Abstract

The ski industry is a significant contributor to the economy of many regions across the United States of America (USA). However, challenges such as climate change, ski resort consolidation, and resort closures, have led to increased visitation and overcrowding. In response to these challenges, ski resorts have implemented variable pricing models to encourage skiers to choose quieter days, and visitation caps limiting the number of visitors allowed on the slopes at any given time.

There is no online resource that geographically and visually represents skier visitation and the elements that impact skier visitation and how they vary for ski resorts across the USA. This project will illustrate the difference in these elements between resorts and offer some indication of why some resorts are busier than others.

The project will create a series of enhanced maps that will illustrate those drivers for skier visitation using data from social media, topographic maps, and ski association data to name a few. This will also be able to be used as a resource for skiers when selecting a ski resort to visit. This project will improve decision-making for skiers as there are no nationwide ski resort maps that this project is going to generate.

Introduction

Ski resorts around the world have been experiencing declining snowfall for several decades, with many areas reporting reduced snowpack and shorter seasons. Climate change is believed to be the main cause of this trend, as rising temperatures have altered weather patterns and led to more precipitation falling as rain instead of snow. In addition to the quality and quantity reduction of snow, declining snowfall has significant economic and environmental impacts on ski resorts, local communities, and ecosystems, highlighting the need for climate action to address this issue.

Geographic Information Systems (GIS) has assisted ski resorts in several ways, including enhancing snowmaking operations, improving trail management, and optimizing resort planning and development. By using GIS technology, ski resorts can track real-time weather and snow data, analyze slope terrain and aspect, and monitor visitor traffic flow to improve snow grooming and maintenance operations. GIS also allows resorts to plan new facilities and services through modeling while minimizing environmental impacts and reducing risk by identifying potential crowd bottlenecks, and hazards such as avalanches and unstable slopes. Overall, GIS has helped ski resorts to increase efficiency, reduce costs, and provide better services to visitors. However, GIS has less frequently been used by skiers to improve their decision-making and planning. Basically, GIS has been used by ski resorts, but this project is going to be used to help individual skiers.

This project will focus on a couple of elements in two main areas. One, what the current visitation looks like at USA ski resorts, and two, what are the various factors that influence skier visitation and how those factors vary across the USA. The project will be a quantitative analysis of existing ski resort data and social media data.

The context and importance of this project are that there are currently no online resources that visually represent the various features of ski resorts on a map as GIS has been used by ski resorts whereas this project will be used to assist individual skiers. This is becoming more important to see visually represented due to things such as climate change which means that skiers need to be a lot savvier when selecting a resort to ski at.

The problem that the project is looking to address is what ski resort to ski at based on numerous features that could be used to create a scoring system for ski resorts to inform skiers of the 'value' of these various features. The literature review indicates that a large problem impacting the ski industry is warming temperatures and lower snow packs and how a resource that the project is going to provide will give individual skiers access to a lot of information summarized about ski resort aspects including historical snowfall totals and season length.

Literature Review

The literature review of ski resort visitation includes research from various disciplines, including tourism, climate research, and sociology. Many factors influence the decision to visit a ski resort, including snowfall, price, proximity to population centers, and amenities offered. The academic review could also explore the socio-demographic characteristics of ski resort visitors, such as age, gender, income, and education level. In this review of the literature, three key areas are being focused on are climate change, amenities, and crowds.

Climate Change

The weather that produces snow is the biggest driver of skiers to a resort as skiing is snow dependent, if there are no freezing temperatures, there is no snow to ski on. Climate change is one of the biggest threats to the ski industry, leading to compressed ski seasons and, with that, more crowded days on the slopes. 'Resort managers are concerned about shorter season lengths, shifting ski seasons, less snow cover, and poorer snow quality. Many resorts are already adapting, with the most common adaptations being snowmaking and diversifying outdoor recreation offerings (particularly during the summer and shoulder seasons). Barriers to adaptation reported by managers include financial costs, adequate water availability for snowmaking, and uncertainty about climate change projections.' (Wilkins, et al, abstract, 2021). Many predictive studies suggest that climate change will have moderate to extreme impacts on winter resort operations. The biggest problem being observed which is occurring this winter in many European ski resort regions is that 'Many mountain communities have snow-

based recreational and tourism opportunities, anchored by ski resorts, that are extremely vulnerable to climate change (Gilaberte-Burdalo et al 2014; Steiger et al 2019). Mountain communities are often at higher elevations, which are warming even faster than other environments (Pepin et al 2015; Minder et al 2018)' (Wilkins, et al., introduction, 2021). And 'this increase in surface temperatures has important consequences for the hydrological cycle, particularly in regions where water supply is currently dominated by melting snow or ice. In a warmer world, less winter precipitation falls as snow and the melting of winter snow occurs earlier in spring.' (Barnett, abstract, 2005). This is particularly noteworthy in areas such as the Seattle metropolitan area, where so much of the water supply is dependent on the winter snowpack. 'With more than one-sixth of the Earth's population relying on glaciers and seasonal snowpacks for their water supply, the consequences of these hydrological changes for future water availability—predicted with high confidence and already diagnosed in some regions—are likely to be severe.' (Barnett, et al. abstract, 2005).

Some modeling does forecast increases in snowfall in certain areas but this is due to the fact that snow does not fall below certain temperatures and with warming temperatures, those areas that historically have experienced temperatures below that snowing temperature threshold will experience more days above that threshold where snow can potentially fall. This is mentioned in the article by Wobus, et al. that some modeling predicts an increase in season length in a few areas, but the vast majority of resorts will see a decline. 'Nationally, changes in projected downhill skiing season lengths range from slight increases at a few areas (10 areas and 6 areas, respectively,

for RCP4.5 and RCP8.5 in 2050; and 4 areas for RCP4.5 in 2090) to declines of more than 80% under RCP8.5 in 2050 for some locations' (Wobus, et al. 3.2.2 Downhill skiing and snowboarding, 2017).

Other academic writings reviewed agree that ski resorts are going to be impacted by climate change with Wobus, et al, contending that 'virtually all locations are projected to see reductions in winter recreation season lengths, exceeding 50% by 2050 and 80% in 2090 for some downhill skiing locations.' (Wobus, et al., abstract, 2017). Elevation is an influential factor as Wobus et al. contend in the conclusion of their article that 'Underlying these national results, we found considerable variability at all levels of the analysis, particularly with respect to the spatial distribution of impacts. In general, sites at higher elevations (such as the Rocky Mountains and Sierras) tend to be more resilient to projected changes in temperature and precipitation, whereas sites at lower elevations (generally in the upper Midwest and New England) are more sensitive to climate change.' (Wobus, et al., conclusion, 2017). However Gilaberte-Burdalo et al. contend that 'The lack of a common methodology makes it difficult to compare results in this field.' (Gilaberte-Burdalo, Highlights) and that 'Greater interaction between scientists and ski managers is needed to identify key topics for further research.' (Gilaberte-Burdalo, Highlights, 2014).

The evidence is quite clear that climate change is going to influence the ski industry, it is just a matter of how much, and in some parts of the world, the impacts will be felt a lot

more than in other areas. 'Ski tourism is a multi-billion dollar international market attracting between 300 and 350 million annual skier visits. With its strong reliance on specific climatic conditions, the ski industry is regarded as the tourism market most directly and immediately affected by climate change.' (Steiger, et al. abstract, 2013). The change in climate change will shorten ski seasons and with the same amount of skiers visiting resorts over a shorter season means that visitation will be higher due to the shorter length of the ski season.

Scott & Mcboyle suggest some adaptations that ski resorts could to compensate for climate change can be organized into two main types: technological (snowmaking, slope development and operational practices, cloud seeding) and business practices (ski conglomerates, revenue diversification, marketing, indoor ski area).' (Scott, D. McBoyle, G, Ski area operators section, 2007). Some of these elements could be included to advise skiers of the benefits of skiing at particular resorts. As this information isn't readily available for all resorts across the USA these elements will not be included in the project. But It is important to be aware of additional things that ski resorts are doing to compensate for climate change.

Amenities

Amenities such as high speed lifts and snow making infrastructure since the 1990's have become increasingly influential drivers in deciding which ski resort to visit. In the1960's & 1970's 'Entry barriers into this market were comparably low, as ski lifts were technologically simple and cheap, and because government actively supported

improved transportation access and ski tourism development as a labour-intense economic strategy in disadvantaged mountainous regions. Demand grew quickly in this era of significant economic growth and increased leisure time. This favourable market situation together with several snow abundant winters in major markets of Western Europe and North America fostered the development of new ski areas in – from today's point of view – climatically suboptimal locations. In the 1980s and 1990s, growth in the number of ski areas and skier visits slowed and the markets matured. Intensifying competition and higher customer expectations forced ski areas to invest in comfort (e.g. high speed lifts, chair lifts, or gondolas instead of surface lifts) and to improve the reliability, quality, and season length of the snow product (e.g. slope grooming, snowmaking).' (Steiger, et al. Introduction, 2022, 2008).

'Knowing how to improve skiers' experiences in ski resorts is vital for developing the ski industry.' (Shang, et al. Abstract, 2022) with ski resorts closing and seasons getting shorter, there is still quite a bit of competition between resorts to attract skiers, and the biggest variable that resorts have control over is amenities. 'The ski industry suffered a substantial loss in 2020 because of COVID-19, and ski areas have reinvested profits into the infrastructure of ski resorts to improve skiers' experiences. Understanding skiers' experiences for ski industry development is important.' (Shang, et al. Introduction, 2022). The study by Shang et al. 'identified the key service quality attributes that are more salient in skiers' ski resorts experience, that is, 'F&B', 'lift line service', 'slope variety', 'rental equipment', 'information service', 'resort amenity', 'tour service', 'ski lesson', 'staff', and 'pistes grooming' (Shang et al. Conclusions, 2022).

As there is increased competition amongst ski resorts they need to 'offer attractions that can offset the economic losses resulting from a worsening in ski conditions.' (Gilaberte-Burdalo, Highlights). Unfortunately though according to Scott & McBoyle 'There has not yet been a comprehensive review of climate adaptation in the ski industry.' (Scott, D. McBoyle, G, Introduction, 2007) which Dawson & Scott share a similar sentiment 'Failing to examine an entire marketplace – as has been done in much of the climate change and ski tourism literature – means it is difficult to understand the regional implications that vulnerability at one ski area could mean for an adjacent ski area, for the regional ski marketplace, or for communities and individuals reliant on the sector generally.' (Dawson, J. Scott, D, Abstract, 2013). Some resorts may fail themselves by not analyzing nearby resorts and with that not adding infrastructure which may influence a skier to ski at one resort or another one nearby.

Crowds

Demand and supply are interesting terms in Skiing the consumer wants low demand and lots of supply so that whenever they go skiing the resorts are not busy. Whereas the owners want more demand and less supply so they can charge more for the winter sport of skiing. Over the last several years there has been a lot of consolidation of ski resorts between to corporations, Vail Resorts and Alterra. What the consumer has noticed is longer lift lines at resorts owned by the corporations. There is some discussion that consolidation can give the resorts a boost but the consumer is left wondering if it is worth spending $200 for a day lift ticket to spend half that day standing in a lift line.

'It is rather unknown how skiers move inside ski areas. However, new data collection systems, such as RFID chips on ski passes (which allow counting skiers at the gates of the cableways), can be used to analyse the movement of skiers in the cableways network and in the ski runs graph. This will show how queues arise at the cableways departures and how crowds are formed on the ski runs.' (Barras, et al., Abstract, 2014). This relatively recent addition of RFID chip tracking has allowed ski resorts to better monitor the flow of skiers around a resort. This allows resort management to understand where bottlenecks are and where to invest in new infrastructure such as high-speed quad lifts to replace older fixed-grip slow lifts to eliminate crowded lift lines. In the study by Barras et al. the utilized the ski-optim model to simulate the behavior and movement of skiers in a ski area. 'In leisure spaces, particularly theme parks and museums, researchers and managers have long been using simulation tools to tackle the big issue associated with attractiveness – flow management.' (Poulhes, Abstract, 2011), however, ski resorts have not until recently utilized similar simulations of crowd flow and how to manage that flow.

The significant advantage of utilizing models such as the ski-optim method is the ability to evaluate skiing infrastructure changes, such as converting a ski lift to a chairlift or installing a new ski lift and analyze their impact on skier flow. From the methodological point of view, the Ski-Optim model can be transposed efficiently on all issues on networks with queues or jams such as urban traffic. Furthermore, this approach has the advantage to give the opportunity to handle an unknown or only partially known

situation.' (Barras, et al., Conclusion, 2014). Utilizing models to test proposed infrastructure updates is definitely a cost-effective way to try out various proposals before investing in capital improvements allowing for greater efficiencies in ski management.

Another modeling method in the article by Revilloud, el al. that can alleviate crowding 'presents the Juste-Neige system for predicting the snow height on the ski runs of a resort using an agent-based simulation software. The aim of Juste-Neige is to facilitate snow cover management in order to i) reduce the production cost of artificial snow and to improve the profit margin for the companies managing the ski resorts; and ii) to reduce the water and energy consumption, and thus to reduce the environmental impact, by producing only the snow needed for a good skiing experience.' (Revilloud, et al. Abstract, 2014). The Just-Neige model 'proceeds in three steps: i) interpolation of snow height measurements with a neural network; ii) local meteorological forecasts for every ski resort; iii) simulation of the impact caused by skiers using a multi-agent system. (Revilloud, et al. Abstract, 2014).

Ski areas that are too crowded are definitely a negative experience for any skiing experience and modeling is one way that ski resorts can virtually review how infrastructure changes or additions can improve crowd flow and remove ski area bottlenecks and thus improve the skier experience.

So by far, the biggest impact on skiing is climate change which is already being felt in alpine regions around the world. As noted almost all models indicate that ski seasons will become shorter with less snow impacting visitation at ski resorts. As seasons are getting shorter, ski resort owners are also looking at what amenities they have and what amenities they can attract customers not just in the winter ski season but also by adding more nonskiing options for the non-snowy months of the year, which is becoming a longer season that the winter ski season. And the final thing looked at in this literature review what the use of computer modeling to observe crowd behavior prior to the investment into new or upgraded equipment which means that infrastructure can be better positioned around a resort to remove congestion and make the ski resort experience for the customer a lot more enjoyable. There are many other things that can be an influencing factor impacting visitation to ski resorts but as seen in this literature there are a number of things to consider when considering a resort to ski at in just the three areas of weather, amenities, and crowds.

Methods

The project is conducting a research study on the dissimilarities among ski resorts throughout the United States and their corresponding influence on the selection process of a skiing destination by skiers. The project aims to explore various factors that affect a skier's decision when selecting a ski resort, which are outlined as follows.

1. Location: The distance from home or other travel destination.

2. Terrain: Slope direction and types of terrain available at the resort, such as groomed runs, backcountry, and terrain parks.

3. Skiing level: Check the difficulty levels of the runs and whether the resort caters to beginners, intermediates, or experts.

4. Amenities: The amenities offered at the resort, such as ski schools, rental equipment, childcare, and dining options.

5. Weather: weather and snow conditions in the area.

6. Crowds: How busy is a ski resort during the week/weekend?

7. Cost: Compare the cost of lift tickets, lodging, and other expenses at different resorts to find one that fits your budget.

For example, some skiers prioritize access to challenging terrain and good snow conditions, while others may prioritize amenities, crowd size, and convenience. The variability of what different people prioritize will be difficult to measure and include in this project as the project is primarily concerned about the resort features and the difference of those between resorts. Additionally, skiers may also consider the size and reputation of the resort, as well as its proximity to other activities and attractions. Ultimately, deciding which ski resort to choose depends on individual preferences and priorities. This study aims to geographically visualize some of those influencing factors to assist a skier in better selecting a resort to ski at. GIS is a valuable tool for researching ski resorts and geographically representing the various elements listed.

The following is a preliminary methodology, and the methods and timeline will most likely be revised as the project progresses.

Anticipated Project Timeline								
Task	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug
Identify objectives	x							
Locate data	x	x						
Literature review		x	x					
Analyze the data		x	x	x	x			
Visualize the results				x	x	x	x	
Present the data							x	x

Step 1: Identify objectives.

The first step of the process is to identify the objectives. As mentioned above, this GIS project aims to determine ski resort suitability based on the differences between ski resorts. Many websites offer lists of ski resorts, stats, and amenities. Still, there isn't a website that geographically visualizes the various aspects of a ski resort, how one resort differs from another, and how these factors can influence skiers in selecting a resort. To address these different aspects of ski resorts, this project will attempt to review the following elements and ideally develop some weighted scoring system to assist skiers in selecting a resort. As the project advances, the elements will be refined, and most likely, some of the following elements will not be included, and possibly some other elements will be added.

- Snowpack analysis
- Weather analysis
- Density of social media posts
- Slope analysis
- Google popularity times

- Size by acres
- Number of lifts
- Amount of vertical
- Closest major airport
- Proximity to population centers

Step 2: Locate relevant data sets.

The second step of the process is to locate relevant publicly available data sets to address the various elements defined in step 1. When looking for the data, I will consider what the different layers needed are to answer the questions set out in the objectives of the project, the spatial extent required, and if I want to analyze past, current, or future trends and conditions.

Most of the data currently gathered comes from the National Ski Resorts Association. This non-spatial data set addresses elements such as the number of lifts, the size of the resort, and the year it opened. Several spatial layers are available from NOAA, Census Bureau, and OpenStreetMap, which contain either a point or polygon representation of ski resorts that the non-spatial data can be joined with to conduct spatial analysis. Nationwide topographic maps will be clipped to the areas within ski resorts and then used for slope analysis, and APIs will be investigated to determine the best data source to define the popularity of a resort.

To access the various social media APIs a developer account will need to be created to provide a more comprehensive view of the conversation around a ski resort, including metrics such as sentiment, demographics, and topics based on the geolocation of conversations being made in the ski resort boundaries. This project will be using quantitative data sets which are highlighted below, the project is currently half way through the 'locate data' section of the process, so more data will most likely be discovered to assist in the project over the next month.

Source	data	Description
BestMapServer	USA ski areas & resort directory	This nonspatial data set was joined by the state name attribute with the spatial state layer to highlight the number of resorts by state.
NOAA	ski areas all	This polygon layer was used in combination with Eric Wisemans point layer.
Eric Wiseman	github/Ewiseman – ski resort stats	Ski resort stats including 12 data element
FreeGIS data	https://freegisdata.rtwilson.com/	Various free GIS data sets, including weather and climate
BestTime	besttime.app	Paid service with an API to see visitation
Github	Google popular times	A potential method to gather google popular times
StackOverflow	Instagram geotag	A potential method to gather Instagram post by location
StackExchange	Facebook posts by location	A potential method to gather Facebook posts by location

Step 3: Literature Review

To determine the best approach to address what this project aims to achieve, various academic literature has be reviewed to determine the appropriate visualizations, research techniques, and GIS models for analysis. Several journals, articles, and books reviewed include.

Step 4: Analyze the data.

After the data has been assembled, the data requires preparation for analysis. Some of the data will be usable as is. Other layers will need additional cleaning, normalizing, and processing. Python and GIS libraries and tools will be reviewed to determine how some of the data processing can be automated and how it can be used to answer the question of the project. During this step of the process, there may be occasions where several different types of analysis are used until the correct analysis process is discovered. Most of the analysis will be done using QGIS and, to a lesser extent ArcGIS Pro.

Based on some of the elements being reviewed in the project slope analysis will be used to determine a breakdown of slope direction in ski resorts, and some form of density analysis when reviewing social media posts to determine popularity. Out of these two analyses, web maps will be created using proportional symbols to highlight how each resort compares to other resorts.

During this process, it may be discovered that different or additional data sources will be required, and it will be helpful to create a diagram of how the different data sources work together or address a particular element of the project to answer the initial question. The output of this step will be used to visualize the data.

Step 5: Visualize the results.

The result of much of this project will be multiple geographic visualizations of the various elements, established in step 1, of ski resorts across the USA on a web map. Depending on the output of the analysis Mapbox, Leaflet, or Openlayers will be used to visualize the analysis results. These maps will allow users an interactive experience to view various elements of ski resorts that they may find necessary to know when deciding which resort to visit.

The target audience for this project is skiers that are a well-informed audience they know the value of having a go-to resource that contains all the various elements that are influential in determining where to ski. The project aims to provide factual knowledge in a different format. The expectation is that most people using this resource will understand why each element is included on the web maps. To incorporate all of the elements being analyzed, ideally, a scoring system can be defined that can be illustrated on a single web map.

Most of the visualizations mapped will compare a feature in the context of all ski resorts in the USA. For example, proportional symbols could be used to highlight the size of one resort compared to all resorts. The larger the resort, the larger the symbol.

Step 6: Present the results.

When all the previous steps have been completed, a final report will be compiled with all the information either mentioned or included. It is hoped that the web maps created in this project will be used as an ongoing resource for skiers.

Summary

In conclusion, there are many factors that influence visitation to ski resorts for skiers this project is primarily focused on those physical factors that can be compared and contrasted to over some answers to why visitation may be higher at one resort compared to another. And also beyond how GIS is going to be used in this project, there are many other ways that GIS is significantly being used currently by ski resorts such as with snowmaking operations, trail management, weather tracking, and modeling of future infrastructure. By leveraging real-time data and analytics ski resorts can better manage snow conditions, trail systems, and visitor traffic, ultimately resulting in a better customer experience on the mountain in the resort village area. GIS will

undoubtedly remain a critical tool for ski resort management and planning, providing a valuable resource for sustainable and successful operations.

Currently, the project has no preliminary results. It is anticipated that the project will highlight how more people are skiing over the last several decades and that seasons are getting shorter. With season being compression ski visitation is more concentrated over the fewer days in a season.

The significance of this project is to highlight how there are various factors that go into influencing visitation to ski resorts and why some ski resorts are more popular than others. Most of the outputs of this project are really designed to be a resource for skiers to use when deciding where to ski and when to ski.

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