intervals T between 30 and 300 years falls below 30 kPa. Areas affected by powder avalanches with reoccurrence intervals $T < 30$ years and a pressure <3 kPa are also marked in blue.

  The run-out areas of powder avalanches with reoccurrence intervals $T > 30$ years and a pressure <3 kPa are marked in yellow, as well as theoretically not excludable but extremely rare avalanches with a reoccurrence interval $T > 300$ years.
- In Austria, red color indicates areas where pressure from avalanches with recurrence intervals $T = 150$ years exceeds a limit ≥ 10 kPa.

  Yellow indicates areas where pressure from avalanches with recurrence intervals $T = 150$ years is >1 kPa and <10 kPa.

According to Equation 13.1 it becomes apparent that all parameters have a linear influence on the results of risk analyses. The procedure of hazard assessment is methodologically reliable in determining the hazard potential and the related probability of occurrence (p_{Si}) by studying, modeling, and assessing individual processes and defined design events [9,10]. So far, little attention has been given to the damage potential (A_{Oj}) affected by hazard processes, particularly concerning spatial patterns and temporal shifts. Until now, studies related to the probability of exposure of an object ($p_{Oj,\ Si}$) to a defined scenario and the appropriate vulnerability of the object ($v_{Oj,\ Si}$) have predominantly been carried out as proposals to determine the risk of property and human life with the focus on a specific location and a specific point in time [6,9,11,12].

However, risk changes over time. Due to climate change processes and the associated impact on the Alps [13], magnitude and frequency of the natural process will most probably slightly increase for those processes where water is the driving agent [14]. In contrast, recent studies with respect to snow avalanches suggested that the natural avalanche activity seems to be constant in the European Alps during the last decades [15]. This led to the conclusion that the change in risk—presumably indicated by remarkable damage in the 1990s—has to be attributed to changes in the damage potential affected [16].

Socioeconomic developments in the human-made environment led to asset concentration and a shift in urban and suburban population in the Alps. Thus, the temporal variability of damage potential is an important key variable in the consideration of risk. Recently, conceptual studies related to the temporal variability of damage potential exposed to snow avalanches have been carried out, focusing both, the long-term and the short-term temporal evolution of indicators [17–19]. Furthermore, owing to the requirement of economic efficiency of public expenditures on mitigation measures, there is a need for a precautionary, sustainable dealing with natural hazard phenomena, taking into account particularly the values at risk [20–22].

On the basis of these studies, the multi-temporal development of values at risk is presented with respect to snow avalanches in Alpine settlements. This multi-temporal approach aims to demonstrate the different superimposed temporal scales in the development of damage potential complementing each another.

Temporal Development of Values at Risk

Case studies have been carried out in Davos (Switzerland) and Galtür (Austria) [17,18]. Both villages represent typical mountain resorts dependent on winter tourism, thus, the results mirror recent developments of society in Alpine destinations. Methodologically, the areas affected by avalanches were deduced using the incident cadastre of former events, the legally valid hazard maps, and the avalanche model AVAL1-D. This model is a one-dimensional avalanche dynamics program that predicts run out distances, flow velocities, and impact pressure of both flowing and powder snow avalanches (a detailed description is given in Ref. [23]).

The values at risk were obtained analyzing the zoning plan with respect to location and perimeter of every building. Additional information, such as building type, year of construction, and replacement value, as well as the number of residents were provided by the official authorities and joint using Geographic Information Systems (GIS). The number of endangered tourists was derived from tourism statistics of the municipalities.

A general shift in damage potential resulted from the development of mountain areas from traditionally agricultural societies to tourism centers within the twentieth century. This development could be evaluated using decadal study periods, and provided a general idea about the development of assets in endangered areas. This approach mainly focused on the development of values in areas endangered by avalanches, such as the number and value of buildings, or the number of persons inhabiting those buildings.

A second development of damage potential, especially focusing on mobile values and intangible assets, is based on a seasonal and diurnal assessment of variations in damage potential. This approach had also been applied for an application related to the number of tourists staying temporally at a specific endangered location.

Long-Term Development of Values at Risk

Regarding the long-term development in numbers and values of endangered buildings, a significant increase could be proven in both study sites for the period between 1950 and 2000 [17].

In Davos, the total number of buildings has almost tripled, from 161 in 1950 to 462 in 2000 (Figure 13.1). This increase was due to the shift from 51 to 256 in the category of residential buildings, while in the other categories the number of buildings was approximately unchanging. A significant increase in number dated back in the 1960s and 1970s before the legally hazard map came into force [16]. The total value of buildings increased by a factor of almost four. In 1950, the total sum of buildings was EUR 240 million and in 2000, the total sum was EUR 930 million. In 1950, the proportion of residential buildings was less than 15 percent, compared to the total amount of endangered buildings. Until 2000, this ratio changed to almost 50 percent. Regarding the category of hotels and guest houses as well as the category of special risks, nearly no increase in value could be observed. However, those categories showed a higher average value per building than residential buildings. The number of endangered permanent residential population increased slightly. In 1950, a population of 1098 persons was exposed to avalanche hazards, until 2000 this value increased to 1137 persons.

This is a relatively moderate increase of 3.6 percent, compared to the increase in tangible assets. If the classification into different building functions is carried out,

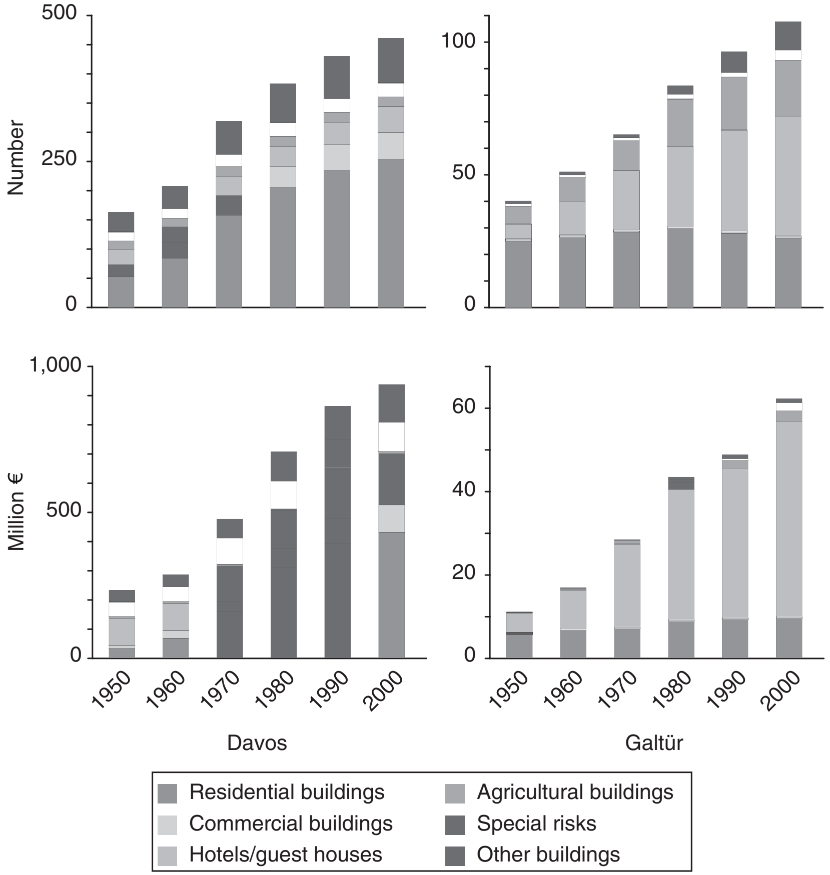

Figure 13.1 Development of values at risk in Davos (CH) and Galtür (A) related to the respective avalanche-prone areas, subdivided in decades and building categories. (From Fuchs, S., Keiler, M., Zischg, A., and Bründl, M., *Nat. Hazards Earth Sys. Sci.*, 5(6), 898, 2005.)

this increase turned out to be larger. In residential buildings, 673 persons were concerned in 1950 and 1116 in 2000, which is an increase of two-thirds.

In Galtür, the total number of buildings inside avalanche-prone areas rose by a factor of 2.5 (Figure 13.1), from 41 in 1950 to 108 in 2000. This increase is due to the relative development in the category of hotels and guest houses, and—obviously less important—in the category of agricultural buildings. The number of buildings in all other categories stayed nearly constant. The decrease in the number of residential buildings since 1980 resulted from a modification of buildings formerly used for habitation to accommodation facilities subsequently used for tourism. The total value of buildings rose by a factor of almost six. In 1950, the total value of buildings amounted to EUR 12 million and in 2000 to EUR 64 million. Since the 1960s, the category of hotels and guest houses held the highest proportion of the total amount of endangered values per decade and per category. In 1950, the proportion of hotels and guest houses was about 30 percent, compared to the total value of buildings. In 2000, this ratio changed to approximately 75 percent. In contrast, the number and value of residential buildings showed nearly no change between 1950 and 2000. Generally, the number of buildings in the community of Galtür has risen above average in comparison to the numbers of the federal state of Tyrol. In 2000, a quarter of the total value of all buildings in the municipality was found to be located in the avalanche-prone areas. The proportional increase in the value of buildings was significantly higher than the proportional increase in the number of buildings. Buildings inside avalanche-prone areas showed a lower average value as buildings outside those areas. The number of endangered persons increased substantially between 1950 and 2000. In Galtür, in 1950, approximately 850 persons were located inside exposed areas, consisting of 460 residents and 390 tourists. Until the year 2000, this value increased to 4700 persons, of which 770 were residents and 3930 were tourists. The increase in residential population was about 60 percent, while the increase in temporal population was a factor of ten.

Short-Term Development of Values at Risk

Parallel to the long-term increases described in "Long-Term Development of Values at Risk," remarkable short-term variations of persons at risk were detectable. Those variations could be determined on seasonal, weekly, and hourly resolution.

Results of the community of Davos have shown, that subdividing the utilization of hotels and guest houses into months, peaks arose during holiday periods such as Christmas and the end of February.

According to the analysis of the avalanche bulletin of the Swiss Federal Institute of Snow and Avalanche Research SLF, these periods coincided closely with periods when there was an above-average occurrence of days with high avalanche danger, resulting from typical meteorological situations with a stationary cyclone above Northern Europe and an anticyclone above the Atlantic Ocean (Figure 13.2). As a result, considerable amounts of snowfall occur in the Alps, and temporal risk peaks within the time frame of weeks arise.

In the community of Galtür, similar developments have been quantified for the number of endangered persons. Over the whole study period, the total number of endangered persons fluctuated by a factor of almost six. Based on a fluctuation approach outlined in Ref. [18], strong variations could be observed during the winter season as well as in daytime (Figure 13.3). The seasonal fluctuation was characterized by a strongly increasing number of tourists at Christmas time and the Easter travel season. The end of the winter season was highlighted by a sharp decrease in the number of persons to nearly the amount of the permanent

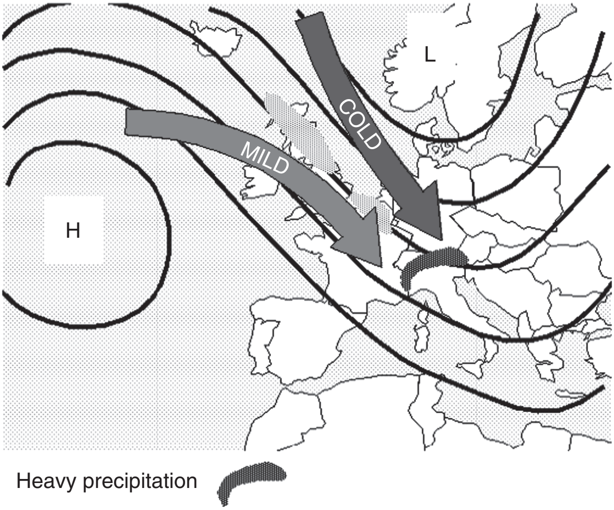

Figure 13.2 Typical meteorological situation in Europe, leading to heavy precipitation in the Alps.

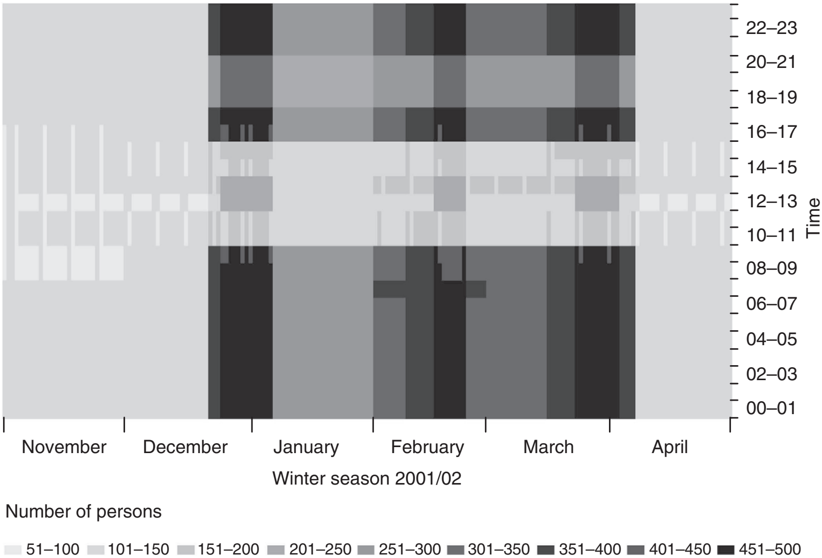

Figure 13.3 Monthly, weekly, and diurnal fluctuations of the number of exposed persons in the study area of Galtür (A). (From Keiler, M., Zischg, A., Fuchs, S., Hama, M., and Stötter, J., *Nat. Hazards Earth Sys. Sci.*, 5(1), 55, 2005. With permission.)

population. Considering the diurnal fluctuation, the weekly structure could be easily followed. From the beginning of the winter season, these patterns were overlapped by general movements of the tourists during daytime. The number of persons varied by a factor of 1.4 between minimum and maximum in the off-season, and by a factor of 3.4 in the period of the main season. These changes could occur extremely rapid within one or two hours.

Multi-Temporal Approach for an Effective Risk Reduction

As presented in the previous sections, the development of values at risk due to socioeconomic transformation in the European Alps varies remarkably on different temporal levels. Long-term changes and short-term fluctuations have to be considered when evaluating risk resulting from natural hazards.

Long-term changes in values at risk could be considered as basic disposition (Figure 13.4). To reduce the risk resulting from this basic disposition, permanent constructive mitigation measures could be constructed and land-use regulations implemented. As a consequence, the basic risk could be reduced due to a spatial reduction of the process area. As pointed out in Ref. [24] for the study area of Davos, the risk due to snow avalanches decreased fundamentally since the 1950s, even if the values at risk increased in the municipality. This development could be mainly attributed to the construction of permanent mitigation measures, and is strongly related to immobile values. Similar results were obtained for the study area Galtür [25]. However, extraordinary losses could be estimated if rare events with

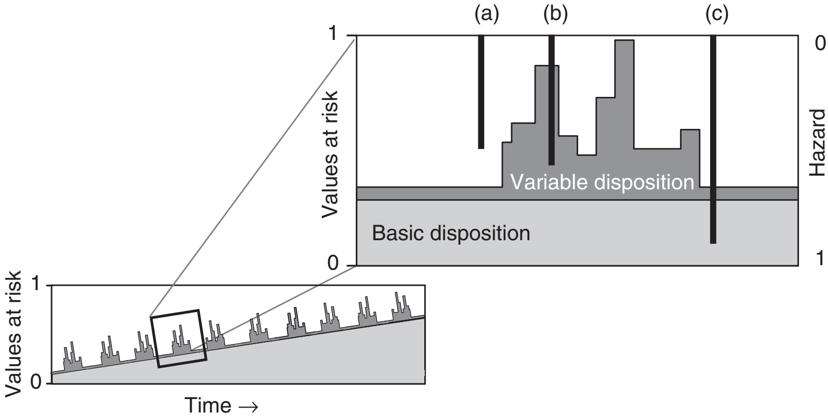

Figure 13.4 Schematic description of the concept of basic (long-term) and variable (short-term) damage potential and the relation to triggering events.

severe effects occur, because the delimitation of the respective process areas is based on defined design events. This problem emerged during the avalanche winter 1999 in Switzerland [26] and Austria.

Short-term fluctuations in damage potential supplement this continuing development of damage potential within a specific range. Thus, they have to be considered as variable disposition. To mitigate those fluctuations, temporal measures could be applied, such as evacuations or temporary road closures.

Furthermore, because socioeconomic development differs within Alpine regions, studies on the long-term behavior of values at risk contribute to the ongoing discussion of passive and active developing regions and suburbanization [16]. However, if a potentially dangerous natural event occurs, it depends on the actual amount of values at risk (basic and variable disposition) within the process area whether or not damage will be triggered.

Long-term as well as short-term variations in damage potential should be implemented into risk management approaches. In Figure 13.4, the significance for a consideration of variable as well as basic damage potential is presented. As shown in example (a) the event will not hit any values at risk, and thus, the level of risk reduction is sufficient. In example (b), due to high amounts of variable values at risk, damage will occur. As a result, temporal mitigation strategies could reduce the variable damage potential until a critical level. In example (c), basic and variable values at risk are affected by a process. Thus, temporal measures are no more sufficient enough for an effective risk reduction. These examples clearly indicate the strong need for an incorporation of dynamic assessments of damage potential in community risk management strategies.

Such risk management strategies should include an objective risk assessment that is based on both, hazard analysis and an analysis of damage potential. Risk assessment has to be followed by a risk evaluation procedure. In this evaluation process, the level of accepted risk and the level of (residual) risk to be accepted should be defined by a participative process. Using these results, the risk management strategy could be defined, aiming at both a risk minimization and an economic efficient use of public expenditures. Thus, a combination of mitigation strategies, such as passive and active measures, could be chosen to meet these prerequisites. Thereby, temporal variations of the risk have to be considered seriously.

Discussion

Information on the general development of damage potential and seasonal, weekly, or diurnal peaks should be implemented in the risk management procedure, because the range of the results is remarkably high, and the values at risk have a key influence on the risk equation. Even if the results with respect to avalanche risk suggest—due to the long-term increase in damage potential—a similar shift in risk, in general, the risk decreased fundamentally as a result of the construction of mitigation measures and the introduction of land-use restrictions in endangered areas.

However, short-term fluctuations in damage potential might lead to a temporal increase in risk, resulting from a modified recreational behavior within the society. Until now, there is a particular lack in information related to short-term fluctuations of values at risk. In contrast to the immobile damage potential (buildings and infrastructure, etc.), persons and mobile values can either leave or be removed out of hazard-prone areas in case of dangerous situations. For developing efficient and effective evacuation and emergency plans, information on the numbers of persons and mobile values as well as their location and movements in the area is needed. In consequence, permanent mitigation structures could be complemented by temporal measures to achieve an efficient and effective risk reduction.

Information on the temporal variability of values at risk both from a long-term as well as from a short-term point of view provided in combination with process knowledge is the basis for dynamic risk visualization. Such information may help to recognize high-risk situations more easily and enables a situation-oriented and risk-based decision making [19,27,28]. Apart from the damage potential, risk analyses are based on the concept of recurrence intervals of hazard processes. If those defined design events would be exceeded, the remarkable increase of values at risk would result in a significant shift in monetary losses (and presumably fatalities). First results on risk associated with torrent hazards suggest an increase in the probabilities of the design events in the Alpine region, however, these results still need some additional analyses to be verified, and are subject to ongoing research.

To conclude, risk analyses concerning natural hazards should be carried out with respect to a dynamic change of input parameters. This is essential for efficient disaster risk reduction and contributes to the concept of resilience as part of proactive adaptation. Regarding snow avalanches in the European Alps, the most important input parameter is the temporal variability of damage potential, because the natural avalanche activity did not vary substantially during the past decades. Thus, future research is needed to quantify the impact of modifications in damage potential on (1) the result of risk analyses, (2) the assessment of risk in the cycle of integrated risk management, (3) the adjustment of coping strategies, and (4) the perception of risk by all parties involved, including policy makers.

The latter is the most crucial issue in Europe, because until now, dealing with natural hazards is based on mono-disciplinary approaches. In Austria, the forest law of 1975 restricts all hazards planning to forestry engineers [5], in France, experts responsible for these issues are predominantly geologists [29], while in Italy, the requirement for those specialists is a PhD in agriculture or a master's degree in forestry or geology [30]. However, because risk resulting from natural hazards is a subject matter affecting life and economy within the whole society, multiple stakeholders' interests have to be considered when mitigation measures and coping strategies are developed and decisions are made. Thus, there is a particular need to involve (1) economists with respect to an efficient and effective use of public expenditures, (2) social scientists with respect to both society's risk perception and an enhanced risk communication, (3) geographers and land-use planners as well as (4) all other disciplines representing any other party involved.

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