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Conception of a location based service for evaluation of location dependent avalanche risk

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AFFIDAVIT

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Abstract

This thesis proposes and describes a new, multi-level strategy for avalanche risk assessment for a precisely localized avalanche alert level. The strategy is embedded into an online (geographic) information system, available for desktop and mobile use. It should assist ski mountaineers to estimate the risk of avalanches both at home, and on their current location in alpine terrain.

Internationally recommended strategies (avalanche reports) for estimating the risk of avalanches are suited only for large-scale areas, thus e.g. estimating a specific risk value in the extent of mountain ranges. Changing conditions provide a big challenge for accuracy of the report as well as for the interpretations by the sportsmen. Specific expositions and slope inclinations have declared alert levels and are mentioned in textual form in avalanche bulletins only. Furthermore, no off-site decisions can be made. Skiers and ski mountaineers often do not carry maps, compasses, or altimeters - all of which are crucial to assess the situation. This could be due to a lack of knowledge in navigating and determining the exact position, height and aspect. For on-site avalanche risk assessment, information about slope inclination and exposition is essential. A smartphone may provide this vital information or receive it from a web portal. Another important aspect is the ability to interpret an avalanche report, which is influenced by the aforementioned factors. Either way, this conceptual design for a location-based-service will provide a solution to help navigate with the smartphone or tablet skiers already own – and therefore to evaluate the situation they find themselves in. The system will do so by providing all the location based information that is needed to assess the hazard of avalanches.

A new methodology, adding information and situation assessment from users on-site, will be illustrated. It can help to improve the risk assessment for small-scale, local areas. This strategy combines up-to-date meteorological data from nearby observation platforms, current avalanche risk levels for the affected area, user-submitted on-site data, and information derived from digital elevation models (DEM). Meteorological parameters include temperature, recent precipitation in rainfall and snow, as well as both wind speed, and wind direction. Avalanche experts from a meteorological station can enter information about surface specific situations (formerly provided in text form) into an online form, which can be linked to the geo-data / processing tool chain. On-site user-generated information includes position, slope inclination and aspect. Data extracted

from DEM ranges from height, slope inclination, and aspect to relief features (steepening, chutes, basins etc.), which then can be processed into general risk maps.

Users are able to access the service through a so-called “web app“, capable of running inside the smartphone’s web browser. Data required from the user is acquired by the HTML5 Geolocation API, which enables users to access data derived from smartphone sensors. In current smartphones, these can be position (GPS), attitude (gyroscopes) and height information / difference delivered by barometric sensors.

Further steps involve testing and evaluating the system’s capabilities and realizing a feedback function: users will have the possibility to give feedback about general tour conditions, current wind packaging, snow profiles and relevant events including avalanches. The feedback can be submitted via smartphone app or the online web platform and should pass an automated integrity test that can be reviewed and commented on by other users. The report and feedback system allows users to register relevant observations in a database that is publicly accessible. This user-generated information can be valuable to meteorological stations as well. Another possible future approach is to implement land cover information about underlying surface, which affects the set-off of avalanches.

To help ski mountaineers in perceiving avalanche risk elements, a smartphone device relying on server-sided processing can help to point out and evaluate these risk elements. However, it is not the goal of this thesis or application at this time to calculate a specific risk for the position as it’s still very difficult to do this with raw data and could give a wrong sense of security to novice skiers. This system cannot replace basic mountaineering knowledge and the skill to judge the situations but it can assist the experienced mountaineer by providing useful information. One result could be a risk map visualization with additional information to interpret the local avalanche risk.

This thesis is scientifically assisted by the Styrian avalanche warning service, Lawine Steiermark, with their expertise, meteorological data and avalanche reports.

Zusammenfassung

Die vorliegende Arbeit beschreibt die Konzeption eines Systems zur Bestimmung der ortsgenauen Lawinengefahr für Wintersportler. Diesen wird dafür eine Vielzahl von positionsrelevanten Daten verschiedener Kategorien zur Verfügung gestellt. Sie sind über ein webbasiertes Geoinformationssystem abrufbar, welches sowohl auf mobile Endgeräte, als auch für die Desktopnutzung abgestimmt ist und damit die Tourenplanung im alpinen Gelände von zu Hause ermöglicht.

Lawinenlageberichte werden von amtlichen Lawinenwarndiensten in Europa und Nordamerika ausgegeben. Die Gebietsaufteilung ist durch Staats- und Verwaltungsgrenzen geben, welche in weiterer Folge auf regionaler Ebene auf Gebirgszüge heruntergebrochen werden. Es handelt sich hierbei allerdings meist um sehr große Gebiete, welche mit einer einheitlichen Warnstufe kategorisiert werden. Besonders gefährdete Hangexpositionen im Lawinenlagebericht werden sowohl in der Textfassung als auch in Form einer Windrose ausgewiesen. Änderungen der Gefahr mit der Höhe und dem Tagesverlauf werden im Lawinenlagebericht in statischen Karten herausgegeben. Die ständig wechselnden (Wetter-)Bedingungen, besonders im hochalpinen Raum, verändern die Situation jedoch oft innerhalb weniger Stunden. Diese ohnehin schon schwierige Einschätzung wird durch oftmals sehr kleinflächige Unterschiede innerhalb eines Hanges erschwert. Hangexposition und Neigung können ebenfalls einen sehr starken Einfluss auf die Gefahr haben.

Im vorgestellten Prototypensystem werden die Informationen des Lawinenwarndienstes mit Hilfe eines Höhenmodells (DEM) in einer Karte visualisiert. Diese wird über einen Geoserver als Web Map Service (WMS) den Nutzern zugänglich gemacht. Zusätzlich erweitern positionsgenaue und für die Einschätzung der Lawinengefahr relevante Wetterstationsdaten die Karte. Nutzer-generierte Daten (z. B. von Wintersportlern) können ebenfalls in das System einfließen.

Eine Upload- bzw. Feedbackfunktion ermöglicht den Benutzern, positionsgenau „Ereignisse“ verschiedener Kategorien hochzuladen und somit weitere Einschätzungshilfen für die Lawinengefahr zu geben. Diese Ereignisse umfassen unter anderem beobachtete Lawinenabgänge, Altlawinen, diverse Gefahrenzeichen (Setzungsgeräusche, Risse in der Schneedecke) oder besonders gefährliche versteckte Gefahren wie etwa zugeschneiten Oberflächenreif. Sämtliche Ereignisse werden mit

Informationen wie Ort, Lage (Hangneigung, Exposition), Zeit, Datum und der Gefahreneinschätzung des Nutzers erweitert.

Der Zugriff im Gelände wird den Benutzern mit einer Web-App innerhalb des Browsers eines mobilen Endgerätes ermöglicht. Über die Geolocation API und die Device Orientation API (beides HTML5) des Browsers kann auf die Position und Attitude des Users zugegriffen werden und ihm nicht nur seine Position, sondern auch seine Lage im Raum gezeigt werden. Durch die Informationen bei einem Upload können so neben den jeweils nächsten Ereignissen auch die ähnlichsten (betreffend Höhe, Hangneigung und Richtung) abgefragt werden.

Das beschriebene System kann Ausbildung, Wissen und Erfahrung im alpinen Bereich nicht ersetzen und soll auch aufgrund fehlender Formeln und Modelle zur Berechnung der Lawinengefahr keine treffsichere Lösung bzw. Entscheidung für eine Position ausgeben. Eine exakte Einschätzung würde nach aktuellem Stand der Wissenschaft unwissende bzw. unerfahrene Wintersportler einer potentiellen Lebensgefahr aussetzen und ist kein Ziel dieser Arbeit.

Dieses Projekt wird wissenschaftlich vom Lawinenwarndienst Steiermark mit Wissen und Erfahrung sowie Wetterdaten und Lawinenlageberichten unterstützt.

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List of Abbreviations

API – application programming interface

CSS – cascading style sheets

DEM – digital elevation model

DOM – document object model

GIS – geographic information system

GPS – global positioning system

GSM – global system for mobile communications

HTML – hypertext markup language

IIS – internet information service

LBS – location based system

OGC – open geospatial consortium

PHP – hypertext preprocessor

RFID – radio frequency identification

W3C – world wide web consortium

WLAN – wireless local area network

WMS - web map service

WFS – web feature service

ZAMG – Zentralanstalt f. Meteorologie

1. Introduction

The topic of a localized avalanche risk assessment strategy using user generated data arose from my personal interest. In my role as a ski instructor I saw people ignoring the avalanche risk deliberately as well as not evaluating all the available information. When taking classes on location based services (3.1 Location Based Services) the idea to realize a service specifically for avalanche risk assessment took form.

With the employment of a location based service much of the available information can be displayed. These data layers then allow a user to assess the situation and risk. Identifying the right factors is a problem the present work faces. While there are only two recognized ways for rating the avalanche hazard of a mountain slope only one can be used in a bigger scale environment offering a continuous service. The most accurate risk assessment is to measure all the forces (shear, pull, push) within the snow cover with sensors placed all over a terrain of interest and identifying when one of these forces exceeds its limit. Though this being the most "scientific" way it's still under research (SEGOR V. et al 2013, also see chapter 2.1) as well as impossible to realize everywhere, anytime and for everyone. The second way takes into account known risk factors (chapter 3.6) and combines these factors with other parameters like terrain weather and so on to assess the risk as a combination of all available information.

To estimate ones risk for triggering an avalanche one is highly information-, knowledge- and observation-dependent. As there are also many different types of avalanches and ways of triggering them (chapter 3.2 and following), precise, positioned and oriented information is essential for making a facts-based educated decision. With the recent rise of popularity in ski touring and off-piste skiing (newspaper articles 2014, KLEINE ZEITUNG, ORF, PRESSE TIROL) a system offering additional information to current avalanche bulletins (LAWINENWARNDIENST STEIERMARK 2014) should lead to more informed sportsmen/women. When reflecting personal experiences and observations made by the author, better educated and informed skiers would have made less risky situations for themselves as well as others. The added information from the proposed LBS leaves less room for making a possibly wrong decision and therefore could increase safety for everyone immediately affected.

As the result of this master thesis is a prototype for a possible future Web-Application. The main goal is to provide all basic information available, breaking it down to its respective location and expanding it with information by so called “prosumers” (prosumer is someone who contributes – produces – to a service as well as consumes its). It will be created with a focus on mobile devices and touch inputs to ensure mobility and practicability but also to offer the information for the planning stage at home before a user’s outing.

All of the above mentioned points lead to the following research questions (which will be answered in chapter 6, Results):

- How can a user assess the avalanche situation at a specific position now and is there a way to calculate the risk so that an individual can trust the results?
- Which information should be included in a location based service for avalanche risk assessment?
- Is user-feedback a reasonable tool to expand the avalanche bulletin within a location based service?

2. Literature review

2.1. Snow Avalanche Research

Snow avalanches are a natural hazard that occur in countries and regions that have seasonal or year round snow fall. The aftermath of an avalanche depends heavily on its size and type both of which may differ tremendously; but are linked to each other. The two main release types are slab avalanches and loose snow avalanches. Loose snow avalanches start from a single point and depending on the snow conditions, have a pear shaped path. Slab avalanches on the other hand result from a failure within the snow stratification and can have a release crown length starting from a few meters to several hundred meters. While both types of avalanches threaten humans as well as infrastructure the type of triggering can generally distinguish between the two. A natural or spontaneous release is more likely to affect the safety of humans indirectly by destroying infrastructure. Unintended human triggered avalanches are usually a direct threat to the ones triggering them in the first place (JAMIESON et al 1996).

Keeping these risks in mind one might want to know how and why an avalanche does occur to protect humans from harm. Later on the questions for when and where will also

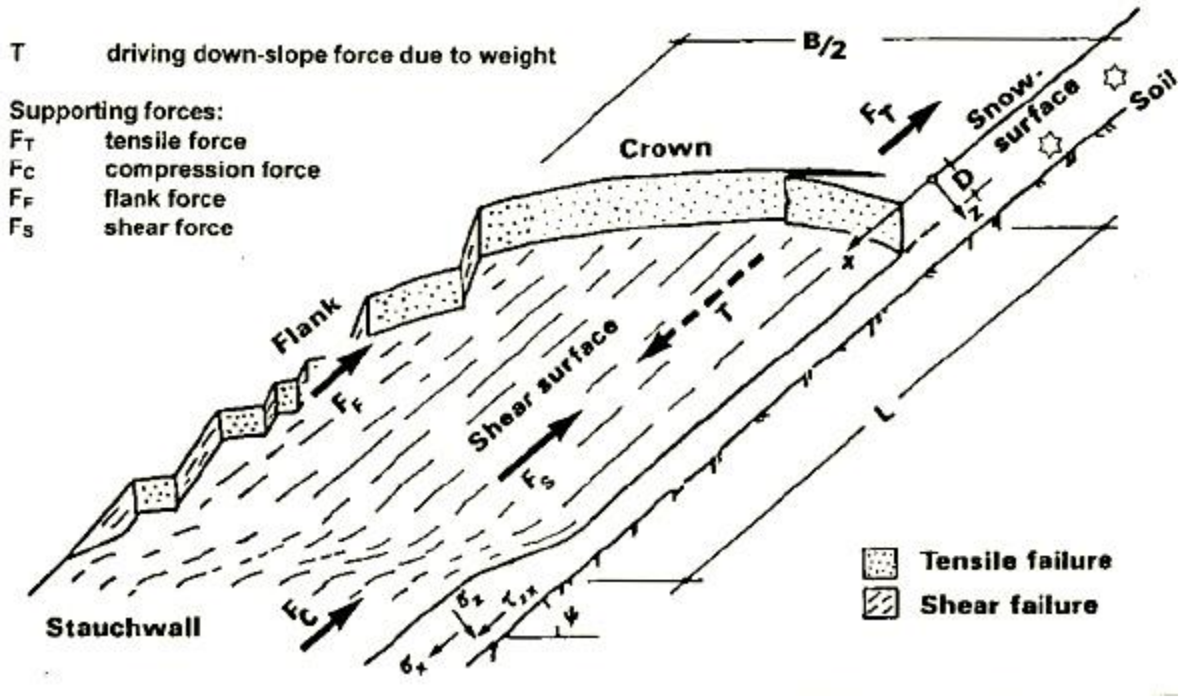


Figure 1 Forces supporting snow cover from: http://www.ngi.no/upload/ICG/Research/Vulnerability_Risk_Assess/Case_studies/figur6.jpg

become relevant. Avalanche and snow science address these questions to try to predict and/or prevent avalanche accidents from happening.

To answer these questions there are only two perspectives. The first perspective requires looking at the dynamics and forces inside the snow cover. Within the snow cover there are several forces (see Figure 1) that hold it in its place on the slope. These can be pull- (at the top), push- (at the bottom), shear- (multidirectional) loads as well as friction between the snow layers and the ground (SCHWEIZER 2005). A project currently taking place at Seehore peak in Aosta Valley in the Northwestern Italian Alps by multiple Italian institutions is trying to measure these forces. The goal of this project is to analyze the recordings of multiple sensors that have been planted on the slopes of Seehore peak. Within the setup sensors for weather observations as well as infrastructure measure the force of a frontal hit by an avalanche (BARBERO M. et al 2013). The Italian research group investigates small to medium sized human-triggered avalanches, which in the case of this study are mostly triggered purposely with explosives, as the ski resort would be affected otherwise (MAGGIONI M. et al 2013). Correlation or connections with the weather station data, specifically the snowdrift, is only examined in the event of a spontaneous triggering, which happens infrequently. Due to this limitation most of the current work focuses on the forces an infrastructure has to withstand when hit by an avalanche. As more sensors for different types for recordings are implemented these observations could provide viable insights into the physics and dynamics of avalanche formation in the future (SEGOR V. et al 2013). Regarding this rather complex setup to measure all the relevant forces leads to the conclusion that this way of avalanche forecasting is impossible to implement for large-area avalanche prediction.

The second way to predict avalanche formation is by assessing known factors that can be linked to the triggering. Schweizer describes "five essential factors: terrain, precipitation, wind, temperature, and snowpack stratigraphy" that are contributing most to avalanche danger (SCHWEIZER et al 2002). These factors can be seen as headings for many more factors that have a significant influence on the hazard. Assessing all these factors is the tactic for prediction used by avalanche service providers, experts and recreationists. In the following paragraphs the contributing factors and their relevance mentioned by Schweizer will be explained further.

2.2. Existing Avalanche Applications

There are currently already several avalanche applications on the consumer market. These can generally be divided into simple and complex systems. Simple systems do not have any additional, synthesized information or otherwise added value for risk assessment. Useful systems can be further divided into mobile applications and desktop tools. Desktop tools offer a variety of information for the planning level with a lot of functionality. Some features include an elevation profile or precise tour planning with a variety of possible routes and identified risk points. The result of these desktop tools can be viewed on a desktop computer or printed out (alpenvereinaktiv.com) or transferred to a mobile device (whiterisk.ch and alpenvereinaktiv.com since January 2015, see Figure 2). "Alpenvereinaktiv" includes many different sports and activities combining winter and summer sports. Its character and features resemble a social media website for outdoor enthusiasts. Contrary "White-Risk" (see Figure 3), designed by the „Eidgenössisches Institut für Schnee- und Lawinenforschung" in Davos (SLF Davos) is specifically used for avalanche assessment and risk reduction purposes. The desktop version is optimized for tour planning while the mobile version allows viewing created tours as well as static avalanche bulletin maps, written reports, weather station data, some decision tools and general rules of conduct. Once the tour is planned the user can see his location along the track but lacks all avalanche information.

Figure 2 Alpenvereinaktiv App making the functionality available on mobile devices in January 2015 from: http//www.alpenverein.at

A mobile-only application worth mentioning is SnowSafe. This app available for Android and iOS Devices reads the CAAML file made available by Avalanche service providers and shows this written report to the user. CAAML is an XML-based standard for distributing avalanche bulletins developed by the Canadian Avalanche Association. In summary one can say that there are many applications, and while most offer valuable information in most of these applications the provided data is not localized yet. There is no connection between the user's position and the avalanche bulletin established. Small static maps (White-Risk) force the user to zoom and pan to his position should he know it. SnowSafe enables the user to send feedback to avalanche service providers, but other than that no application allows the user to give feedback, especially not the general public. To conclude, it can be said that an application that synthesizes all the available data and localizes it combining it with a user feedback function is a new innovative approach that hopefully improves the safety of skiers (WHITE-RISK, SNOWSAFE, ALPENVEREINAKTIV, all 2014).

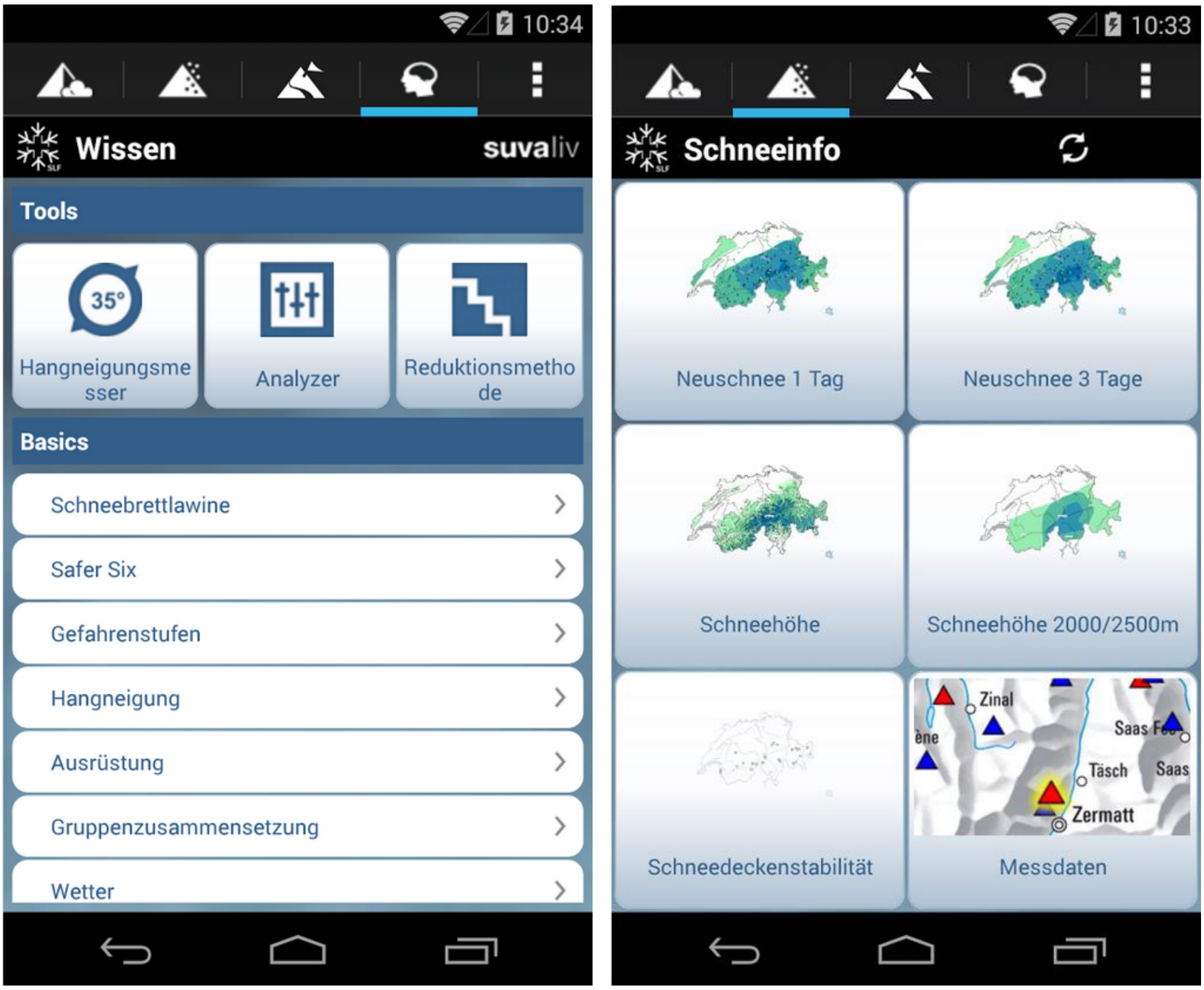


Figure 3 White-Risk by LSF from: Google Play Store, Feb. 2015

Another interesting avalanche GIS project was conducted by Andreas Eisenhut. The goal of his work is to create a plan for a ski tour based on a starting and end point taking into consideration the avalanche risk, the ascent-effort, exposition, and height. The results should reflect a scientific approach to finding the most logical route (least dangerous and least ascent-effort) for a given destination. With the routing based on digital elevation models and a digital map the calculation of the avalanche risk relies mostly on the 3 x 3 Method (3.7.1 Reduction Method and Elementary Reduction Method by Munter). Risk assessment inputs therefore are the surface as well as the avalanche report (risk level only). The routing results are very good and he was able to prove them empirically. The risk assessment however does not adapt to the predominant risk situation in the real world at a specific time leaving the decision making to users (EISENHUT 2014).

In the following Table 1 a comparison between the above mentioned avalanche applications and their functionality is made. Both "White-Risk" and "Alpenvereinaktiv" have a mobile as well as desktop version available and the link within the desktop and mobile solution is being updated constantly. During the time of drafting and writing this master thesis many advancements have been made by both providers. This table represents the development at the time of February 2015. At this time neither provider has a coherent feedback function deployed while the other features within these providers is rather similar. When looking at avalanche safety focus only “White-risk” is the most advanced application though only available in Switzerland, “Alpenvereinaktiv” is not bound to Austria but cannot be seen as a winter and therefore avalanche only application but rather a general outdoor application for alpine regions throughout the whole year.

Appendix May 2016: When checking the development of these Apps in May 2016, a few advancements were made. White-Risk now offers the possibility to give Feedback and mark Avalanches, these will be used for the Avalanche Report for the following day. This information is not made available to the public. Snowsafe did not make any advancements with new features. Alpenvereinaktiv is now offering additional features for their mobile Application such as an Inclinometer, compass and GPS-Height measurement. The White-Risk Desktop version is not free anymore and therefore no additional features could be discovered. In the Alpenvereinaktiv desktop version no new features could be found.

		Application				
		White-Risk	SnowSafe	Alpenvereinaktiv	White-Risk	Alpenvereinaktiv
Functionality	Avalanche	✓	✓	✓	✓	✓
	Maps	✓ 1)	✓ 5)	✓ 8)	✓	✓
	Feedback	✗	✓ 6)	✗	✗	✓ 11)
	Education /	✓ 2)	✗	✗	✓	✗
	Localized Data	✓ 3)	✗	✓ 9)	✓	✓
	Additional	✓ 4)	✓ 7)	✗	✓ 10)	✗

Table 1 Comparison of avalanche applications by functionality as of February 2015

1) Maps displaying different kinds of Information (static)
2) Expert system-like “Analyzer”, reduction method (see chapter 3.7.1)
3) Weather station data (Snow height and wind)
4) Inclinometer, general Avalanche Education, rich/complex Content
5) Same view as avalanche bulletin
6) Not available for other Users
7) Inclinometer
8) Dynamic Maps, allowing to search tours posted by other Users for different sports
9) Tours created on desktop or by others
10) Pay-content for additional Information
11) Non-structured User Feedback (multi-line type)

2.3. Avalanche bulletin

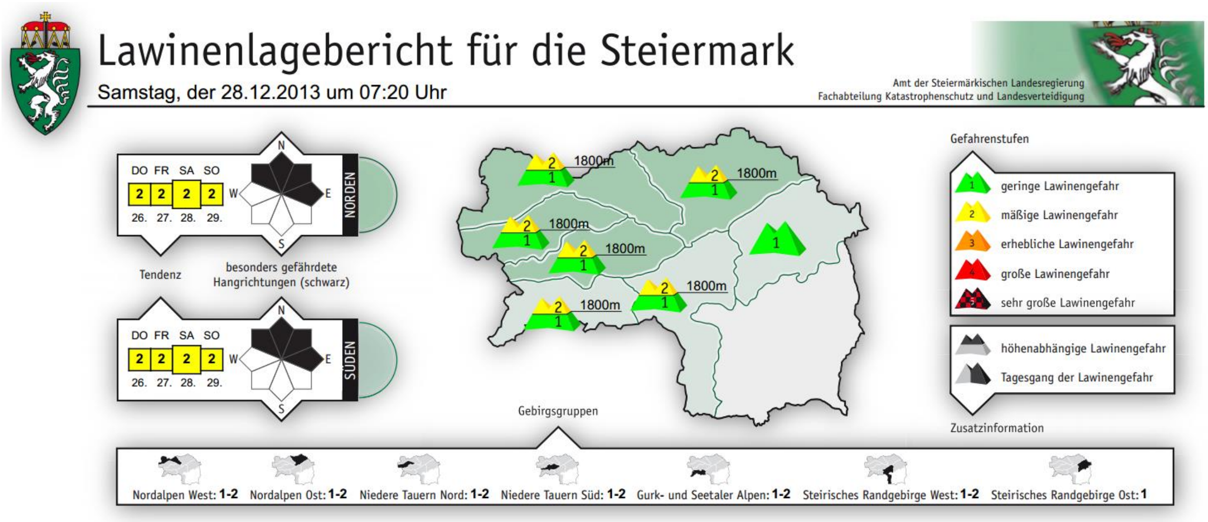


Figure 4 Avalanche bulletin map from the avalanche bulletin from 28 December 2013, Lawinenwarndienst Steiermark

The avalanche bulletin is a service provided by an avalanche service provider. Since the beginning of avalanche bulletins (ca. 1945 in Switzerland) the up-to-dateness has increased from weekly updates to a service frequency depending on the general avalanche situation but usually once or twice (morning and evening) a day. Traditional avalanche bulletins consist of at least three interlocking parts. According to a survey by the “Lawinenwarndienst” Styria (LWD Stmk) the part that is “most important” to users is the risk level which ranges from 1 to 5, where 5 is the highest possible risk. A map (Figure 4) displaying the regional variation of the risk level is the second part. These regions are rather large homogenous areas (usually mountain ranges) with related weather patterns. Besides these warning levels there is information about the affected exposition (8 directions – each 45 degrees) and daily variation of the hazard (morning vs.

afternoon). The third part is the written report explaining the situation in further detail and identifying especially dangerous areas or circumstances. The avalanche bulletin is a combination of various forms of information available to the avalanche service provider. This information is then processed and published every morning. Data processing happens manually by expert operators who then give out a forecast based on knowledge and experience. Avalanche bulletins are currently published through different channels with different options. The most widely used channel is through the website of avalanche service providers, but also available as spoken text on a telephone-responder or print out in ski resorts. One has to keep in mind that the main “customer” for the avalanche service provider as a public institution in Austria are avalanche committees whose responsibility is to ensure the safety of infrastructure and settlements. Skiers and ski mountaineers are additional users addressed as well, which need certain skills to interpret the written report. The avalanche bulletin alone is not able to exactly predict an avalanche nor prevent or reduce any risk taken by a recreationist.

3. Theory/Basics

3.1. Location Based Services

The conceptual and practical work in this master thesis can be classified as a location based service application (LBS). With the rise of smartphones and other similar devices that include GPS the market for LBS applications became bigger and bigger. LBS has found its way into many different areas of interest and different functionalities and features have been realized. The geographical position of a person or device offers an added value that cannot be ignored in today's world. Navigation devices in cars for example become smarter and offer more information than just directions. A lot of smartphone applications today require the devices position and offer functionality or information suited to the user and his whereabouts. While some of these applications are intended for fun, others offer additional safety or security for its users. The present thesis and the practical work presented is positioned somewhere between all these fields as users are offered more safety but in their leisure time and based on their own decisions.

Of the three main areas (military/government, emergency services, and commercial sector) of LBS the present thesis can be classified mostly in the commercial sector. When looking at the position accuracy needed for different applications it has to be noted that for avalanche prediction the highest possible accuracy is needed. Similarly, to emergency services and navigation services it is of importance to know a position as even small changes make a difference in avalanche risk. The present application can be classified as a person-oriented LBS with a pull service as the user actively has to request the information for his position. (SCHILLER J. et al2004)

3.2. Avalanche triggering factors

3.2.1 Terrain

Of the five factors described in Chapter "3.2 Avalanche triggering factors", terrain is the only static one as it usually doesn't change over short periods of time. When assessing terrain, several integral properties have to be kept in mind: slope angle, aspect, height, small scale topography and terrain cover. The main parameter is slope angle. Many research results come to the conclusion that slopes with an angle <30° rarely are affected by avalanches while those with slope angles >40° are much more likely for triggering. However, there is no research regarding the strict connection between slope angle and the probability of triggering. The parameters height and aspect are in close connection to short and long term weather events as well as the geographic position due to changes in solar radiation. Micro topography of avalanche starting zones does not underlie well established rules either, though concave cross-slope profile terrain features are more frequently triggering avalanches (SCHWEIZER et al 2002). Different groups of scientists have already tried using digital elevation Models (DEMs) to model potential avalanche release areas. Bühler (BÜHLER et al 2013) tried to automatically identify potential avalanche release areas based on a DEM in connection with a forest mask derived from remote sensing high resolution data. Their approach was aimed to identify dangerous areas in the Indian Himalaya. They came to the conclusion that a DEM with a spatial resolution of at least 2 to 10 m is needed to correctly identify dangerous areas. What might seem surprising is that a higher spatial resolution does not mean better results because the snow cover smoothes out the surface (minimal depth of 0.3 – 1 m according to SCHWEIZER et al 2002) meaning that a rock, ridge or dell might lose its effect with enough snow. Bühlers approach is aimed at regions where there is no, or little access and no expert knowledge about the terrain (BÜHLER et al 2013). The exclusion of forested areas needs to be differentiated as well as only forests with enough density (>200 trees of diameter >16cm per hectar) reduce the risk of avalanche release (SCHWEIZER et al 2002).

3.2.2 New Snow

Heavy snowfall of 30 to 50 cm increases the likelihood of avalanche formation, more precipitation during one snowfall event can result in catastrophic avalanches. However, it has to be noted that even with this amount of snow the risk of multiple combined avalanches is less than 50%, eliminating snow depth as a single identification parameter. Still, the rate of snowfall plays a role, as a weak layer below the new snow might not have enough time to settle and transform, therefore; releasing an avalanche because the load of the new snow gets too heavy. As skiers put more stress on the snow cover the critical value identified by Munter is between 10-20 cm under unfavorable and 30-50 cm under favorable conditions. When measuring the snow depth, it is necessary to take into account the settling of the layers beneath the load of the fresh snow and of course the big parameter described in the next chapter (SCHWEIZER et al 2002; MUNTER 2013).

3.2.3 Wind

"Wind is the builder of avalanches" – this statement made by Wilhelm Paulcke during the 1930s is still true. Surface near wind results in unpredictable snow drift (see Figure 5) resulting not only in different layering or snow depth but also irregular deposits regarding hardness and density. With higher winds these variations happen quickly and might change within a short period of time (GAUER P. 1999). When trying to model snowdrift and erosion in a numerical manner Lehning had to consider the "wind field over steep topography, the preferential deposition of snow during snowfall, the possible redistribution of snow during snowfall, the different snowpack conditions and development at the sites of erosion and deposition" (LEHNING et al 2000). Additional to all these variables there is another parameter that influences the snowpack stability, namely the mechanical transformation influence which affects snowpack stability.

Figure 5 Windgangeln - wind effect on snow from: http://www.lawine.salzburg.at/

3.2.4 Temperature

Being a comparatively easy parameter to automatically measure, temperature has a big impact on snow stability. Starting with the temperature during snowfall, the possible snowflakes have different appearances, resulting in different snowpack strength. Once the snow has fallen, temperature affects snow stability even without further loading. Since temperature is variable within the snow cover (close to 0°C at ground level) depending on its thickness and humidity ratio this factor contributes to either weakening the whole slope or settling a weak layer within. Temperature parameters also include radiation and high frequency radiation both of which have an effect on the snow cover which is not yet fully understood (SCHWEIZER et al 2002).

3.2.5 Snow cover stratigraphy

Stratigraphy in snow cover plays a big role in snow surface strength. Occurrences of surface hoar, near surface faceting, or poor bond to sun-generated crusts, weaken the following layers above these events. Once covered by a new layer of snow, these events can only be seen when digging a snow profile and remain "active" for triggering a slab avalanche until the load is high enough to pressure-sinter the layers together eliminating the weak spot. Numerical modeling of snow cover from meteorological data is a key research subject. While most modeled layers were in accordance with manually created profiles in terms of grain type and size the more important stability factor seems more difficult to simulate. With the influence of wind and its small scale changes in mind, one has to take these variations into account when assessing a snow profile or conducting a strength test, such as a "Rutschblock-test" (SCHWEIZER et al 2002).

Regarding these five highly variable parameters and the underlying factors which take a part in avalanche formation one can see the challenges an assessment system or model faces. Taking all possible available information and combining it into a yes or no result for avalanche hazard is impossible, especially when considering the risk skiers might take because of it. To provide these users with a viable and accurate prediction avalanche bulletins were created.

3.3. Typical Skier avalanches

Rudi Mair and Patrick Nairz from the avalanche Warning Service Tirol identified 10 Danger Patterns for different avalanche types where one can be identified as the most typical skier avalanche of all. A persistent weak layer within the snow cover is responsible for at least 95% of all avalanche fatalities. Such a layer results in slab avalanches, which are the most prone to be triggered by skiers and ski mountaineers. This danger pattern can mostly be found in the northern sector and typically occurs in higher altitude. The risk usually comes with the second snowfall of the season. The reason why the second snow fall creates such a big risk is the bond between the fresh snow and the old snow layer of the first snowfall. If the bond is weak a persistent problem can cause a dangerous situation during the whole winter season (LAWINE TIROL 2014).

3.4. Avalanche accident statistics winter 2013/14 in Austria

In all of Austria a total of 127 avalanche events with people involved happened in the 2013/14 season. In the long standing statistic of recording avalanche events this winter marked one of the lowest accident rates since the start of recording. Also the number of casualties with 13 deaths is half of the average yearly death toll. When thinking about these numbers one has to keep in mind the relatively mild and snowless winter, which in return does not mean a lower avalanche risk. On the contrary a winter like this bears higher risks as the snow cover is less stable and settles worse than it would with high precipitation. Even though accident numbers have dropped in recent years, (see Figure 6) there is still room for improvement. The best way to ensure a sustainable improvement is educating people about the risks and providing all information they need to make the right decisions. Looking at single avalanche events shows that a wrong or uneducated decision can have fatal results (LAWINENWARNDIENST STEIERMARK, 2014).

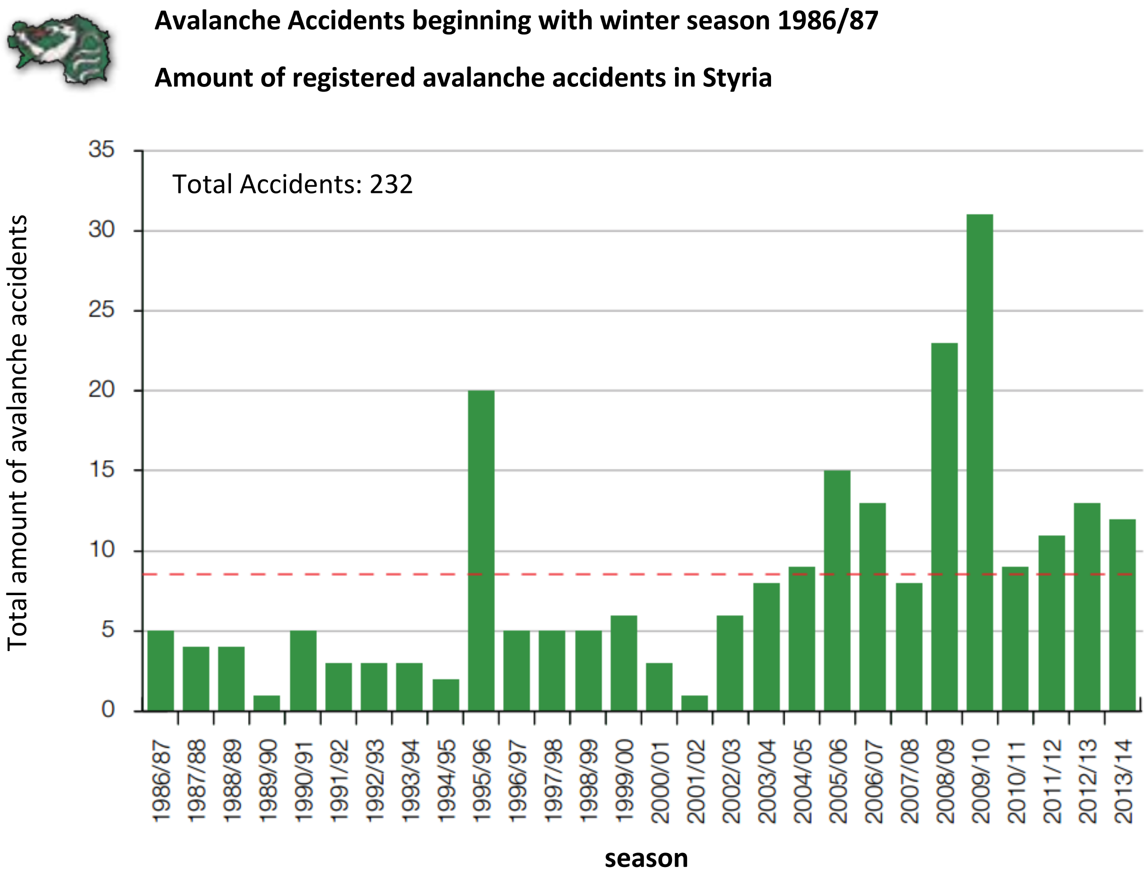


Figure 6 Avalanche accident statistic since 1986, Lawinenwarndienst Steiermark 2014, translated to english

3.5. Prediction

Different technical and research approaches have been made for avalanche prediction but they can be divided into two groups; a static approach and a more dynamic approach.

Projects classified as static mostly rely on either, experience or terrain features derived from DEMs for mapping dangerous areas. Such approaches use orthophotos for mapping known avalanche paths and depending on a parameter, the impact size of an avalanche. Such spatial analyses usually cover a small area and are very specific for a location or settlement (Dynamic Avalanche Consulting Ltd., 2013). Considering the terrain factor (already mentioned in chapter 3.2.1) there are more complex approaches that can still be classified as static one-time analysis for identifying avalanche slopes on a more automated basis. An approach used by Bühler relies merely on the DEM and does not incorporate changing weather factors (BÜHLER et al 2013). Since there are many more factors playing a role in avalanche prediction these solutions need additional information for real predictions. Jaedicke stated that "Avalanche warning is a dual process with two major parameters, time and space" (JAEDICKE et al 2014). A static approach therefor might be enough for an expert avalanche committee but recreationists may need more information.

Dynamic approaches try to create this kind of information as an automated process. Numerical models were made to identify the time and type of risk some modelling approaches only consider weather input in regions where weather stations are not in a tight grid research is concentrating on trying to create weather models from low resolution raster data. Roeger was able to break down a two kilometer raster to reach accuracies around 75% for different weather factors and use this information for avalanche prediction in a very small region in British Columbia, Canada (ROEGER et al 2001). A similar approach in the Indian Himalaya region, with mesoscale weather predictions (precipitation and surface temperature only) and a resolution of five kilometers was not able to make any accurate predictions at all. As stated in the paper too many important factors were missing for a reasonable result (SINGH et al 2005). In another study in British Columbia, Canada, Cordy was able to use data from weather stations to predict avalanches automatically within a small region surrounding two mountain passes. The results reached levels just above 70% accuracy. With these values an expert still had to validate these findings with his own sightings. (CORDY et al 2009).

Further papers by Schirmer and Ghinoi face the same problems with numerical modelling. The main obstacle are small scale changes within the snow depth, stratigraphy and exposition factors (SCHIRMER 2013; GHINOI 2005). Others include avalanche risk factors that can't be "seen", such as sounds or surface hoar (SCHIRMER 2010). Modelling surface hoar alone is a very challenging undertaking and even with good detection the results vary in a spatial relation that leaves too many unknowns for real time avalanche prediction (HORTON 2013).

In summary and in accordance with the avalanche service of Styria it can be said that automatic avalanche prediction based on numerical models has not yet reached acceptable accuracy for predicting and forecasting avalanches that is intended for the general public and practical use. With possible life or death decisions based on these predictions no risk can be taken.

3.6. Risk assessment

As described in chapters 2.1 and 3.5 numerical modelling of avalanche risk is no safe way for prediction. A technical solution with a sensor web measuring all the forces within a snow cover currently does not seem as a possibility specially to realize on a larger scale. Besides the technical risk assessment there is only one more way for avalanche risk evaluation: known avalanche triggering factors (MAIR 2012)

Knowledge based risk assessment of multiple information layers is the safest and most viable way of avalanche prediction to individuals. This type of assessment faces some challenges: a potential user needs to have specific knowledge and training in avalanche assessment. The more experienced a user is, the better the assessment, and the safer the decisions. While this knowledge has to be learned and experiences need to be made to recognize danger signs there are also information layers that need to be considered and consulted not only by inexperienced users, but also experts - before making any decisions.

Inexperienced users might rather rely on predefined risk strategies (chapters 3.7 including subchapters) than expert users for systematic decision making, but the underlying information is basically the same. This information includes at the very least: (a) the avalanche bulletin given out by the avalanche service providers, (b) the weather information from weather stations on a short term as well as long term basis and (c) terrain information. With all this information available somewhere to the user it still needs to be set into relation to each other, localized and assessed.

Further information layers currently only available to experts are observations made on site in the field. Observations are available to the trained eye only and there is no way of incorporating this information at the planning level yet. Knowledge about some of these avalanche triggering factors might change decisions usually made otherwise. Incorporating this layer into the present prototype played a big role and is an innovative factor (see chapter 2.2 especially Table 1 as well as chapter 5.2 about the Mobile Component).

3.7. Reduction strategies

Avalanche risk assessment is a difficult skill to master for non-experts. Interpretation may be biased and information can be misleading if the user doesn't have the necessary skills. To address this problem, different risk reduction tools with a step by step rule based approach have been realized by different groups. A general distinction can be made between knowledge based and rule based strategies. The five most commonly used rule based tools have been compared by McCammon et al (2005 and 2007). Evaluated tools were: (a) reduction method, (b) elementary reduction method, (c) NivoTest, (d) SnowCard and (e) Obvious Clues Method. Comparison with historical avalanche accident data showed a prevention rate from 60% to 90% depending on the test. This means that not all these tests "react" in the same way to different situations. As the reduction strategies and assessment itself is not a part of this present work, the results of McCammons study will not be questioned. However, some of these tests were identified to work better in specific climates than others. Besides that, it has to be mentioned that rule based decision tools target the group of less experienced recreationists, while knowledge based decision making is the preferred tool of ski guides and other experts. Both approaches rely on information made available to them and observations made by skiers, though with a different weighting (McCammon et al2007).

The tools evaluated by McCammon will be presented in the following paragraphs and identified factors and indicators for risk assessment will be used in the practical part of this work (McCammon et al 2005).

3.7.1 Reduction Method and Elementary Reduction Method by Munter

Munters 3x3 formula is focused on less experienced users and some assumptions were made. These include that the avalanche bulletin is accurate enough, decision making is focused on terrain and slope angles. The method is simple, very user friendly and does not need extra snow study skills or specialized equipment for interpretation of stratigraphy or the like (McCammon et al 2005). Therefore, identified information sources and field skills need to include the following:

- avalanche bulletin (danger rating, unfavorable aspects and elevations)
- slope angle at planning level/ estimation outside
- slope aspect at planning level/ estimation outside

- elevation at planning level/ estimation outside
- usage frequency of the trip/route/slope
- human factors – group size/spacing

3.7.2 Stop-or-Go by Larcher

Created by Michael Larcher, trainer at the Austrian Alpine Club, this rule based tool is a modification of the Reduction Method. Larcher felt that acceptance for calculations as well as exclusion of more traditional evaluation knowledge decreased the results of Munters tool. He therefore transferred Munters tool into a step by step guide (see Figure 7) consisting of three components. The goal was to simplify the process and expand the information going into decision making (McCammon et al 2005).

Figure 7 Stop or Go Strategy by Larcher version '12/'13 - tourenwelt.at

Identified information resources and field skills include the following:

- Avalanche bulletin (danger rating)
- Slope angle at planning level/ estimation outside

Observation and interpretation of:

- Snowfall
- Drift snow
- Recent avalanche activity
- Water saturation
- Settlement signs

3.7.3 SnowCard and Faktorencheck by Engler

Englers SnowCard is also based on the Reduction Method by Munter. The SnowCard consists of two cards (Figure 8), both of which show optical charts with fuzzy borders between different danger ratings. It incorporates the avalanche bulletin, slope angle and general conditions. Accompanied by the Faktorencheck, which allows interpretation of five or seven main factors favoring avalanche incidents, it offers a complete tool. Differing from the two first strategies, the combination of SnowCard and Faktorencheck offers a distinction in decisions made, based on the expertise of the user. This means the more knowledge a user has, the more feedback he can get from Faktorencheck. When information about required factors is scarce, even an expert user might return to the simple SnowCard for assessment (McCammon et al 2005).

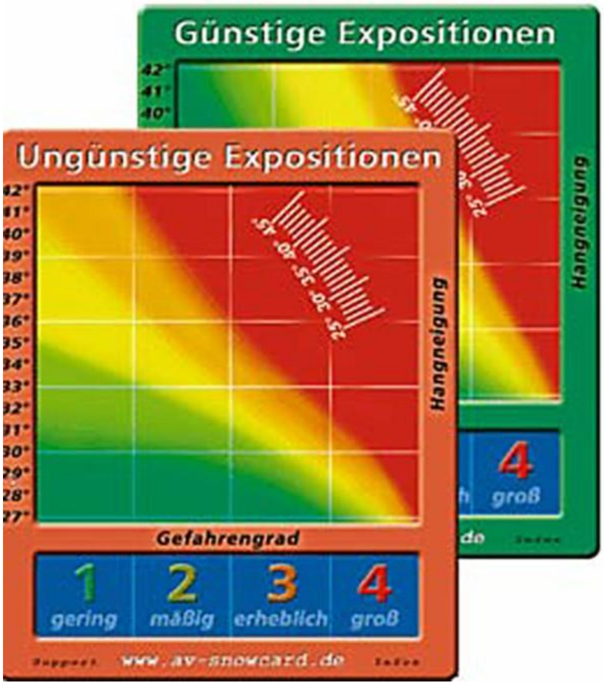


Figure 8 SnowCard for favorable and unfavorable Aspects, Engler, Powderguide 2014

Identified information resources and field skills include the following:

- Avalanche bulletin (danger rating, unfavorable aspects, elevation and terrain features)
- “additional information about conditions” (advanced)
- Slope angle at planning level/ estimation outside
- Slope aspect at planning level / estimation outside
- Elevation at planning level /estimation outside
- usage frequency at planning level

Observation and interpretation of:

- Recognizing terrain features
- Determine usage frequency
- Examination of new snow situation (advanced)
- Inspection of old snow condition (expert)

- Detailed terrain analysis (expert)
- Human factors in decision making (expert)

3.7.4 Nivotest by Bolognesi

While all described methods require an avalanche bulletin to offer accurate information and danger ratings, the Nivotest by Bolognesi allows the user to re-evaluate a given bulletin with a focus on the user's location and surroundings. To generate an estimation, users need to answer 25 questions regarding, weather, snowpack, avalanche activity, the planned route, and some human factors. To answer these questions general information as well as observation is necessary, where sometimes expert knowledge is required to interpret observations, especially regarding snowpack (McCammon et al 2005).

Identified information resources and field skills include the following:

- Avalanche bulletin (danger rating)

Observation and interpretation of:

- Weather conditions
- Snow conditions
- Recent avalanche activity
- Terrain characteristics of intended route
- Condition and equipment of participants

3.8. Combined risk factors from reduction strategies

When combining all the factors and observations needed from the reduction strategies described in chapters 3.7.1 to 3.7.4 one comes to the following findings. As for information and resources available at planning level a skier needs:

- An avalanche bulletin containing danger rating, locations of special risks (aspect, elevation and slope as well as terrain features)
- Slope angle, slope aspect, and elevation for any position at planning level
- Usage frequency of the region, tour, slope
- "additional information about conditions" (advanced knowledge from SnowCard)

This last information layer consists of the following factors which a skier needs to observe and interpret correctly:

- Weather conditions
- Snow situation and condition of old snow (current and past -> stratigraphy)

- Terrain features and analysis
- Recent avalanche activity
- Water saturation
- Settlement signs (sounds as well as visual)
- Human factors (equipment, decision making, group leading)

All of these, besides the human factors, can be translated and modelled in a database system. They can provide a viable and most importantly localized source of information that is relevant for beginners who use any of the reduction strategies. But also experts who rely on a knowledge based strategy might benefit in their process of decision making in avalanche terrain.

3.9. Limitations

Restrictions had been made when realizing the prototype development in this master thesis. When talking about an “avalanche application” most responses were about safety of prediction. As already explained in chapter 3.5 a reliable prediction of avalanche danger is impossible to make. Inclusion of all relevant factors and user feedback is not yet incorporated in any model. Spatial variation of snow cover and resolution of numerical models can’t be broken down to a “skier-friendly level” (i.e. less than a couple of meters). In accordance with the experts at the Lawinenwarndienst Steiermark the conclusion was drawn, that no prediction or reduction of information should be created. Users should still be the ones “computing” the input and making critical decisions. The resolution of the map in a current avalanche bulletin shows where avalanche service providers make a drawback. Legal claims along with the possible quick temporal change in conditions lead to this solution. With this in mind, it is a necessity for the user to have a minimum knowledge of snow avalanche formation and risk management in order to correctly interpret the information, to observe their surroundings and in succession to make the safest decision possible.

Further restrictions are result of time resources. These limitations include: the completeness of the prototype result as well as software-testing. Privacy and usability drawbacks have to be made as well. When talking about privacy, the only concern in this prototype development is the user position, derived from the mobile device, which has to be allowed by the user and only stores point data.

3.10. Goals

To conclude all the mentioned aspects, factors, established methods, numerical models and existing forecast types the following chapter will act as a proposal for what to implement in the practical part of this mater thesis.

First and foremost a prototype web GIS system shall be created for mobile devices. This system should display the information identified in chapter 3.8 about “Combined risk factors from reduction strategies”. Furthermore, queries about past information need to be possible. The position of this data and especially the parameter describing the situation (slope, aspect, height) are of importance and similarity of the user’s position needs to be considered.

Additionally, users shall be allowed to enter observations into the database. To prevent abuse of the upload system, the input will be registered and sanatized in a form allowing only specific values for each type of observation. Observations will be localized not only in position but also slope, aspect and height as well. In the following chapters the technologies used will be described in a short manner followed by the implementation of the system.

4. Materials and Methods

4.1. Technologies

4.1.1 HTML

Hypertext Markup Language is under constant development by the World Wide Web Consortium (W3C). The most current version of HTML is 5 since October 28, 2014 but was already used and implemented in many modern web browsers before. HTML is a markup language to structure digital web documents including text, hyperlinks, images, videos and so on. Design and layout of different elements can be done in HTML to a simple extent. For more advanced styling CSS (Cascading Style Sheets) is needed. Dynamic functionality is outsourced to scripting languages such as JavaScript and allows to change already loaded content any time by the client (MÜNZ et al 2013).

4.1.2 JavaScript

The first implementation and objective of JavaScript was to validate user input at client side as opposed to requesting information from a server. This simple but useful employment turned JavaScript into the scripting language responsible for making websites dynamic and responsive. Every modern web browser has JavaScript (standardized under the ECMAScript, which is an ISO certified language specification) is not limited to forms anymore but it interacts with all parts of a website (DOM-Document Object Model) and browser (BOM-Browser Object Model) content. However, it is restricted to the available content and users input from a keyboard or a file. Its popularity as well as importance has risen over the years and made it a very powerful scripting language used by most web developers (ZAKAS N 2012).

4.1.3 PHP

PHP is a script language with influence from Perl, C, C++ and Java. It is free software and is used to make dynamic websites. One of the biggest advantages is its support and the ease of connections to databases. In comparison to JavaScript, code is interpreted and processed on the server at specific loading times (KANNENGIESSER 2009).

4.1.4 PostgreSQL

For database management PostgreSQL will be used. This open source object-relational system has a long history of active development and many interface options with other programming languages. Together with PostGIS (chapter 4.1.5) it offers many standardized features. With all the different types of data needed to be stored and queried for the prototype application pgSQL is an optimal solution (POSTGRESQL Dev. Group, 2014).

4.1.5 PostGIS – PostgreSQL Extension

PostGIS, an extension of PostgreSQL, manages geodata and provides geo functions. It is an Open Source development group. Functions and operations are written in C++ supporting the common GIS geometry types as well as queries. Extensions for routing (pgRouting) and standardized interfaces to other GIS software or libraries are available (POSTGIS 2014).

4.2. Services/API's

4.2.1 jQuery Mobile

JavaScript library jQuery Mobile was chosen as it offers cross-platform, cross-browser and touch event optimized development of mobile browsers, devices and the development of mobile applications. This framework offers easy prototype development especially in terms of cross-browser support and user interface and experience (JQUERY MOBILE FOUNDATION 2014).

4.2.2 OpenLayers

Another JavaScript library used in the prototype development is OpenLayers. This API makes it possible to display geodata within a web browser. Besides usual map elements OpenLayers supports some standardized OGC (Open Geospatial Consortium) formats and services like WFS (web feature service) and WMS (web map service). With this framework the server-side geodata and map data are separated from tools and functions manipulating these data (OPENLAYERS 2014).

4.2.3 GeoServer

One of the interfaces served by PostGIS is Mapserver. GeoServer is a mapserver software developed by OpenGeo. OGC conform services provided by GeoServer are a Web Coverage Service, Web Feature Service, Web Map Service as well as Web Processing Services. Data provided by GeoServer may include vector and raster and can be accessed as a web service. This allows for the use of desktop GIS systems such as QGIS or web applications like OpenLayers (GEOSERVER 2014).

4.2.4 Geolocation API

The HTML 5 Geolocation API and its characteristics are specified by the W3C, an international community for web standards. A user's / smartphone position can be accessed with the Geolocation API. Depending on the availability of the GPS (Global Positioning System) signals other data from a mobile device can be used to determine its position such as RFID (Radio Frequency Identification), WLAN (Wireless Local Area Network) or GSM (Global System for Mobile Communications) cell ID's. User positions can either be retrieved with a singular request or by constantly repeating the request and therefor tracking a device. Querying cached positions is possible as well. Location data is provided in the World Geodetic Coordinate System (WGS84) with longitude and latitude, altitude, accuracy, altitude accuracy, heading and speed. Privacy is provided by implementing a user confirmation of giving away his location or withholding it if wanted (W3C a 2014).

4.2.5 DeviceOrientation Event (API)

The DeviceOrientation Event and its characteristics are specified by the W3C as well and addresses devices with one or more of the following sensors built in: gyroscopes, compasses or accelerometers. The interface provides not raw but rather high-level data about the physical orientation of the device in a local coordinate frame. The output is read-only, so it is not possible to modify or manipulate the output data in any form (W3C b 2014).

5. Implementation

5.1. Database design

The PostgreSQL/PostGIS database administration for storing all necessary data for the prototype development was done in pgAdminIII. A focus was put on database scalability. For this reason, a variety of tables were created. A general schema displaying all database tables used within this prototype can be seen in Figure 9 and will be further described in the following chapters.

The included database tables and attributes of each table are based on the risk factors identified in risk reduction strategies in chapter 3.7. With the usability and transparency of user uploads in mind some risk factors had to be omitted and/or modified. Water saturation of snow for example is very difficult to measure against a benchmark making it very difficult to assess. As a consequence, interpreting this parameter poses a risk. Also, the factor "terrain" which is part of almost all reduction strategies was omitted at this stage. It consists of many different factors itself and leaves room for too many different scenarios that are based on terrain parameters to be part of this master thesis (see the Ph.D. Thesis by SCHIRMER M. (2010) about this topic – also mentioned in chapter 3.5).

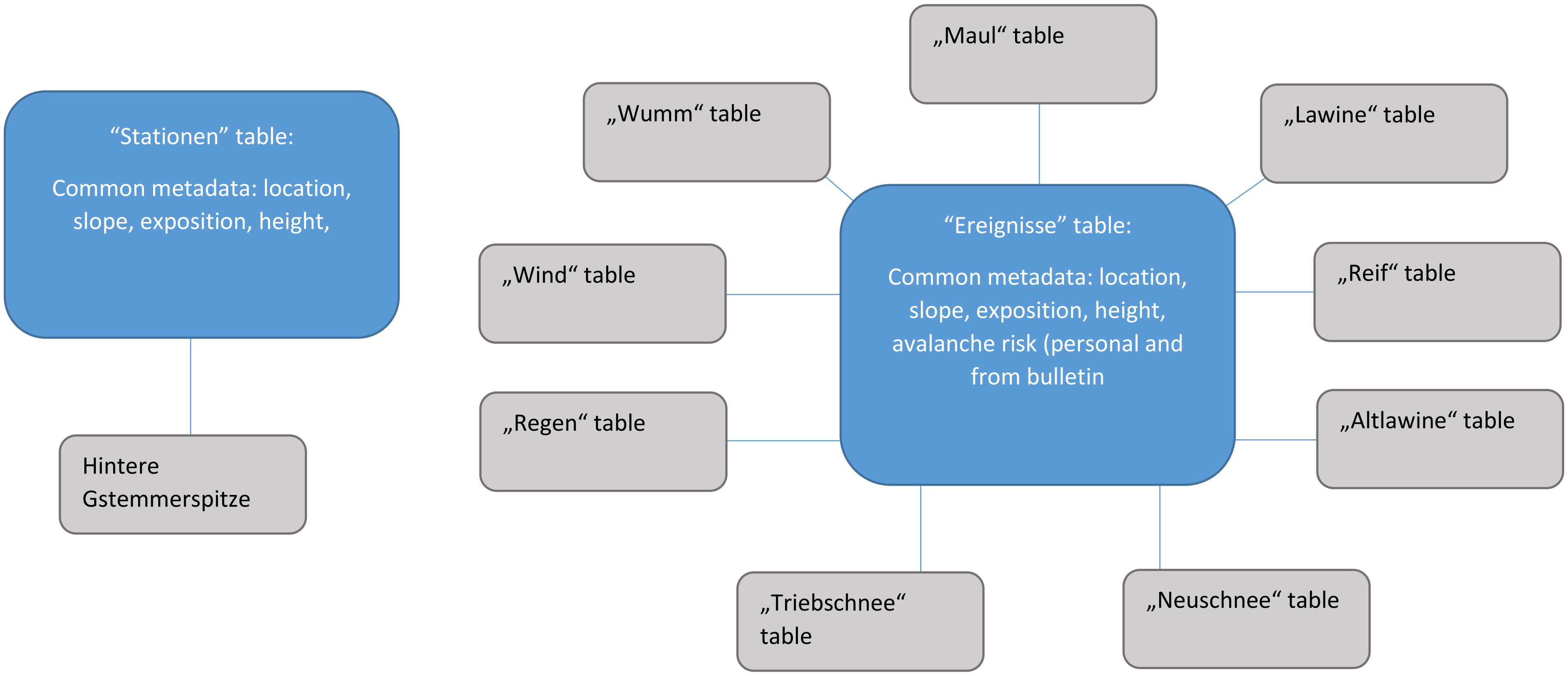


Figure 9 Database: tables and their connections

5.1.1 Weather Data

	id [PK] serial	station integer	datum_zeit timestamp without time zone	temp_schnee double precision	feuchte_schnee double precision	schnee double precision	temp_wind double precision	feuchte_wind double precision	wind_wg_mw double precision	wind_wg_max double precision
19049	19049	1	2014-02-10 07:40:00	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
19050	19050	1	2014-02-10 07:50:00	-2.4	41.6	136.8	-5.4	47.2	46.98	69.444
19051	19051	1	2014-02-10 08:00:00	-2.8	46.3	136.6	-5.4	45.7	44.46	56.988
19052	19052	1	2014-02-10 08:10:00	-2.4	42.8	136.6	-5.6	47.2	42.732	57.744
19053	19053	1	2014-02-10 08:20:00	-2.7	44.8	136.8	-5.4	45.4	45.756	58.464
19054	19054	1	2014-02-10 08:30:00	-2.5	45.3	136.6	-5.3	47.5	49.32	58.788
19055	19055	1	2014-02-10 08:40:00	-2.5	46.7	136.6	-5.4	48.8	49.86	59.508
19056	19056	1	2014-02-10 08:50:00	-2.5	47.9	136.5	-5.7	49.7	51.588	65.88

Figure 10 Weather station data "Hintere Gstemmerspitze" from October 2013 to June 2014

Sample data provided by ZAMG Steiermark is weather station data from the station "Hintere Gstemmerspitze" (see Figure 10 for parameters) on Planneralm in Upper Styria. The recorded data consists of a variety of parameters which were put into the database. As this thesis is a prototype and there was no access to a web service or API by ZAMG Steiermark this part of the database was realized in a static way. Processing weather data was of high importance with a focus on displaying the information, in case such an interface providing live weather data should become available in a production environment. The ten-minute-interval data has no location values included, which therefore were put into another table, making it easy to add or modify the corresponding weather stations. Height, exposition and slope information are also stored in this table (see Figure 11) containing the location. Besides scalability, data querying and processing is sped up by splitting up this information.

	stationsid [PK] integer	name character varying	height integer	position geometry(Point,43	exposition integer	slope integer
1	1	Hintere Gstemmerspitze	2105	0101000020E6100(	5	25
*						

Figure 11 Weather Station table containing weather station information for "Hintere Gstemmerspitze"

5.1.2 Uploaded Data

The Feedback data tables were created along the lines of the weather data. In a central table called "ereignisse" (see Figure 12) all the metadata containing geolocation, exposition, height, slope and so on were stored. Two additional columns store the

id [PK]	event_kategorie integer	datum timestamp \	anmerkung character varying	exposition double pre	slope integer	height integer	lage_persoen integer	lage_dienst integer	upload_date timestamp wi	position geometry(F
1		2015-01-11	38a595pqek	130	19	2822	2	2	2015-01-11 :	01010000020
2	8	2015-01-11	mdhh13hpaa	255	15	1966	5	5	2015-01-11 :	01010000020
3	1	2015-01-11	1f1shid4eb	169	26	508	1	1	2015-01-11 :	01010000020
4	3	2015-01-11	97wqixpm64	4	25	790	3	3	2015-01-11 :	01010000020
5	2	2015-01-11	sr20x5n90y	261	48	2073	3	3	2015-01-11 :	01010000020

Figure 12 Feedback table containing user feedback data - metadata columns

avalanche risk information provided by the avalanche bulletin provider and the avalanche risk users came across outside when making their observation or sighting of an incident. Date and time information is later used for calculating the age of different sightings which are displayed and described further in chapter 5.2.4 and following. All types of incidents have their own table in the database as they all have their own individual characteristics. These different parameter values stem from the findings in the theoretical part of the thesis in chapter 3.2 “Avalanche triggering factors”. In Table 2 the different tables with their individual columns can be seen.

Table	Contains:	Columns:	Datatype	Stored Information
altlawine	old avalanches which are still observable	id	serial	PRIMARY KEY
		event_id	int	foreign key to "ereignisse"
		art	char	type of avalanche
		size	char	size of avalanche (categories
		age	int	age of avalanche
lawinen	observed avalanches	id	serial	PRIMARY KEY
		event_id	int	foreign key to "ereignisse"
		art	char	type of avalanche
		ausloeser	char	type of triggering
		schwachschicht	char	description of weak layer within snow cover
		anrissgebiet	char	description of the area where the avalanche started
		anrisshoehe	int	slab thickness
		breite	int	slab width
maul	observed glide crack	id	serial	PRIMARY KEY
		event_id	int	foreign key to "ereignisse"
		width	int	width of glide crack
		depth	int	depth of glide crack
		length	int	length of glide crack
neuschnee	fresh snow	id	serial	PRIMARY KEY
		event_id	int	foreign key to "ereignisse"
		hoehe	int	amount of new snow in cm
		feuchte	char	moisture in fresh snow (categories)
		kristall	char	physical form of fresh snow crystal
		große korn	double	size of fresh snow crystal
		altschneeschicht	char	description of snowcover before fresh snow event
regen	transition of precipitation	id	serial	PRIMARY KEY
		event_id	int	foreign key to "ereignisse"
		schneedecke	char	description of snowcover at time of event
		kons_niederschlag	int	direction of change (liquid to solid or solid to liquid)

reif	observed surface hoar	id	serial	PRIMARY KEY
		event_id	int	foreign key to "ereignisse"
		hoehe	double	height of surface hoar flakes
		breite	double	width of surface hoar flakes
triebschnee	observed snowdrift	id	serial	PRIMARY KEY
		event_id	int	foreign key to "ereignisse"
		ablagerungshoehe	int	height of snowdrift accumulation
		umfang	int	extent of snowdrift accumulations in categories
		windrichtung	char	wind direction at snowdrift event
		merkmal	char	observed signs of snowdrift
		festigkeit	char	stability within the snowdrift accumulation
		hangzone	char	description of the slope area
wind	observed strong winds	id	serial	PRIMARY KEY
		event_id	int	foreign key to "ereignisse"
		richtung	int	wind direction in degree
		geschwindigkeit	int	wind speed in km/h (estimated)
wumm	Whumpfing, collapsing sound	id	serial	PRIMARY KEY
		event_id	int	foreign key to "ereignisse"
		riss	int	true if combined with gliding cracks

Table 2 All database tables and columns connected to "ereignisse" table containing user feedback data

Additionally, to these parameters a user can upload pictures. Image data is handled through PHP and is further described in chapter 5.2.4, however the connection to the corresponding user upload event data is stored in the database. Differentiations between these two properties results in better scalability as well as upload and download speeds. Hyperlinks to and identification of the images stored on the server are put into the table "pictures" along with a foreign key to the table "ereignisse". A unique name property (consisting of the event id and picture id as a minimum) is given to all the uploaded pictures to prevent matching problems when later displaying the corresponding image as seen in Figure 13.

	id [PK] serial	event_id integer	kategorie integer	name character varying
1	4	515	1	evtid_515_picid_4_images.jpg
2	5	516	1	evtid_516_picid_5_images.jpg
3	6	518	7	evtid_518_picid_6_1421086765045-1501164940.jpg
4	7	520	1	evtid_520_picid_7_14211432419241465107777.jpg
5	8	521	1	evtid_521_picid_8_14211432419241465107777.jpg

Figure 13 Picture Table containing the metadata for uploaded user images

5.2. Mobile Component

The mobile component of the application consists of two interlocked parts which are connected thematically and technically. However, to describe their functionality the two parts will be disjointed in the following chapters. After the parts are described in detail, a chapter with a user story in mind will show the functionality of the application in a real world scenario; it will be demonstrated how this technology could help users. In the following chapters screenshots will show the interface of the application. These screenshots are taken either from the authors private mobile devices or the emulation feature in Google Chrome, which allows a quick change between screen sizes, and emulating not only the position of a device but also the orientation.

5.2.1 Design and Compatibility

As this master thesis is a prototype system it was never the goal to create a fully compatible application for all browsers and devices. Some trade-offs had to be made, especially concerning design/responsiveness of the layout and browser compatibility. During development, mostly Google “Chrome” was used for debugging and design corrections. Because of this step some functionality might not be available in other popular browsers like Microsoft Internet Explorer or Mozilla Firefox, or information could be displayed differently as all these browsers interpret some HTML tags differently. Responsiveness was a minor point of focus but not a major concern as jQuery Mobile takes care of a lot of the issues concerning screen size. Testing of responsiveness and different devices was conducted on private android devices (5 and 10 inch screens) as well as through the emulation function of Google “Chrome” (as can be seen on all of the screenshots taken for this master thesis)

5.2.2 Upload form and functionality

The main unique feature of this web application as opposed to other avalanche tools is the upload section. And resulting from this feature, the opportunity for all users to see this input, turning normal users into prosumers. It allows the user to upload an observed event from a variety of different scenarios and with specific characteristics for each type of event. The included events and the programmed solution will be described in the following paragraphs.

When clicking the “add”-button (Figure 14 Index page of the mobile web application centered on the Planneralm with the Icon for “Hintere Gstemmerspitze” weather station, emulated device: Nexus 7, own screenshot upper left corner) the user gets transferred to the upload.html. This site is an individual jQuery Mobile construct that basically consists of three parts: (a) an overview map showing the users position on the ground, (b) a

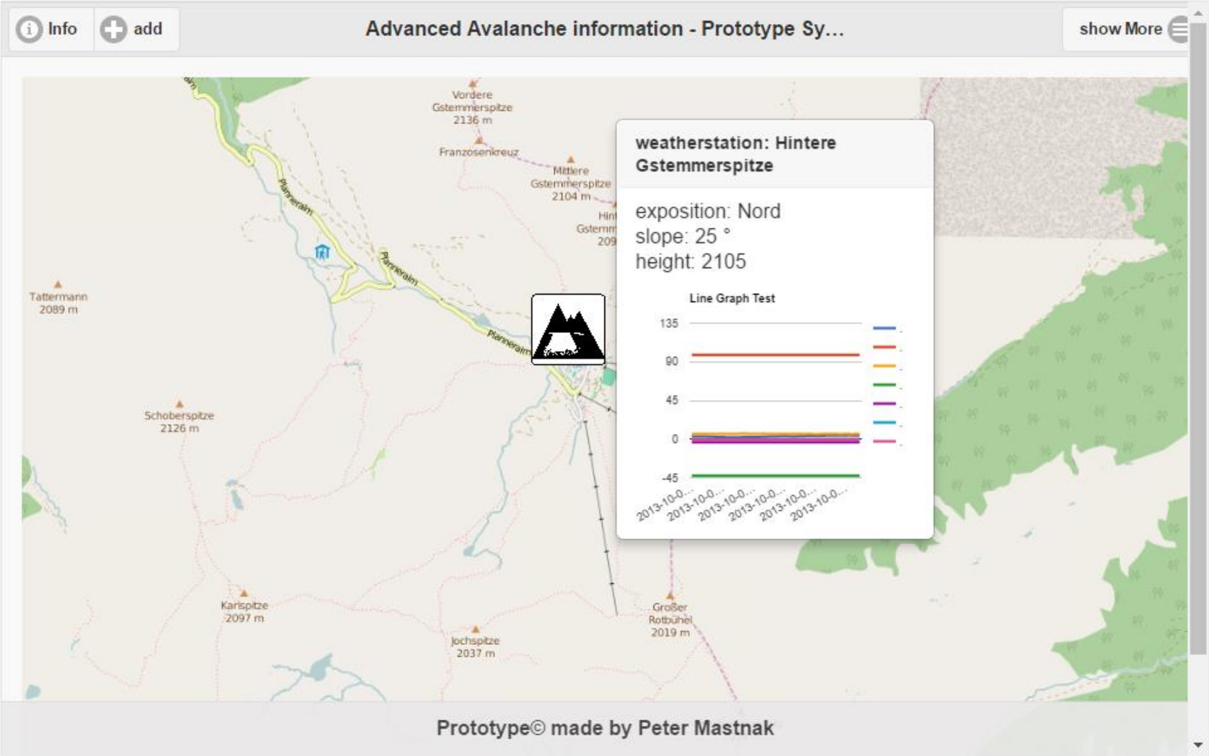


Figure 14 Index page of the mobile web application centered on the Planneralm with the Icon for “Hintere Gstemmerspitze” weather station, emulated device: Nexus 7, own screenshot

dynamic html/jQuery form, and (c) a jQuery page to determine the aspect and slope angle should the user don’t know it.

The overview map is realized through JavaScript initiating an OpenLayers map object. At this prototype stage this map object could display any open source type of map. With possible further development this base map could be adapted to the specific needs skiers have (the possibilities and options are described in chapter 7.2). To show the users

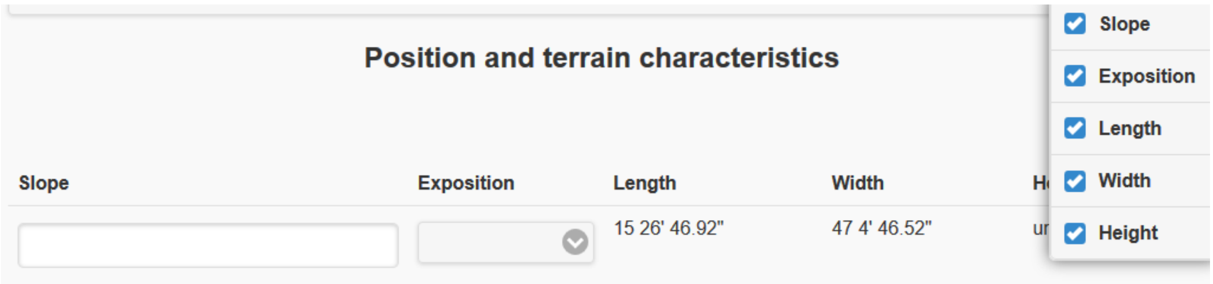


Figure 15 Slope, exposition and position parameters, responsive and adapting to screen size table, emulated device: Nexus 10, own screenshot

position the map automatically focuses on the current position in the center. The geolocation API determines latitude and longitude from the mobile devices sensor readings. When on the main page a programmatic event receiver is used to listen for changes in the user's position and therefore tracking his position continuously. When a user is adding an event through the form the current position is determined and used when submitting the event data. High accuracy (GPS) solutions as well as a maximum age of 10 seconds were chosen for position requests. Within the upload-form the WGS84 position is displayed (Figure 15) in degree values so users can verify the accuracy easier if a traditional map is used alongside. Height parameters are determined as well, though there is a high uncertainty in the accuracy as most mobile devices do not feature a barometer and rely on calculations depending on the GPS signal. These values are displayed in a field next to aspect and slope values, which can be selected manually as well as determined automatically as described in the following paragraphs.

The form is located on a single jQuery Mobile page element. In a select field the user first has to choose between 3 general event types (Figure 16):

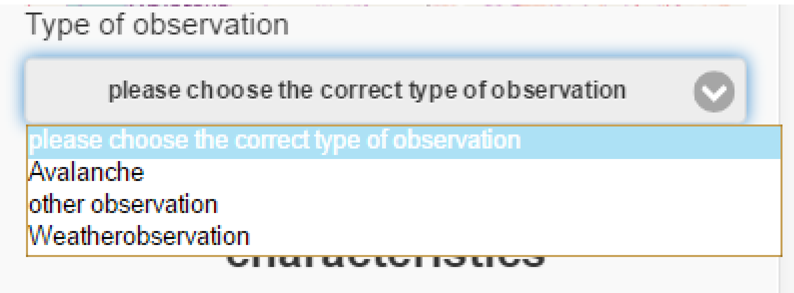


Figure 16 Dynamic form - first distinction between event types, emulated device: Nexus 5, own screenshot

- Avalanches
- Warning signs
- Weather events

Once an observed event is chosen a JavaScript function is triggered through the “change” of the input select field, showing only the possible parameters for the selected event. All input elements are located within a “div” element making it possible to change the form parameters dynamically by user selections. A fluid and quick navigation throughout the application is possible, because the HTML part of the web application is on a single jQuery site. Omitting unnecessary form elements leaves less room for wrong input (at least when browsing the site from a mobile device), though user input is validated in a later step as described in chapter 5.2.3 about validation.

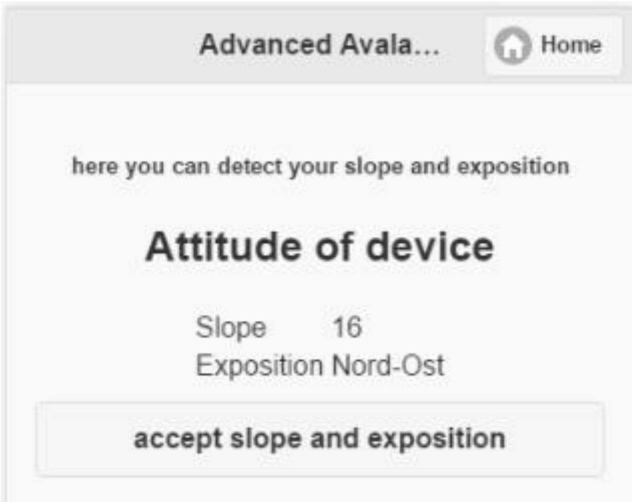
Figure 17 Observation form of snowdrift with sample data, emulated Device: Apple Ipad 3/4, own screenshot

If a user wants to report the observation of a hazard sign a variety of form elements allow definition of type, size, height and triggering factor, some comments and so on (see Figure 17). But if the observed event is a slab avalanche, some of these form elements do not make sense and therefore are not visible in the form.

In addition to the specific event parameters there are some universal factors recorded with every event. These parameters include:

- Position

- Aspect
- Slope
- Date
- Users avalanche risk rating
- Comments
- Photos



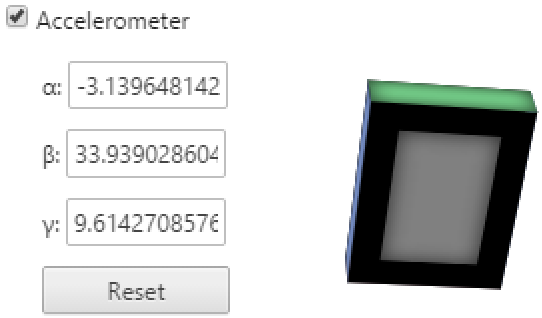


Figure 18 DeviceOrientation API use case: identifying slope and exposition on the left. On the right the emulated accelerometer values can be seen. Emulated device: Nexus 5, own screenshots

Besides the automatically determined position that was already described in the prior chapters, the exposition and slope can be determined automatically as well. In the separate JavaScript file, a function calling the DeviceOrientation event listener is realized. The two parameters alpha and beta are used to determine orientation (beta - slope) and the tilt (alpha - exposition) of the mobile device (see Figure 18). By confirming the values visible on the display users can send them back to the upload form into the specified fields. Orientation values are calculated and aggregated into 8 directions each 45° wide. Users can access this page not only through the form for submitting events but also from the start page, allowing fast measuring of aspect and slope.

Default date is set to the current date but can be changed so a passed date is a valid choice considering previous avalanches or events that happened days ago and can still be recognized. A user's avalanche risk rating is voluntary information and is based on to the "lawinen forum" by LWD Steiermark where experienced users may enter valuable ratings online already according to the LWD Steiermark. The comment field is optional, leaving further possibilities to the user. Adding pictures is not mandatory either as the data connection quality in alpine regions has to be kept in mind. As seen in the "lawinen forum" though, a picture together with the required information usually offers a great basis for interpretation.

5.2.3 Input Validation

To improve the quality of uploads and dismiss chances of wrong user input as much as possible, JavaScript form validation is implemented. For this purpose, part of the "jQuery validation plugin", written by Jörg Zaefferer, a member of the jQuery team, was included. A simple class parameter on the input type element "activates" the validation for each required form element and displays an error message (see Figure 19). After a successful upload the user is redirected to the index page where the new upload can be seen immediately.

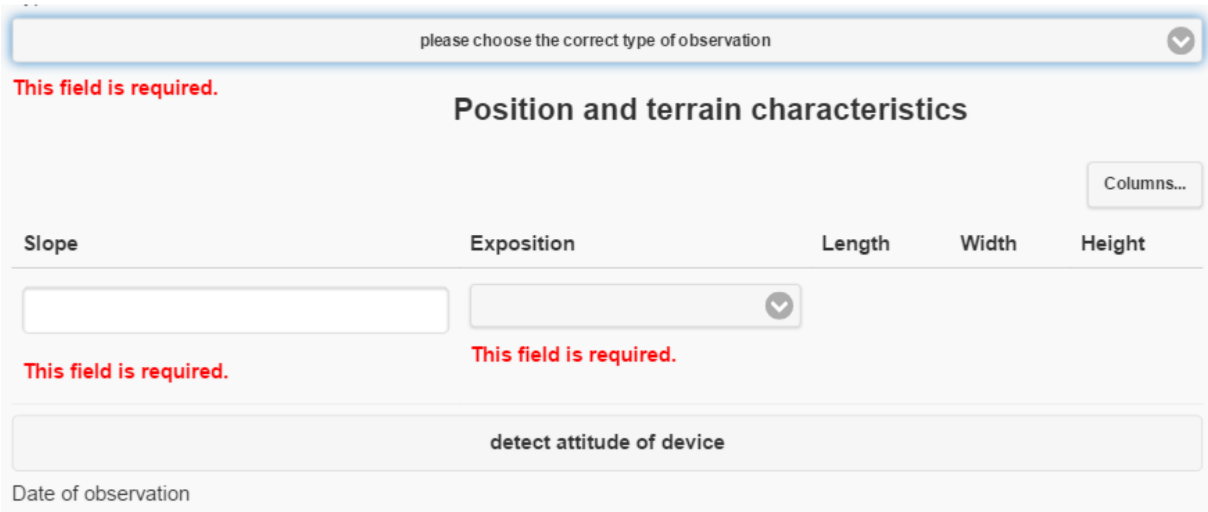


Figure 19 Form validation, error messages on submit, emulated device: Nexus 7, own screenshot

5.2.4 Image Upload

Users can upload images together with a description into the dynamic upload form. Uploaded images are handled in a PHP script storing the image data in a folder on the server with a unique name. Image filenames and paths are in combination with the event type and ID in the "pictures" PostgreSQL table. This leaves room for making requests regarding specific event type pictures or for a specific event only. Images are displayed in the location specific filtering feature described in chapter 5.2.6.

5.2.5 Visualization of user input

User input is visualized on the start page with individual symbols for each type of event observed by users. Symbols were created for the specific purpose of making the events recognizable on mobile devices. The following symbols (in Table 3) were designed and used, again with the issues about browser compatibility and layout from chapter 5.2.1 in mind:

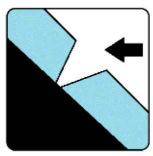
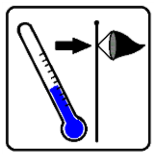
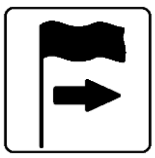
Symbol	**Meaning:**	**Symbol:**	**Meaning:**
	drift snow		dry snow avalanche
	fresh/new snow		precipitation transition
	surface hoar		crack/tear in snow cover
	slab avalanche		snow crevasse
	snow cornice		permanent weather station
	(strong) wind		Settling sound (whoompfing)

Table 3 Visualization symbols, own creation

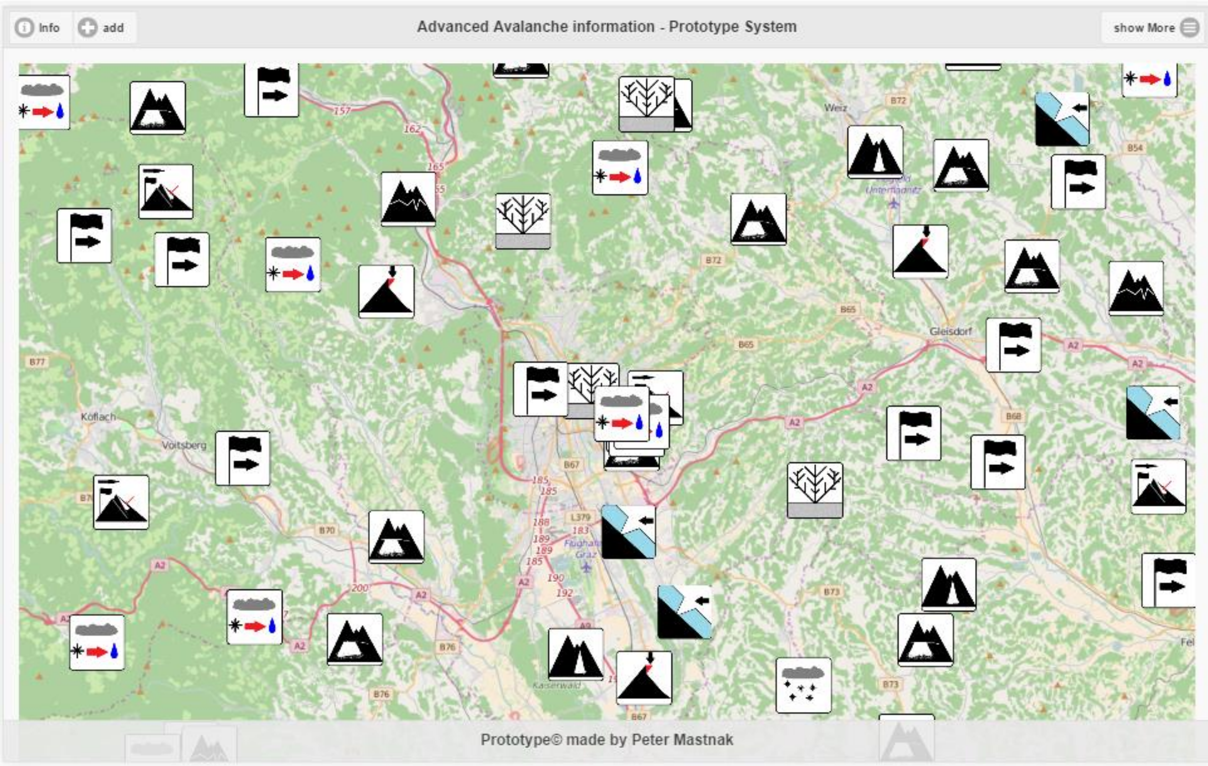


Figure 20 Index page with visualization symbols of dummy data, own screenshot, emulated on: nexus 10

The index page therefore gives users an instant overview of the area surrounding them and the events recorded. During testing and writing the index page dummy-data was used and spread over the whole state of Styria as can be seen in Figure 21.

Event type filtering is possible through the "show more" Button (see Figure 21 and Figure 22 where each type can be turned off individually. To access data connected to an event a simple click on the symbol opens up a small window. This window is divided into two areas: the upper one displays general information from the "ereignisse" table which is also used for locating the events. In the lower part event specific data which is stored in a different table (as described in chapter 5.1.2) is loaded through an Ajax call. As detailed in information in the lower part is loaded asynchronous it can sometimes take a little longer until it is displayed.

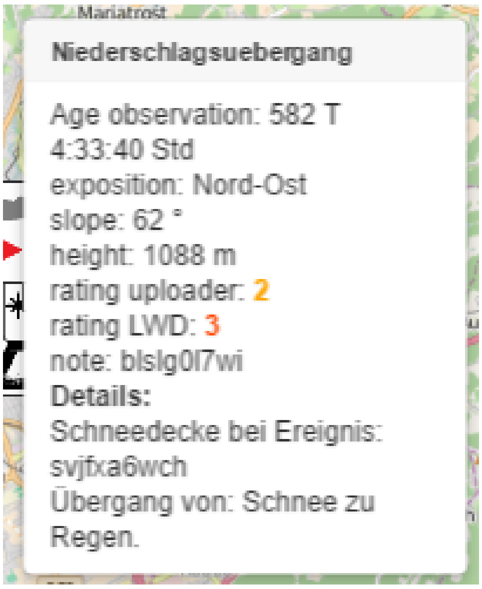


Figure 21 Detailed event information of an avalanche sighting (dummy data), own screenshot, emulated on Nexus10

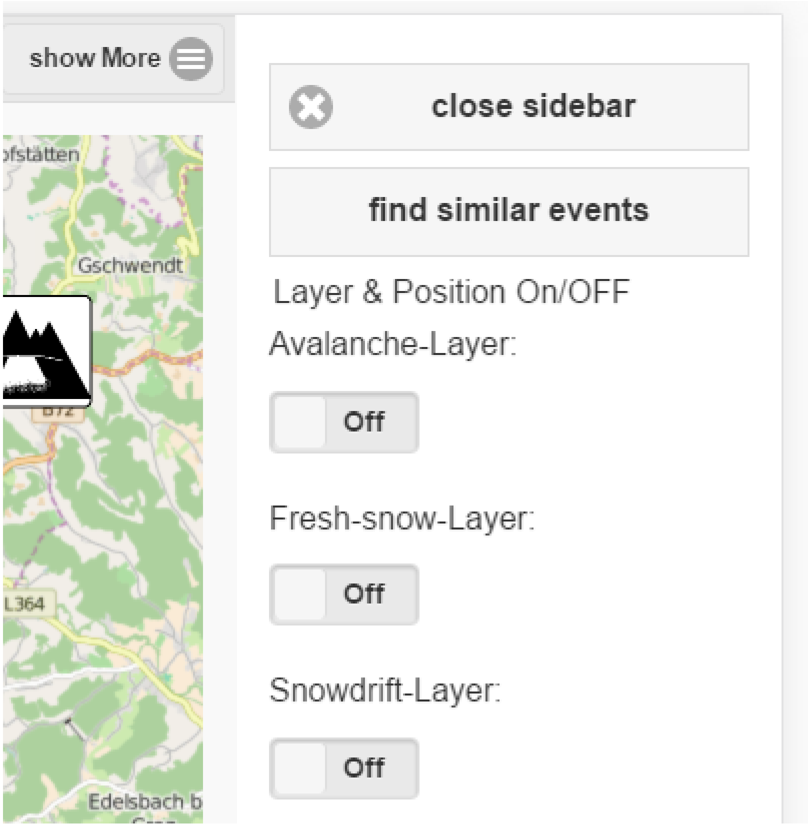


Figure 22 Filtering options on index page, own screenshot, emulated on Nexus 10

Detailed event information (dummy data in this case) about an avalanche sighting can be seen in Figure 20. The first few lines are displaying the general information connected with every sighting. After the “Details:” row the information is event specific and loaded through an XMLHttp request. Information can be formatted to fit users’ needs as seen in the two rows displaying the avalanche service provider rating and the user rating.

5.2.6 Location specific filtering

The second button in Figure 22 Filtering options on index page, own screenshot, emulated on Nexus 10 with the label “finde ähnliche Events” (find similar events) allows users to find events. The queried events are in a defined distance around the user’s location. Additionally, the exposition, slope, and height of events can be sent into the query. As described in chapter 5.2.2, exposition and slope can be determined automatically through the device orientation object and used for this query, or put in manually for checking exposition and slopes of interest. The height parameter has to be put in manually if the information is not available through the geolocation API. A buffer surrounding the user’s position can be chosen from a minimum of 5 kilometers to a maximum value of 100 kilometers. Results are displayed in a table showing the distance to the specific event, some event type information like age and ratings, and type of event. Additionally, on a desktop computer the picture to the corresponding event can be viewed in a slideshow. Since mobile devices have limited screen resolutions, only selected information is shown for each event on mobile phones.

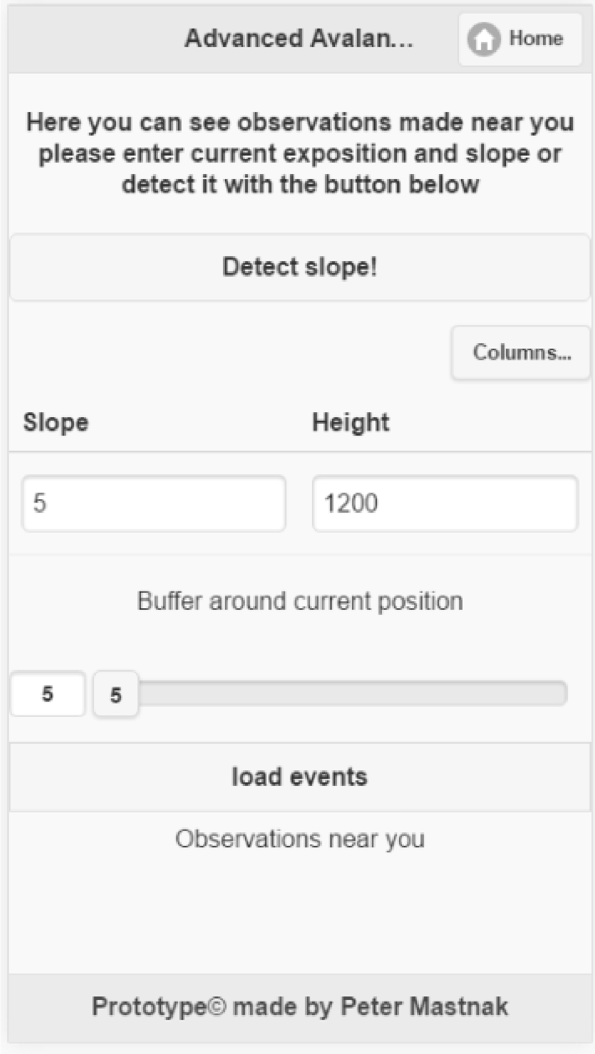


Figure 23 Location specific filtering, own screenshot, emulated on Iphone6

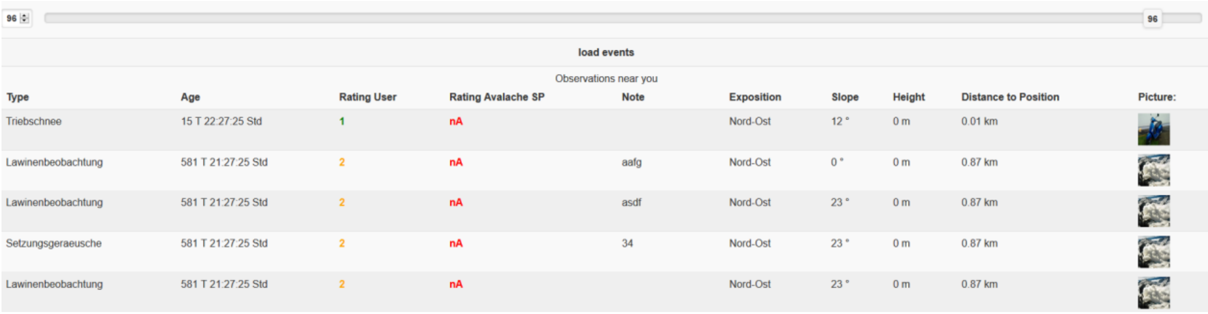


Figure 24 Result of a query for events located at a similar position, own screenshot, emulated on Nexus 7

5.3. Server sided processing

As most of the implemented application runs on JavaScript and the jQuery Library, as well as some PHP and CSS bits, the server side processes are meeting only minimum requirements for interaction with the client side processing. The server is mostly used for storing all kinds of data (sightings in the database and pictures in the general file system). Of course, without running instances of different services a publically available website would not be possible (IIS, a mapserver and so on). Besides SQL queries and data storage many more features could have been realized server sided but were omitted as most of the time client side processing was delivering results more quickly and easily.

6. Results

6.1. Research questions

In the following paragraphs the three main research questions of this thesis are rephrased and answered in a short manner. With a reference to the chapter in this thesis or literature more in-depth answers can be found.

- **How can a user assess the avalanche situation at a specific position and is there a way to calculate the risk so that an individual can trust the results?**

  Many ways for assessment have been shown in the theoretical part of this thesis, though none of them offer expertise for specific positions. This is a result of the very difficult task of making precise forecasts. These forecasts are still made by an expert who has to go outside and check conditions or take into account the information another expert from a specific region can offer. As most scientific attempts on calculating the risk have failed, it does not seem likely that there will be a formula or anything similar to get trustworthy results in the near future. The risk assessment still depends on the knowledge and experience of each individual.

- **Which information should be included in a location based service to assess avalanche risk?**

  The database created for this thesis with all its properties represents the minimum information that is needed to evaluate the avalanche risk situation based on either of the assessment tools that already exist. As stated in the answer of the first question, experience is an important and additional source of information for making the right decision.

- **Is user-feedback a reasonable tool to expand the avalanche bulletin within a location based service?**

  One thing that can't be measured is how close a specific situation was to a fatal outcome. There is no way of knowing how much more weight the snow surface could have taken once a skier finished skiing a slope. However, there are signs and events someone might have observed, that could offer additional information to someone else planning to go to these exact places. This information is still not recorded nor made available to other skiers. Therefore, user-feedback and event recording is a reasonable tool to offer more information and could lead to a better assessment of the predominant situation.

6.2. Scientific presentations

Parts of these findings as well as at the time ongoing research were presented in oral presentations at the following events:

- **11th Symposium on Location Based Services in Vienna, November 2014**
- **AHORN 2014 - der Alpenraum und seine Herausforderungen im Bereich Orientierung, Navigation und Informationsaustausch, November 2014**

Links to both events can be found in the references section. The slides (English as well as German) to both presentations shown at both events are handed in together with the source code of the application in a separate folder.

7. Conclusions and further Development

7.1. Conclusion

From the first idea till the finished master thesis a lot of time has passed. In this time, starting with a very general knowledge about avalanches, a lot of additional know-how was acquired. Different perspectives put already known “rules” and theories into a new light and changed the view on the whole field of avalanche prevention. After all, there are many factors playing a role in the formation of avalanches. The amount of factors from different scientific approaches seems to merge almost all meteorological observations, some aspects of statics and dynamics, fluid mechanics, and so on. At the beginning of this thesis it was clear that not all factors could be incorporated into a single system and therefore have been left out of the scope. The theories and rules of different reduction strategies soon appeared to be the right lead to create a prototype system that offers additional value to the end-user. Through the different factors considered in these strategies the idea to create a feedback system to offer information that wasn’t available on a big scale to the wide public was born. During the duration of writing this thesis similar ideas were picked up by two winter outdoor application providers (White-Risk and Alpenvereinaktiv). This development suggests that in order to produce better informed users and therefore a lower number of avalanche incidents an application of this type could be the right direction. The prototype application resulting from the thesis fulfilled its goal of finding an area that wasn’t given much attention yet and a way of providing added value in this area. The current prototype offers an opportunity to further develop this application possibly realize the suggestions from the following chapter.

7.2. Further Development / Work

Further development resulting from this master thesis includes the development and realization of a “native” app for operating systems deployed by mobile devices. Such an application could use the structure and findings of this thesis and improve the basic character by including further information layers. These layers might be provided by the avalanche service providers, weather data services or geodata service providers. Useful geodata layers would be:

- land cover classifications on a very small scale

    Useful for identifying vegetation such as alpine meadows or dwarf pines

- orthophotos or high quality laser scanning data

  for identification of larger terrain features

- high resolution DEM's

  for identification of small scale terrain features and identifying slope inclination as well as incident solar radiation

A base map displayed not only for orientation purposes could be created by custom rendering OpenStreetMap data adding further quality information for end-users and allowing quick overviews (low data transfer rates for remote regions) as well as better visibility (contrast/saturation/color adjustments with bright situations due to snow reflection in mind). When talking about further geodata, high quality digital elevation models should not be forgotten as these would not only provide a big improvement for orientation and interpretation of terrain but would also allow closing a gap many mobile devices still have: height determination. Getting height information for a determined position from a DEM could provide much greater accuracy.

Since avalanche service providers do not base their bulletin on weather station data and have to check conditions manually, inclusion and systematic analysis of the user feedback data could improve forecasts for a wider area. Outdoor inspections can be done where the situation is critical, while in other areas the avalanche service providers could resort to the user feedback data for interpretation.

Avalanche accident statistics may be matched spatially with user activity and predominant conditions when such an incident occurred in the affected region. The SLF in Davos conducted such a survey by connecting touring conditions described by users in online forums and actual accidents which the SLF tracks in a general database published every year. By storing the location of all the user interactions more questions in this field could be answered easier than in Techel's research (TECHEL 2014). New findings could appear in the intricate fields of trust and obedience in the avalanche bulletin. An especially interesting question could investigate whether users are more likely to "obey" the avalanche bulletin during specific conditions (i.e. fresh snow versus less favorable conditions). Possible questions could include: „ Under which touring conditions are skiers most likely to trigger avalanches?" or „Are there more avalanches happening in less frequently toured/reported areas?" or „Is a certain recorded event more likely to be ignored and the affected area still toured throughout the following days even though it would indicate a higher risk?“

Another interesting area of research would be to automatically identify small scale areas that are currently only mentioned in the written avalanche report such as ridges, crests, and so on. These critical topographic features have different levels of danger and give the avalanche service provider the chance to rate these small scale areas differently depending on the predominant weather situation. This could improve the small scale accuracy of the assessments.

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