Ontology-Based Knowledge Modeling of Muli-factors for Severe Weather Risks in Snow Sports

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Abstract. With the frequent occurrence of severe weather events in winter snow sports, it is important to ensure the agility of response to meteorological emergencies and the intelligence of decision making. To solve the semantic heterogeneity of risk information and insufficient knowledge representation related to severe weather in snow sports, we proposed a knowledge modeling approach driven by ontology to integrate multi-level meteorological risk elements, and constructed a relatively complete knowledge model of severe weather risk. This study found that the unified expression of decentralized concepts and semantic relations within the domain improved the current normalized description of hazard factors and risk emergency for severe weather events in snow sports, providing theoretical support for meteorological risk prediction and emergency response for the upcoming 2022 Beijing Winter Olympics.

Keywords: Severe weather · Risk management · Knowledge model · Ontology · Snow sports

1 Introduction

The successful bid for the 2022 Beijing Winter Olympics has promoted the booming development of outdoor snow sports in winter, which urgently requires the enhancement of refined meteorological service capabilities. As one of the important risk sources of snow sports, severe weather not only affects the physical function of athletes and other participants but damages the ski trails and equipment under serious conditions, causing economic losses and personnel safety issues. The sensitivity of snow sports to the meteorological environment increases the probability of severe weather events. The regional, recurrent and sudden climatic features pose risks that can even be exacerbated in complex topographic environments. In the 2018 PyeongChang Winter Olympics, several competitions, including women's slalom, men's downhill, and super slalom of the alpine skiing, were postponed due to high winds and low temperatures. In addition, the International Ski Federation (https://www.fis-ski.com/) has developed standards related

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to severe weather for skiing events. There is a growing demand for risk management of large-scale ice and snow sports events.

The current description of weather risk knowledge in snow sports is incomplete. The growing maturity of ontology-based semantic knowledge modeling technology [1] helps to integrate multi-source heterogeneous weather risk information and provides a more explicit and standardized description method. There are few studies on systematic knowledge modeling of severe weather risks in snow sports. In previous studies, many scholars have applied ontology models to meteorological hazard description and risk management [2–5]. These studies have achieved good results, but the impact of the association between severe weather events and complex risk elements is easily ignored by only focusing on qualitative or quantitative meteorological factors.

How to construct a complete knowledge model of severe weather risk management has become the key work to ensure the smooth operation and widespread promotion of snow sports. Through the semantic representation of snow sports weather risk-related knowledge, this study a more complete description of the intrinsic semantic correlation between risk elements of severe weather events and provides decision support for effective prevention and control of snow sports emergencies.

2 Severe Weather Elements

Due to the high dependence of snow sports on meteorological conditions, the environmental evolution of ski resorts triggered by global climate change in recent years, including reduced snowpack stability, shorter snowfall periods, less snow, and high temperatures, is a deadly threat to outdoor snow sports in low latitude areas. Considering the meteorological conditions affecting the development of snow sports, the main elements of weather risk can be divided into temperature, wind, and snowfall.

2.1 Temperature

Given the climatic suitability conditions for snow sports, ski resorts are usually sited in temperature zones. However, according to the historical data, extreme weather may occur with abnormal temperature changes. The change in snow quality brought by strong cooling reduces the friction between skis and trails, affecting the skiing action of athletes. The over-warm weather in winter causes the snow to melt on ski trails, and the efficiency of artificial snowmaking is also greatly reduced.

2.2 Wind

Dust from strong winds not only reduces visibility but can also damage the smoothness of the ski course. High instantaneous wind speed affects the athletes' movements and spectators' physical condition, especially for ski jumping which is very sensitive to wind speed and direction. The range and intensity of strong wind vary with the altitude of the ski resorts. Conditions of wind scale and wind direction at the top of the mountain are more prone to cause catastrophic weather events than at the base of the mountain. In addition, high winds increase the snow load and also cause snow particles to condense, forming a hard and brittle snow layer so that the frictional resistance between the trail and snowboard is reduced.

2.3 Snowfall

The essential parameters for the ski trails monitoring are the hardness and thickness of the snow layer. The snowfall in winter is too low to meet the snow storage requirements of ski resorts, and the low relative humidity influences the snowmaking effect, making the snowmaking work more difficult. The snowstorm can easily lead to avalanches, seriously threatening personal safety.

3 Knowledge Hierarchy of Severe Weather

Based on the triangle theory of public safety [6], weather conditions are not the only source of meteorological risk, the geographic environment characteristics of snow sports venues [7, 8], the vulnerability of the objects within the range of action [9], and the emergency response capabilities [10] also influence the development and evolution of severe meteorological events. Determining all knowledge related to severe weather events in snow sports is a key prerequisite for the comprehensive and integrated meteorological risk assessment.

Focusing on severe weather events in snow sports, we have aggregated the domain knowledge fragments and refined the concepts by dividing the relevant knowledge into four levels in Fig. 1, including meteorological factors, the geographic environment of skiing resorts, objects of the sudden meteorological event, and risk response actions. Severe weather is the major factor directly triggering meteorological emergencies; various objects in snow sports are the risk-bearing bodies; while the environment of ski resorts are the breeding ground for the enhanced or diminished effects of meteorological risk on the bearing body; and the risk response action is the implementation of emergency plans for severe meteorological events to transfer or mitigate the risk.

The whole process of severe weather risk events from conception, occurrence to end is accompanied by cumulative effects in time and dynamic changes in the influence scope. Therefore, the introduction of spatio-temporal semantics enriches the description of knowledge dimensions in the field of severe weather of snow sports. The multi-level

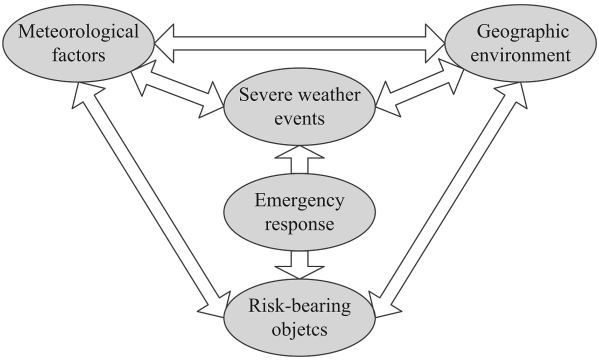


Fig. 1. Hierarchical classification of the severe weather knowledge in snow sports

knowledge system of severe weather events with complete contents and accurate descriptions is more valuable for intelligent command and decision-making in meteorological disaster prevention and mitigation actions.

4 Knowledge Modeling Application

Based on the above hierarchical analysis of modeling elements, we constructed the ontology-based knowledge model for the risk of severe weather events in snow sports with the conceptual level by Ontology Web Language (OWL) and supported by the ontology editing tool, Protégé. In the construction process, concepts related to the severe weather risk of snow sports are extracted and integrated, and the semantic associations and constraints among these concepts are formally expressed. Finally, the instance data of Nanshan Ski Resort in Beijing is input into the constructed ontology. The characteristic indicators and threshold conditions in the area are described by data attributes and object attributes, and a clear and complete expression of the risk of severe weather events in snow sports scenes is realized.

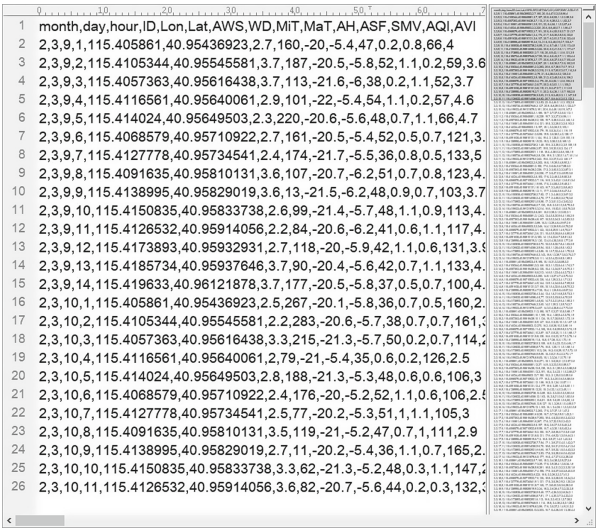
By extracting the core knowledge of severe weather risk elements for snow sports, we took a top-down approach to construct the ontology model. We defined five upper concepts, including *Severe-weather-events*, *Weather-factors*, *Affected-objects*, *Geographic-environment*, and *Emergency-actions*. On the basis of ensuring the consistency of concept hierarchical classification, we extended the definition of subclass by combining the relation between concepts with attributes.

4.1 Severe Weather Events

The concept of *Severe-weather-events* includes 2 subclasses of *Event-types* and *Event-level*. The type of severe weather event can be divided into *Gale*, *Snowstorm*, *Extreme_low_temperature*, and *Over-warm_snowmelt*. We also divide the level of meteorological risks into four classes, *BlueWarning*, *YellowWarning*, *OrangeWarning*, and *RedWarning*, with increasing risk intensity in that order, which is closely related to emergency command and decision making.

4.2 Weather-Factors

As the subclass of *Weather-factors*, *Snow*, *Temperature*, and *Wind* correspond to different triggering factors for different types of severe weather events. It should be noted that the same catastrophic factor may lead to different severe weather events under different conditions. Figure 2 shows the sample data of the ski resort based on the simulation of the historical meteorological data from the National Meteorological Information Center (http://data.cma.cn/).



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month,day,hour,ID,Lon,Lat,AWS,WD,MiT,MaT,AH,ASF,SMV,AQI,AVI
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2,3,9,8,115.4091635,40.95810131,3.6,107,-20.7,-6.2,51,0.7,0.8,123,4.
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2,3,10,9,115.4138995,40.95829019,2.7,11,-20.2,-5.4,36,1.1,0.7,165,2.
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Fig. 2. Fragment of the weather sample data to be input into ontology

4.3 Affected Objects

Snow sports involve complex scenarios, and the objects affected by severe weather can be divided into three categories, *Human*, *Facilities*, and *Sports*. Personnel is one of the most active and challenging risk factors in snow sports. The sub-category concept of *Human* consists of *Athletes*, *Spectators*, *Administrators*, and *Staffs*. We define *Ski_trails* and *Ski_equipment* as subclasses of *Facilities*. Snow sports include concepts such as *Racing_skiing*, *Bobsledding*, and *Sledding*.

4.4 Geographic Environment

Given the geographical characteristics of entities in the snow sports scene, the class *Geographic-environment* includes subclassed such as *Altitude*, *Slope*, and *Location*. Among them, location is the reference for the representation of spatial information in snow sports severe weather events. Spatial semantic relation (Fig. 3a) is the basis of spatial reasoning to describe the occurrence, impact, and response of catastrophic meteorological events.

4.5 Emergency Actions

The class of *Emergency-actions* includes subclasses of *Plans*, *Organizations*, and *Resources*. The concept of *Plans* represents the pre-defined emergency response plan. The concept of *Organizations* indicates that the subject of emergency actions is the agencies or departments responsible for and performing emergency tasks. All risk management events have temporal semantics (Fig. 3b), including temporal topological relations among snow sports, severe weather events, and emergency response.

a. Spatial object properties b. Temporal object properties

Fig. 3. Spatial-temporal properties in the severe weather risk ontology

Finally, the semantic relationship between multi-factors of meteorological risk can be expressed respectively by defining object properties, such as *TriggerTo*, *PregnantWith*, *RespondTo*, and *BearFor*. We integrate the above five ontology models and associate objects from different class hierarchies through attributes to obtain the conceptual-knowledge graph of the severe weather ontology in snow sports, as shown in Fig. 4.

Then, based on the ontology, the potential meteorological risk of Nanshan Ski Resort is output by inference and query operations. In Fig. 5, We found that the severe weather types in the area are snowstorms and extremely low temperatures. The risk level, *Orange-Warning*, means that there is a high risk of skiing movements, equipment, and personal safety. The number of hazard-bearing trails in the Nanshan Ski Resort is 14 of 25, that is to say, the weather risk has significantly affected most of the trails. The response to the risk requires emergency decision-making by managers of each trail at the resort, supplemented by the guidance of risk management experts, including snow clearing, security protection, time adjustments, and other actions.

Fig. 4. Conceptual-knowledge graph of the severe weather ontology in snow sports

- Position *Nanshan Ski Resort*
- Events type *Snowstorm; Extreme_low_temperature*
- Risk description *OrangeWarning*
- Affected ski trails

ID	Trails	Length (m)	Slope (°)
1	Beginner's Slope	450	8
2	Mini Park	125	8
3	Small Beginner's "S" Trail	900	9
4	Jumping Trail	300	18
6	Halfpipe	110	17
7	Advanced Mogul Trail	510	30
8	Wave Slope	150	18
9	Snowboard Trail	130	8
10	Ski Trail	320	8
11	BMW xDRIVE Trail	160	18
12	West Intermediate Trail	800	25
13	X-Chute	400	35
14	Connection Trail	140	6

Fig. 5. Illustration of the risk of the severe weather in Nanshan Ski Resort

5 Conclusion

The occurrence of severe weather increases the difficulty of risk emergency in snow sports. And the integration of information from massive multi-source information is the key to realize effective risk identification and response. The knowledge modeling method proposed in this study for severe weather risk of snow sports integrates the semantic features of domain knowledge from four levels and formalizes the domain knowledge into a form that computers can understand and make command decisions through manual interaction. The form of interaction between severe weather events and the geospatial environment determines the risk intensity. The spatio-temporal relationship between hazard and affected objects can be used as the basis to measure the vulnerability of the hazard-bearing body. And emergency management reflects the risk reduction capacity of the region where the skiing resort is located.

Ontology-based knowledge modeling of the severe weather constructed in this study based on the proposed method provides a more complete systematic knowledge description framework for meteorological risk management of snow sports. In this study, the description of the severe weather risk types, levels, and affected objects in the region is obtained by the ontology application of Nanshan Ski Resort, proving the effectiveness of the knowledge modeling approach. The ontology partly solves the current problem of fragmented information and insufficient domain knowledge coverage for meteorological risks in snow sports.

Consequently, it is important to investigate the occurrence mechanism of severe weather events that have a high impact on snow sports and how to enhance the meteorological service for personal safety and athletes' status to ensure the smooth running of snow sports. However, there are some limitations in this study, and the situational awareness of the meteorological risk in snow sports still needs further research to enhance the semantic description of the whole process of severe weather risk management in snow sports.

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