A Mobile Application for Reducing Skiing Injuries

An Interactive Qualifying Project Report

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By
Mitchell Curbelo
Ralph Grzybek

Advisor
Christopher A. Brown

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Abstract

Skiing and snowboarding are two incredibly popular outdoor activities for people around the world. In the United States, there were 54.7 million ski resort visits in 2016-2017 (NSAA, 2018). Both are risky sports, with about 1.9 injuries per thousand skier visits (Johnson et al., 2008). Many foundations, skiing initiatives, and other groups (such as Your Responsibility Code, Lids on Kids, Smart Style, Kids on Lifts, Collision Safety, Tree Well & Deep Snow Safety, the High Fives Foundation (NSAA Safety Programs, 2018), and the SnowSport Safety Foundation), are dedicated to the elimination of skiing injuries. Even with these efforts, dangers associated with the sport, refusals to acknowledge the occurrence of injuries, and refusals to support campaigns dedicated to the reduction of skiing and snowboarding injuries still exist.

This paper analyzes methods for reducing skiing injuries. The methods include: (a) legislation requiring safer trail construction and maintenance, (b) improving the current trail rating system, and (c) a mobile application informing users about trail hazards. As will be explained, the most practical method with the most potential for reducing skiing injuries was determined to be the mobile application. A mobile application will, at minimal cost, enable the provision of real time information to skiers and snowboarders.

Providing skiers and snowboarders information should reduce injuries. However, the eradication of skiing injuries will not occur without the removal of the injury mechanisms, which cannot be accomplished through a mobile application. Further research must be done to determine the effectiveness of reducing injuries by providing more information to skiers and snowboarders.

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1. Introduction

1.1. Objective

The objective of this project is to study current methods of reducing skiing and snowboarding injuries, devise new approaches to reducing skiing and snowboarding injuries, and use axiomatic design to determine which method has the greatest likelihood of being implemented while providing the greatest benefit.

1.2. Rationale

Although reducing skiing and snowboarding injuries is desirable from a humanitarian perspective, there are financial incentives that also make reducing their occurrence a compelling incentive. Incentives include reducing medical costs and reducing legal costs to both individuals and resorts, occurring as a result of skiing or snowboarding injuries.

In a study conducted on Snowboarding Injuries in Children and Adolescents (Shorter et al., 1999), the data collected was compared with data from a similar study conducted on Skiing Injuries in Children and Adolescents (Shorter et al., 1996). The studies showed that, on average, skiing injuries warranting a hospital stay cost $22,000 and snowboarding injuries warranting a hospital stay cost $10,000. Using these results and information collected (i) in a study on Injury Trends in Alpine Skiing, which states that there are 1.9 injuries per thousand skier visits (Johnson et al., 2008), (ii) a statement from the The National Ski Area Association (NSAA) that there were 54.7 Million skier visits in 2016-2017(NSAA, 2018), (iii) a 2014-2015 NSAA National Demographic Study determining that 73.1 percent of the skiing visits were by skiers; (iv) assumptions that injury costs are consistent among all ages, (v) one percent of injuries warrant hospital stays, and (vi) injury costs only occur when a skier or snowboarder is hospitalized; the total cost of skiing injuries on individuals during the 2016-2017 skiing season can be estimated to be 19.5 million dollars.

As discussed above, skiing and snowboarding injuries can place a large financial strain on a skier or snowboarder. This is worsened when the injured party seeks an address of grievances, which is usually done through a lawsuit. When this occurs, the lawsuit costs are placed on both the individual and their fellow skiers and snowboarders, who pay for the defense of the corporation with increased lift ticket prices.

To demonstrate the existence of lawsuits of this nature, Google Case Law was used to estimate the number of lawsuits related to a customer being injured during a skiing visit. The keywords “skiing”, “injury”, and “resort” were searched. Then, the first five pages of results were examined to determine the number of cases related to skiing and snowboarding injuries. On the five pages, which included ten results per page, the number of results relating to skiing and snowboarding injuries on these five pages were three, two, four, three, and two, respectively. Therefore, the results exhibited an average of 2.8 results related to skiing injuries for every 10 results. Using this and the total number of results, which was 2,030, an estimate of 566 results related to skiing and snowboarding injuries are estimated to be on Google Case Law.

In addition to looking at Google Case Law, websites of companies that file skiing and snowboarding injury lawsuits were found. Three example are AllLaw (AllLaw, 2018), NOLO (NOLO, 2018), and Chalat Law (Chalatlaw, 2018). Each website both explained the type of skiing injuries that justify a lawsuit and provided the ability to connect the users (e.g., the injured skier or snowboarder) with a lawyer. Chalat Law also identified 25 cases that they won on their website (Chalatlaw, 2018).

1.3. State-of-The-Art

When skiing or snowboarding there is always a risk of injury. For each individual, the degree of risk can be correlated with several risk factors. In a study done between 2007 and 2008, it was found that speed, risk awareness, the condition of skiing equipment, snow conditions, and drug consumption, all play a large role in the risks associated with skiing (Hasler et al., 2009). Additionally, in another study done between 2001 and 2002, it was found that being a first-time skier or snowboarder also plays a role in the degree of risk (Langran and Selvaraj, 2004).

With respect to injury mechanisms, during a nine-year study, it was found that injuries typically occur by falling, followed by collisions. The study also noticed a distinct difference in injury trends between different demographics (Dohjima et al., 2001).

There have been several different methods that are used to and seen as good ways of reducing injuries. These methods include skier conditioning, education, equipment improvements, legislation, changes in behavior, and environmental changes (Macnab and Cadman, 1996)(Hébert-Losier and Holmberg, 2013)(Willmott and Collins, 2015)(Williams et al., 2007). The methods evaluated in this paper are education, skier conditioning, legislation, and environmental changes.

Of the methods evaluated, education appears to have mixed results. In some studies on risk factor awareness training (Spörri et al., 2017), education through videos, brochures (Cusimano et al., 2013.), and video presentations (Jørgensen et al., 1998), and education targeting high risk skiers (Tough and Butt, 1993), there were improvements in skier's and snowboarder's attitudes and behaviours. But in other studies on instruction courses (Boldrino and Furian, 1999) and formal ski instruction (Johnson et al., 2009), education had no effect on injuries. The reason for this mixture of results may be the different ways of educating the skiers, as was noted in a 1991 study on the educating of downhill skiers (Bouter and Knipschild, 1991).

Skier conditioning, another method, has shown good results. It was found that most musculoskeletal injuries can be prevented through physical conditioning (Morrissey et al., 1987) and that people at high risk of injury should develop individual training programs to prevent injuries (Spörri et al., 2017). Another study concluded that exercise would both increase a skier's enjoyment of the sport while also reducing the likelihood of injury. Essentially, fit skiers will do more runs, but will also be better prepared for situations requiring strength and endurance (Johnson et al., 2009).

Environment changes target impact injuries and are very effective because they remove mechanisms of injury. This is done through the removal of obstacles (Penniman, 1999) and the foresight of dangerous obstacles during trail design (Penniman, 1996).

Beyond studies, there are many initiatives to reduce skiing injuries. The National Ski Area Association (NSAA) has several initiatives, including Your Responsibility Code, Lids on Kids, Smart Style, Kids on Lifts, Collision Safety, Tree Well & Deep Snow Safety, and the High Fives Foundation (NSAA Safety Programs, 2018). Another group that has done extensive work to reduce skiing and snowboarding injuries is the SnowSport Safety Foundation. Some of their initiatives include striving to pass resort safety legislation in California and giving mountains in California, Nevada, and Colorado safety ratings that are available to the public on their website (SnowSport Safety Foundation, 2018).

Another approach to skier and snowboarder injury reduction that is also analyzed in this paper was the collection and distribution of crowdsourced information to the skiers and snowboarders through a mobile application. This form of information collection and redistribution has been used by applications like Waze, which crowdsources information on road conditions to provide users information regarding the best route to their destination. Although, many skiing and snowboarding applications already exist, each with features making them unique, and none utilize crowdsourcing to collect and disseminate real-time dynamic trail and mountain information.

Some of the most popular skiing applications and crowdsourcing applications were analyzed to determine which features they provide. Based upon the various programs and the studies that we analyzed, we determined the available features in current skiing and snowboarding application. As is also set out in Table 1, the features were determined to be: (i) communication, (ii) maps, (iii) GPS, (iv) trail information, (v) trip journal, (vi) crowdsourced information, (vii) for skiing or snowboarding, and (viii) resort information.

Communication:	An application that allows direct communication between friends and fellow skiers.
Maps:	An application that has maps of ski resorts and their terrain.
GPS:	An application that has GPS tracking.
Trail Information:	An application that provides general to detailed information on trials.
Trip Journal:	An application that collects and stores information from skiing trip.
Crowdsourced Information:	An application that collects information from users and shares it with other users.
For Skiing or Snowboarding:	An application that directly relates to skiing or snowboarding.
Resort Information:	An application that provides information on slopes (number and skill level), ski lifts, equipment rentals, and skiing/snowboarding lessons.

Table 1: Criteria for mobile application features

The applications that were analyzed and their features are tabulated Table 2.

Application	Communication	Maps	GPS	Trail Information	Trip Journal	Crowdsourced Information	For Skiing	Resort Information
SkiLynx	X	X	X	X	X		X	
Avanet		X	X		X	X		
Snocru	X	X	X		X		X	
Trace Snow		X	X		X		X	
SkiTracks		X	X		X		X	
Slopes		X	X		X		X	
On The Snow & Snow Report		X		X		X	X	X
Open Snow				X			X	X
Ski & Snow Report		X		X			X	X
Liftopia							X	X
Mammut Safety	X			X				
Cairn		X	X		X	X		
Rambler		X			X			
Yonder	X	X		X				X
Yelp		X	X			X		
Waze		X	X		X	X		

Table 2: Currently available mobile applications and their features

As is evident from Table 2, nearly all of the applications considered maps to be important. After maps, GPS and trip journal were important, especially for applications that were designed for skiing. Of least concern in the applications directed to skiing were crowdsourced information and communication. Additionally, the only application that is specifically intended for skiing and snowboarding and that uses crowdsourced information, does not use the crowdsourced information to show users that there are hazards on the trails. Considering that crowdsourcing information and communication are the only ways to provide real-time information to the skiers and snowboarders about trail hazards, it is clear that the currently available applications would be ineffective in reducing injuries. From our analysis, it was determined that none of these applications are comprehensive; that is, none of these applications contain all of the key features.

1.4 Approach

The approach to this project is defined by the objectives: (i) to research current methods of reducing skiing and snowboarding injuries, (ii) to devise new approaches to reducing skiing and snowboarding injuries, and (iii) to use axiomatic design to determine which method has the greatest likelihood of being implemented while providing the greatest benefit to reduce skiing and snowboarding injuries.

2. Design Decomposition and Constraints

The customer need being analyzed in this project was reducing skiing and snowboarding injuries. From this, the primary functional requirement (FR), FR0, was determined to be reducing skiing and snowboarding injuries with a constraint of having to be implementable on most if not all mountains. Its design parameter (DP), DP0, was determined to be a mobile skiing information application.

FR0 was then decomposed into FR1-FR7. The decomposed FRs were to reduce injuries caused by trail obstructions (FR1), reduce injuries caused by unsafe trail intersections(FR2), reduce injuries caused by improperly groomed trails (FR3), reduce injuries caused by poor barriers between the trail and the edge (FR4), reduce injuries caused by sharp turning angles on trails (FR5), reduce injuries caused by narrow trails (FR6), and reduce injuries caused by crowded trails (FR7).

FR1-FR7 were determined to have the criteria that DP1-DP7 must be quickly understood, be able to compare trails, provide information on the location of the hazard, and be consistent between mountains. The design parameters for all these FRs were determined to be a graphical representation of each injury mechanism. It is noted that, although FR1-FR7 will be fulfilled by a graphical representation, they still maintain the independence required by axiom one of axiomatic design because each graphical representation will be independent of the other graphical representations.

Having determined that FR1-FR7 will be fulfilled by graphical representations, it was determined that DP1-DP7 will be represented by: an obstacle icon, a trail intersection warning icon, an improperly groomed trail warning icon, a poor barriers warning icon, a sharp turn warning icon, a narrow trail warning icon, and a crowded trail icon, respectively. Table 3 lists the functional requirements and their corresponding design parameters. Further information on the FRs and their DPs can be found in Appendix B.

FR0 - Reduce Skiing and Snowboarding Injuries	**DP0 - Mountain and Trail Information Application**
FR1 - Reduce injuries caused by trail obstructions	DP1 - Graphical representation of obstacles
FR2 - Reduce injuries caused by unsafe trail intersections	DP2 - Graphical representation of trail intersections
FR3 - Reduce injuries caused by improperly groomed trails	DP3 - Graphical representation of improperly groomed trails
FR4 - Reduce injuries caused by poor barriers between the trail and the edge	DP4 - Graphical representation of poor barriers
FR5 - Reduce injuries caused by sharp turning angles on trails	DP5 - Graphical representation of sharp turns on trails
FR6 - Reduce injuries caused by narrow trails	DP6 - Graphical representation of narrow trails
FR7 - Reduce injuries caused by crowded trails	DP7 - Graphical representation of crowded trails

Table 3: Design Decomposition

3. Physical Integration

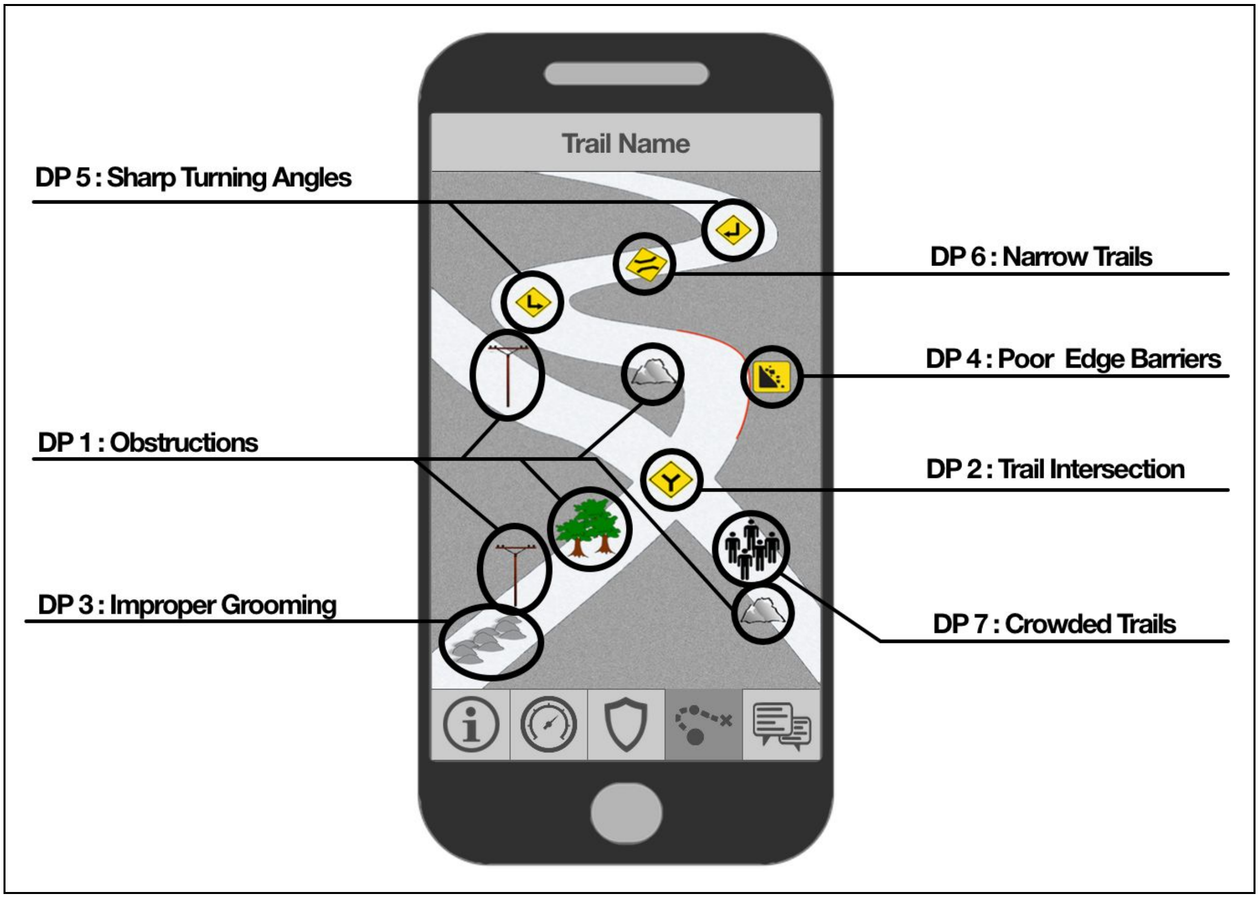

Figure 1: Example of the design parameters in a skiing application

Figure 1 is an example of how DP1-DP7 can be represented with icons. DP1 can make skiers aware of obstacles (e.g., trees, chairlift poles, rocks, etc.), by using obstacle icons (e.g., tree icons, chairlift pole icons, rock icons, etc.). DP2 can make skiers aware of dangerous intersections by using a dangerous intersection icon. DP3 can make skiers aware of an improperly groomed trail (e.g., snow accumulation) by using improper grooming icons (e.g., snow accumulation icon). DP4 can make skiers aware of poor edge barriers e.g., adjacent a drop or cliff, by using a cliff warning icon. DP5 can make skiers aware of sharp turning angles by using a sharp turning angle icon. DP6 can make people aware of narrow trails by using a narrow trail icon. DP7 can make people aware of crowded trail by using a crowded trail icon. As can be seen in Figure 1, the use of graphical designs can be an effective technique of providing important information to skiers/snowboarders and therefore, of reducing injuries.

4. Measuring Success of The Final Design

Before beginning a project, it is important that a way of measuring success is defined. Due to the similarity of the FR1-FR7, the same method will be used to measure their success.

To measure the success of FR1-FR7, when users begin using the application, they will be asked to take an optional survey. The survey is optional so that users are not discouraged from using the application. This is important because the application will be a private sector venture which is therefore subject to market pressures and incentives. In the survey, users will be asked to enter how many times they have been injured and how they were injured. It will also ask for the amount of time the individual has been skiing or snowboarding. This information can then be used to develop a baseline for injury rate, measured in injuries per year. How the individual was injured is asked so that the injuries can be subdivided into their respective FRs. After a predetermined period of time, the user will be asked to fill out the survey again. The survey interval is important so the data collected is consistent. If the interval is too short, users may record smaller injuries during the second survey that they forgot about during the initial survey. If the interval is too long users may record smaller injuries during the initial survey that they forgot about during the second survey. Success will be determined by a statistically significant reduction of the injury rate, with 95% certainty, from the FR's baseline injury rate. The baseline injury rate should also be adjusted based on historical changes in the injury rate over an equal time period. This is to ensure that the changes in the rate can be attributed to the implementation of the application, not a trend that was already taking place.

For the overall skiing application to be successful, FR0 must be accomplished. Because an FR is equivalent to the sum of FR1-FR7, the success of FR0 is dependent on the successful summation of FR1-FR7. Therefore the injuries that were subdivided into FR1-FR7 should be added back together during the success measurement of FR0. Success will be determined by a statistically significant reduction of the injury rate, with 95% certainty, from the baseline injury rate. The baseline injury rate should be adjusted based on historical changes in the injury rate over an equal time period.

5. Discussion

5.1. Design Method

For this project, axiomatic design was used. To fully use the axiomatic design process a decomposition of the problem from the top down must be done. The decomposition of the problem into smaller elements is an important part of solving complex problems because it breaks the problem into more manageable pieces. If a problem has been decomposed sufficiently, the solutions to the problem become obvious.

The decomposition starts by identifying the customer and the customer needs (CNs). Then constraints (CONs) are identified to avoid preventable mistakes and focus the number of possible solutions. Once the CNs are identified, an FR which fulfills the CN and establishes the design intent is assigned. The first FR, i.e., FR0, is then decomposed into sub-functional requirements (SFRs), wherein the SFRs, when summed, equal their parent FR.

In other words, the SFRs must be collectively exhaustive, meaning that they cover all the aspects of the parent FR and the SFRs must be mutually exclusive, meaning they cannot overlap. The reason for these two requirements is that, if the SFRs are not collectively exhaustive and mutually exclusive, their summation will not equal their parent functional requirement.

Once the SFRs for FR0 have been decomposed, the SFRs are then decomposed themselves. The process of FR decomposition continues until the requirements of the design solution are obvious. FR0 and all the SFRs that were decomposed for this project are stated in section two.

After the FRs are fully decomposed, physical solutions, known as design parameters (DPs), that fulfill the FRs are found.There is exactly one DP for each FR. This means that FR0 as assigned its own DP, referred to as DP0. Ideally, a DP only influences its corresponding FR. The selection of DPs are limited by the CONs and by the DPs it was decomposed from or parend DPs. This limits all the DPs for the FRs that are children of FR0 to DPs within the capability of a mobile skiing application. When determining the DPs for a project, it is important that all options are explored so that the best design solution is identified and applied. To choose the best DP, a comparison should be made between the DP options to determine which best fulfills the FR in question. This can be done qualitatively or by developing a numeric rating system. The DPs used in this project can be found in section two and the process used for determining the best DPs can be found in section 5.2.1 and Appendix B.

After the DPs have been determined, a method for measuring the success of the DPs after being implemented must be outlined to determine if the DPs were successful in fulfilling their FRs, to satisfy the CN. The method for measuring the success of the DPs of this project are described in section 4.

Lastly, the DPs are implemented and measured for their effectiveness. If they are determined to not be successful at fulfilling their FRs, and therefore the CN, then the current DPs are altered and tried again. If the DPs are determined to be successful at fulfilling their FRs, but are not successful enough, then both the current method for measuring success and the DPs must be altered and tried again.

For a more detailed description of axiomatic design, use references Nam P. Suh, 1990 and WPISurfMetLab, 2013.

5.2. Application of The Design Method

5.2.1. Determining and Fulfilling functional requirements through Features

The goal to reduce skiing and snowboarding injuries was the intent from the start of the project. However, once introduced to axiomatic design, the direction of the project changed. In the beginning, the method for reducing skiing injuries was to create a universal trail rating system that could be implemented on all mountains. It was theorized that a more consistent and detailed trail rating system would allow skiers to make more informed decisions when choosing a trail. After being introduced to axiomatic design, the project was approached from a different perspective. The customer need (CN) and constraints (CONs) were formalized, and the functional requirements (FRs) were decomposed. As a result, the team realized that the universal trail rating system was just one of many potential design parameters (DPs). Defining the problem allowed the team to realize the variety of available options. After other potential design parameters were theorized, the final three potential design parameters were chosen, namely legislation requiring safer trail construction and maintenance, asking mountains to implement a new, more descriptive universal trail rating system, and creating a trail informational mobile application. The potential design parameters were scored numerically based on their capability to fulfill the sub-functional requirements. From this exercise, legislation requiring safer trail construction and maintenance was chosen to be the most effective at fulfilling the functional requirements of the project.

However, after studying this as a potential DP, a foundation was identified which had unsuccessfully tried to pass legislation in California, twice. This result could happen for any legislation. There is no way of being able to guarantee the implementation of legislation requiring safer trail construction and maintenance in one state, let alone a country. Therefore, seeking the reduction of injuries via legislation is impractical.

Focus was then moved to a universal trail rating system. First, research was done on current trail rating systems in other sports to identify the most important factors in a universal trail rating system. Some of the researched systems included systems for hiking and white water rafting. Systems for hiking included the Alaskan Climbing Scale, Angeles Chapter Rating System, European Climbing Scale, and the Yosemite Decimal System. Systems for white water rafting included the International Scale Of River Difficulty, the Wet Planet Classification system, and the Western River Whitewater Rating System.

From the research, it became clear that information and input from the ski resorts would be beneficial in identifying hazardous locations on the mountains and additional hazard types. Therefore, several mountains were called and asked if they would disclose information on common injury locations. The mountains called included Ski-Sundown, Wildcat Mountain, Redlodge Mountain, Shawnee Mountain, Showdown Mountain, Loon Mountain, Cannon Mountain, and Killington. None of the mountains called were willing to provide the requested information.

Mountain	Response
Ski-Sundown	Said they would call back with information regarding ski safety after speaking to somebody higher in the company, no call back.
Wildcat Mountain	Said this is not information they give out.
Redlodge Mountain	Redirected to patrol office, left voicemail, no callback
Shawnee Mountain	Person directed to was not in, left voicemail, no callback.
Showdown Mountain	Left a voicemail regarding being informed about safety, no callback
Loon Mountain	Called and hung up on, twice.
Cannon Mountain	Called and was put through to the manager of the Operators and he was not in, no call back.
Killington Mountain	Sent to Risk Manager and he said they don't track injury information

Table 4: Summaries of phone calls to ski resorts

As can be seen from the ski resort responses, or lack thereof in Table 4, we were unable to learn from the ski resorts hazardous locations or additional hazard types. Unfortunately, it became clear that the likelihood of ski resorts cooperating with the implementation of an improved trail rating system is low.

After the realizations that the ski resorts are uncooperative and enacting legislation is impractical, it became clear that they would not fulfill FR 0. Therefore, a FR 0 CON was formalized. The CON was that the DP0 must be implementable on most if not all mountains. This criteria cannot be met by either legislation requiring safer trail construction and maintenance or by asking mountains to implement a more descriptive universal trail rating system. So through process of elimination, we concluded that a mobile information application is the best way for reducing skiing and snowboarding injuries and therefore it should be DP0.

The same process was used for determining the DPs for the FR1-FR7. The factors considered during the scoring of the DPs were the ability to be quickly understood, the ability to compare trails, the ability to provide information on the locations of hazards, and the ability to be consistent between mountains. For FR1-FR7, a DP was associated with each FR and then a graphical representation for each type of hazard was chosen for DP1-DP7.

These FRs are restricted to trail design and trail conditions because injuries cannot occur without an issue with the trail design or trail conditions. For example, if a skier is under the influence and skies into a tree, although being under the influence is a factor, an FR to reducing injuries caused by skiers being under the influence cannot be added because it would not be independent of reducing injuries caused by trail obstacles. As noted above, axiom one of axiomatic design requires each FR to be independent.

More information on the reasoning behind the selection of DPs can be found in Appendix B.

5.2.2. Assumptions

For this project, many assumptions were made during the evaluation and selection of the design parameters. The most prominent and influential assumptions that were made were during the selection of design parameter zero. For legislation requiring safer trail construction and better trail maintenance, it was assumed that any group would likely face the same difficulties passing legislation as the Snowsport Safety Foundation. Regarding asking mountains to implement a new, more descriptive universal trail rating system, it was assumed the cooperativeness of mountains could be judged by their willingness to help provide information of where skiing accidents most often occur. Also, it was assumed that providing more information to skiers would reduce more injuries.

However, these are all reasonable assumptions. In many cases, legislation takes years to pass and in others cases never does. Also, asking for general information on where skiing injuries occur is far less intrusive than asking mountains to change their trail rating systems. Lastly, although no studies or papers were found agreeing with the assumption that more informed skiers will reduce the injury rate, and it is a widely used method for solving similar problems.

Additionally, less influential assumptions that were made were related to the sub-functional requirements and their potential effectiveness. This happened specifically with the ratings of each design parameters abilities to fulfill the criteria. The assumptions made during the selection of these design parameters can be found in Appendix B.

5.2.3. Issues Remaining

Despite the potential of the application to reduce the injury rate, the effects can only go so far. Even if 100 percent of skiers and snowboarders used the application diligently and heeded its advice, skiing injuries will likely not be reduced to a point where they are insignificant. People make mistakes; there will be cases when people are aware of the dangers but are unable to avoid them. Especially if they fall or lose control at the wrong time. There is also still the potential of people intentionally taking on unnecessary risk. The only way of minimizing skiing and snowboarding injuries is to remove the mechanisms for the injuries. In other words, without the removal of the hazards there will always be injuries. Despite this, a mobile skiing application would be the best course of action from where the industry is today.

5.3. Design Method

Although the team's unfamiliarity with axiomatic design caused some initial difficulty, requiring much trial and error before the team gained a workable understanding, it proved to be an excellent method for determining the best way to fulfill the objective of the project. With it, problems are clearly defined so that a solution can be found more efficiently. Additionally, the generality and versatility of the design method makes it applicable to any problem where the solution is not obvious. These traits are demonstrated by its ability to direct the project away from the initial goal of creating a universal trail rating system to a mobile application.

5.4. Project Management Assessments

Through the arc of any project spanning a large amount of time, issues are sure to arise. Some of the issues that arose during this project included uncertainty in the direction of the project, concerns of changes in the direction of the project, concerns of ineffectively used time in both team meetings and between team meetings, and clarity of goals between meetings. The issues of uncertainty in the projects direction, concerns about changes in the direction of the project, and concerns of ineffectively used time during meetings were resolved through more targeted and guided meeting discussions. Clarity of goals between meetings was resolved by summarizing the topics covered during each meeting and formalizing goals for the next meeting in a document that was approved by all team members. Lastly, concerns of ineffectively used time between meetings were resolved through the logging of time spent working on the project in work journals.

5.5. Commercial Uses of The Application

As the application will be subject to market forces, it must have market value to be a viable solution. The best way of doing this will be through advertisements which gives value to the application owners and investors, and features, which add value to the application users. The most prominent of these features is the crowdsourcing of trail information. Skiers and snowboarders can find significant value in an application that provides them with up-to-date information on trails. Especially if conveyed in a quick yet effective manner. Requiring only a glance while on the ski lift or right before heading down a trail.

Additionally, the application should not be limited to the DPs that were determined to be the best ways of fulfilling the FRs. Although the graphical representation was determined to be the best way of conveying important and detailed trail information, either the numerical rating of the trail or paragraph could have more value to individual users. They may not be the most prominent and refined features but they should still be included in the application. There are also other features, not related to the functional requirements that could add value.

Even though they do not help the overall goal of the application, they will improve its appeal and the likelihood of people wanting to use it. For this application to exist through advertisements, it needs as many people using it as possible. Also, having the other features can help get the application started, making it so that despite there are not enough people to make the crowdsourced information effective, the application is still appealing. Some features that should be added are already in use by other applications. For a list of some of these features and applications already using them, see Tables 1 and 2. Other features should be original like a vocal warning feature, a quick connect to ski patrol, personal skiing statistics, and trail reviews from fellow skiers.

5.6. Work's Deficiencies

Assumptions in this paper were made as a result of a lack of studies on the topic or an inability to find the prior studies. The most prominent deficiency was the lack of studies on whether providing more information to skiers and snowboarders would result in fewer injuries. Despite this being an assumption made by many people, it is a deficiency and something that should be remedied.

Another work deficiency highlighted by this project is the lack of studies tracking the locations on mountains where injuries occur. Although this is no longer something required for this project to be successful, it is something requiring research. This deficiency was discovered when the team was trying to develop a trail rating system. Without documentation on where injuries occur, there is no way to identify the most dangerous locations on mountains. Although the application will collect information, there should be a formal study done looking into it.

6. Concluding Remarks

- Although legislation is the most effective way of reducing skiing injuries it cannot be practically implemented.
- Ski resorts are unlikely to be helpful with efforts to reduce skiing and snowboarding injuries.
- Axiomatic Design is an effective way of solving problems where the solutions are not obvious.
- A mobile application is the best method for reducing skiing and snowboarding injuries.
- The minimization of skiing injuries will not occur without the removal of the injury mechanisms.
- Studies to determine if providing more information to skiers and snowboarders would result in fewer injuries should be conducted.
- Studies that track where the most injuries occur should be conducted.

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Appendices

Appendix A - Potential Application Layout

The figure above shows a potential application layout. The application should have three levels, (i) a resort search page, (ii) resort information pages including general information, a link to the the resort's website, trail ratings, and a resort discussion page, (iii) trail information pages including general trail information, a trail difficulty ratings page, a trail hazards page, and a trail discussion page. Resort information can be accessed by selecting a skiing resort and trail information can be accessed by selecting a specific trail at the resort.

Appendix B - Design Parameter Selection

FR0 - Reduce Snowboarding and Skiing Injuries

Child Functional Requirements

1. Reduce injuries caused by trail obstructions (rocks, trees, chair lifts, etc..)
2. Reduce injuries caused by unsafe trail intersections
3. Reduce injuries caused by improperly groomed trails
4. Reduce injuries caused by poor barriers at trail edges
5. Reduce injuries caused by sharp turning angles on trails
6. Reduce injuries caused by narrow trails
7. Reduce injuries caused by crowded trails

Additional Criteria

8. Can be implemented on all mountains

Potential Design Parameters

A. Legislation requiring safer trail construction and better trail maintenance
B. Ask mountains to implement a new more descriptive universal trail rating system
C. Mountain and trail informational application

Criteria Comparisons

		Child Functional Requirements and Criteria (1 to 5, 5 being best)								
		1	**2**	**3**	**4**	**5**	**6**	**7**	**FR Sum**	**8**
DP	**A**	5	5	4	5	5	5	1	30	1
	B	3	3	4	3	3	3	1	20	1
	C	3	3	4	3	3	3	4	23	5

DP Criteria Justification

1. Reduce injuries caused by trail obstructions (rocks, trees, chair lifts, etc..)
   A. 5 - would force the removal of dangerous obstacles.
   B. 3 - could allow users to be more informed about obstacles on the ski trail, but it would not eliminate obstacles
   C. 3 - could allow users to be more informed about obstacles on the ski trail, but it would not remove these dangerous obstacles.
2. Reduce injuries caused by unsafe trail intersections
   A. 5 - would force the removal of dangerous trail intersections
   B. 3 - would inform people about dangerous intersections, but not the dangerous intersections.
   C. 3 - would inform people about dangerous intersections, but not the dangerous intersections.
3. Reduce injuries caused by improperly groomed trails
   A. 4 - would force mountains to either properly groom their trails or close trails that are too dangerous to ski on. However, this would be difficult to quantify and enforce.
   B. 4 - would inform skiers and snowboarders about poorly groomed trails, but informing people can only do so much
   C. 4 - would inform skiers and snowboarders about poorly groomed trails, but informing people can only do so much
4. Reduce injuries caused by poor barriers at trail edges
   A. 5 - would force mountains to install and maintain safe edge barriers
   B. 3 - would inform skiers about dangerous trail edges, but would not change or improve them
   C. 3 - would inform skiers about dangerous trail edges, but would not change or improve them
5. Reduce injuries caused by sharp turning angles on trails
   A. 5 - would force the reduction of sharp turns
   B. 3 - would inform skiers of sharp turns, but it would not change or improve them
   C. 3 - would inform skiers of sharp turns, but it would not change or improve them
6. Reduce injuries caused by narrow trails
   A. 5 - would force mountains to increase the width of trails or close trails that are too narrow

B. 3 - would inform people about the size of the trails, but would not change or improve them
C. 3 - would inform people about the size of the trails, but would not change or improve them

7. Reduce injuries caused by crowded trails
    A. 1 - would not reduce the amount of people on a trail. Even if there was an attempt to legislatively keep the amount of people on the mountain below a maximum, it would be difficult to enforce because it is hard to know and control the number of people allowed on each trial and to know and control how many people are on the mountain at any given time.
    B. 1 - would not reduce the amount of people taking a given trail
    C. 4 - would inform skiers of crowded trails and dissuade them from taking those trails. However, there is no guarantee that they will do so.
8. Can be implemented on all mountains
    A. 1 - would be very difficult to pass legislation in all countries and states that would requiring safer trail construction and better trail maintenance
    B. 1 - would be unlikely to all change the current rating system. It could make mountains liable for know hazards. It could also make some mountains look bad compared to others because they don't have as large of a range in trail difficulties.
    C. 5 - would inherently be able to be implemented on every mountain as it only requires a mobile device, users, and it is third party therefore the mountains would not be able to prevent it.

Final Design Parameter

Mountain and Trail Informational Application was chosen as our final design parameter because it is also the most likely to be able to be implemented on every mountain with the greatest efficiency. Legislation was not chosen because although it has the greatest FR scoring, it is not likely to be implemented on every mountain. Additionally, drafting and getting legislation passed can be very expensive and time consuming.

Measuring Success Post Implementation

Success of the design parameter would be determined through the successfulness of the children functional requirements. The summed injuries from the child functional requirements will need to have been reduced in a statistically significant way, with 95% certainty, for this design parameter to be a success.

FR1-FR7

Child Functional Requirements
None

Additional Criteria
1. Must be quickly understood
2. Must be able to be used to compare trails
3. Provides information on the locations of obstruction
4. Consistent ratings and descriptions between mountains and trails

Potential Design Parameters
A. Numerical Representation
B. Graphical Representation
C. Descriptive Paragraph

Design Parameters Comparisons

		Success Measurements (out of 5)				
		1	**2**	**3**	**4**	**Sum**
DP	**A**	5	5	1	5	16
	B	4	5	5	4	18
	C	1	1	5	1	8

DP Criteria Details
1. Must be quickly understood
    A. 5 - would be quickly understood
    B. 4 - could be quickly understood, but cannot be as quickly understood as a number
    C. 1 - would take time to understand a descriptive paragraph of obstacles on a trail
2. Must be able to be used to compare trails
    A. 5 - would be easy to compare numbers between trails
    B. 5 - would be very easy to compare different trail graphics
    C. 1 - a paragraph is not a good form of comparing different ski trails
3. Provides information on the locations of the obstruction
    A. 1 - would only be capable of giving skiers basic information
    B. 5 - would be able to show the types and locations of obstacles
    C. 5 - would have the ability to give the skier information on the types and locations of obstacles
4. Consistent between mountains and trails
    A. 5 - would be consistently calculated through an algorithm
    B. 4 - would have consistent representations of obstructions
    C. 1 - would be difficult to keep writing consistent

Final Design Parameter
Graphical Representation

Measuring Success Post Implementation
Injuries related to this the functional requirements will need to be reduced in a statistically significant way, with 95% certainty, for this design parameter to be a success.

Appendix C - Additional Background

“Our results suggest that what characterizes the injured skiers is not that they take more risk or that they are more motivated by risky behaviors, but that they are less skilled.”(Bouter and Knipschild, 1991)
“Skiing injuries are not typically a result of risky behavior but less skill. “(Goulet et al., 2000)

“Injury rate increased as skill level increased, with experts having a level of previous injuries of 67%, compared with beginners (21%), intermediates (29%), and advanced riders (61%) (chi-square; P = 0.006). Just under half of the local residents in the study group had had a previous injury (55 of 113), but the highest injury rate was found in visitors staying for more than 28 d (65%) (chi-square; P = 0.006).”(Hansom and Sutherland, 2010)

“Only a minority of snow riders made any attempt to warm up before or warm down after riding . Nearly 48% of the sample population believed they were most likely to injure themselves in the late afternoon. The most common reason given for this was fatigue.”(Hansom and Sutherland, 2010)

“Skiing and snowboarding injuries tend to be different in nature.” (Abu-Laban, 1991)