Analysis of Factors Which Contribute to Injury on Artificial Climbing Structures

by

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ABSTRACT

This thesis represents a joining of scientific analysis with high adventure recreation systems. As artificial climbing structures increase in popularity and use, events that are statistically improbable which contribute to human injury during climbing, will be repeated at a higher frequency and the occurence of injury is likely to increase. Through fault tree and survey analysis of the events that are percieved to contribute to injury in these climbing systems, a set of recommendations will be developed to inform climbing structure operators how to reduce and prevent injuries among their participants and potential liability suits related to injury. Through attaining a more complete understanding of the perceptions of staff, managers of climbing facilities can improve organization learning and knowledge alignment among staff, by directing training at staff perceptions which do not support safe operations.

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Chapter I: Introduction

Introduction

In order to gain greater awareness about the conditions that contribute to injury on artificial structure, top-rope belayed, fixed location climbing systems, fault tree analysis was conducted during the preliminary phase of this research. After developing fault tree diagrams through observation and literature review, the preliminary data was validated by three climbing wall professionals. In the next phase of this study, surveys were developed and disseminated to various climbing gyms and ropes courses within the United States. Surveys were created by transforming the original fault tree diagrams into question statements that ask respondents to estimate percentages for the likelihood that events described in the surveys may contribute to injury. The systems being analyzed in this study do not include mobile climbing structures, automatic belaying devices, or natural climbing surfaces. Participants of this study were limited to people employed by an agency that provides climbing experiences. Collecting data on the perceptions of the people that work with these systems should allow trends and potential gaps in the safety policies for artificial climbing structures to be identified and recommendations for improvement to be made.

Statement of the Problem

Artificial climbing structures are becoming increasingly popular and available to inexperienced participants. The safety systems that regulate users and operators of these facilities need to be assessed and updated to reduce future injuries.

Purpose of the Study

Through fault tree and survey analysis of the events that are percieved to contribute to injury in artificial structure, top-rope belayed, climbing systems, recommendations will be developed to inform climbing structure operators about factors that may contribute to injury and how to reduce these factors among their participants and potential liability suits related to injury.

Assumptions of the Study

- The characteristics of artificial structure, top-rope belayed climbing systems are sufficiently similar to allow the same method of analysis for both climbing gyms and outdoor ropes courses.
- User populations for artificial structure top-rope belayed climbing systems are increasing in number and these people lack general climbing experience; the safety policies that govern these facilities are not adapting to this change in user characteristics.
- Collecting data on the perceptions of professionals that operate these facilities about the conditions that relate to injury while climbing will allow generalizations about these systems to be made which can be used to identify trends and potential gaps in existing safety policies.

Definition of Terms

Due to the fact that this study was conducted using an original methodology it was useful for me to very specifically define some terms that have common usage. The terms below were defined for the purpose of creating the fault trees used in this study.

The definitions for these terms are not accepted throughout the climbing industry and should be applied only within the context of this research.

Belayer error. Refers to the actions taken by a person actively or intending to belay climbers involving the operation of equipment provided for the purpose of belaying climbers, which cause or contribute to injury.

Belay technique. Refers to hand and arm motions associated with using belay equipment while protecting a climber between set up and inspection.

Climber error. Refers to the specific actions of a person on belay, engaged in climbing, which cause or contribute to self injury.

Complacency. Refers to a loss of attention, improper technique, or improper equipment use, due to poor attitude, boredom, or other related attitudinal factors.

Distraction. Refers to a temporary loss of attention during an otherwise attentive period of time.

Environmental Conditions. Refers to events like weather, horseplay among participants, facility defects like warped flooring, loss of power, and related isolated events which are very difficult to predict or measure and are responsible for directly causing or contributing to injuries in artificial climbing systems.

Equipment use. Refers to initial set up and inspections of equipment between climbs that are required for safe climbing and belaying.

Equipment failure. Refers to the events or actions involved with the provision of artificial climbing wall experiences that result in human injury due to equipment failure, failure to maintain equipment, or use of equipment that directly causes equipment failure.

Human injury. Refers to the injuries to people that are directly related to ascending and/or descending a climbing route on an artificial climbing structure. Injury refers to any damage to a person that results in first aid or requires a leave from work or climbing to repair.

Installation. Refers to actions or events that occurred during the building or installation period of the climbing structure, prior to official change of ownership or adoption of responsibility by the agency that owns the land, or facility in which the climbing structure is located.

Poor facility management. Refers to administrative practices which allow negligent staff actions or are in known violation of climbing structure vendor/installation agency guidelines.

Limitations of the Study

- Because of my experience with top rope belayed climbing systems I may have falsely interpreted events that contribute to injury based upon my pre-existing beliefs about and experience with these systems.
- Survey respondents may be estimating probability for events with a different understanding of the event than that which is presented in the survey.
- Differences between the work environment and facility structure of the organizations participating in this study may decrease the applicability of these recommendations at any single organization
- Respondents' perceptions about the conditions that contribute to injuries may not reflect the actual or all of the conditions that result in injury

Methodology

This study involves fault tree and survey analysis of artificial structure, top-rope belayed, fixed location climbing systems to identify and assign probability estimates to events that contribute to human injury within these systems. "A fault tree is a graphical representation of logical combinations of causes that may lead to a defined undesired event" (Harms-Ringdahl, 1993, p. 8). In the initial phase of this research, fault trees were created through observation and then validated by three professionals. Completed fault trees were then used to develop surveys to collect data about the perceptions of a greater number of professionals who operate this equipment. The instrument asks respondents to estimate percentages for events listed on the survey which may contribute to injury of climbers during their use of this equipment. Surveys were sent by email, surface mail, or hand delivered to various climbing agencies who agreed to participate in this study. Surveys were returned either by fax, surface mail, or collected upon completion.

Chapter II: Literature Review

Introduction

The sections in this literature review are climbing systems, fault tree analysis, and a review of existing climbing injury data. Major concepts presented in the climbing systems section are that artificial structure climbing is a relatively new sport that is experiencing great growth in popularity and that because of the ease of access to this sport, inexperienced and uninformed participants are able to participate, without formal education or training. Current risk management guidelines need to be updated and improved to account for the characteristics and increase in number of the new user population. The types of accidents that are occurring within these systems seem to represent a gap in the risk management guidelines followed by high adventure recreation providers. Major concepts presented in the fault tree analysis section are that this type of analysis has historically been used to identify and reduce safety deficiencies; climbing systems are sufficiently mechanical to be analyzed through this procedure; and an explanation of the process followed during the fault tree analysis portion of this study is provided. The review of injury reports shows that the fault tree validation conducted in the first phase of this study is consistent with actual injury statistics and lends validity to the methodology followed in this study.

This research is supported by the Dynamics of Accidents Theory (Leemon & Merrill, 2002) and seeks to develop a more precise understanding of the factors that contribute to injury in these climbing systems. The Dynamics of Accidents Theory was developed for analysis of wilderness experiences but can be applied to artificial structure climbing systems. The focal point of this theory is that "The greater the interaction of the two categories [environmental and human] of accident factors the greater the potential for an accident to occur" (Leemon & Merrill, 2002, p. 4). While recognition of these factors is helpful in reducing injuries, this level of analysis is vague and may be prone to errors of omission. The research I have conducted here seeks to demonstrate that fault tree analysis and identification of the perceptions of people that operate these systems will identify factors similar to those in the Dynamics of Accidents Theory but is a more detailed type of analysis and should provide greater understanding of the conditions which contribute to injury when applied and validated within the climbing community.

Climbing Systems

Indoor rock climbing is a relatively new sport that has been widely available to the public in the United States only within the last 20 to 30 years. Climbing is a highly challenging activity which demands great physical and mental strength from the people that engage themselves in climbing regularly. Artificial structure climbing began with experienced outdoor and alpine climbers building small structures that they could practice climbing on when they did not have access to natural climbing surfaces. Most artificial climbing structures use a top rope belay system, which provides continuous safety support to the climber through a rope and anchor system that is above the climber no matter where they are on the climbing route. Top rope belay systems are considered to be the safest belay system available to climbers. The stability of environment and ability to create a variety of self chosen climbing features makes artificial walls attractive to climbers of all ability levels. What started as a training tool for experienced climbers quickly became a source of recreation and development for a new group of climbers that may never desire to climb on natural surfaces. Today there are thousands of indoor and artificial climbing structures all across America.

> What started as a traditional form of adventure climbing has grown into a popular recreational and competitive activity. Rock climbing is the latest extreme sport to spread across America. It has been estimated that over 300,000 people in the U.S. have climbed a rock wall. However, with an increase in participation comes an increase in injuries. As a result, there has been a move to bring more awareness of the risks involved to beginning, novice, and expert climbers in the hope of preventing injuries. (Preston, 2005, para. 1)

What many indoor climbers fail to realize is that despite great stability in the indoor environment, great risk, however unlikely, still exists through participation in this activity.

> In a statistical/engineering sense, large number of repetitions or many, many climbers climbing many, many routes over an extended period of time means unavoidable occurrences of otherwise statistically insignificant events...The real problem stems from combining the known fact that there will be failures of the system with the expectation of the public frequenting gyms that they are not at serious risk of serious injury or death. (Hoisington, 2005, para. 7)

The problem with this situation as stated in the quote above is that the majority of indoor climbers do not perceive the actual risks associated with this activity and engage themselves in a sport which historically required years of training and study before even rudimentary climbs by today's standards were ever attempted. Liability expert and climbing instructor Miles Hoisington comments on the differences in perception between artificial and natural climbing:

> Objective danger in big mountains may be under appreciated by the novice, but at least at some level even the neophyte must understand that rock climbing is dangerous. By contrast, the risk of serious physical injury or death is simply not something that the typical gym climber (let alone his family) even thinks about. (Hoisington, 2005, para. 5)

As extreme sports become more popular and the number of agencies that specialize in building customized artificial climbing structures increases the need for a more systematic procedure to reduce the potential for injuries associated with the growth of this sport becomes clear.

A problem that is receiving increased attention with artificial climbing wall providers and liability lawyers is that climbing is a new and therefore unregulated activity that involves the potential for serious injury but has a significant portion of participants that are largely unaware of the actual risks associated with this sport.

> The collection of incident data for the adventure programming profession has stuttered along in fits and starts. Many organizations have been hesitant to collect data, or if they do collect it, they have been reluctant to share their findings with others. The reasons stated are often based on legal philosophies and a fear of admitting mistakes. (Leemon & Merrill, 2002, p. 8)

Indoor climbing is a relatively small industry nationally. Because artificial wall climbing is a new sport and specific legal regulations have not been widely implemented within the industry it is not monitored by standard safety policy organizations like the Occupational Safety and Health Administration (OSHA). Individual organizations are unlikely to divulge data about injuries that are collected internally because this information could be damaging to the perceived safety and reliability of their businesses. The vast majority of injuries that do occur, result from climbers pushing their own ability levels and creating non-traumatic, overuse injuries, which may not be reported as injury.

This study assumes that all human injuries, specifically related to ascending and descending during climbing, will be caused primarily by three events: belayer error, climber error, or equipment failure. Environmental conditions are recognized within this report as having potential for resulting in human injury but are not examined further. While from a mathematical view it could be assumed that each of these events should have an equal potential for resulting in human injury, this is not the case. The following quote comes from www.rock-climbing.ws, which is a comprehensive online resource for information about indoor and outdoor rock climbing.

> Injuries at a rock gym rarely occur from falls or accidents. The most common injuries result from too much training and climbing. Almost everyone who climbs in a gym will suffer some sort of muscle or tendon injury at some point. Because of the steep and strenuous terrain, gym climbing puts a tremendous strain on fingers, elbows, and shoulders. (Rock Climbing, 2004, para. 2)

This point is further clarified in an article from the British Journal of Sports Medicine:

> Overuse syndromes account for over 80% of the injuries at indoor climbing facilities...The predominant areas of injury are the elbow, wrist, forearm, and hand. Research has suggested that 75%-90% of rock climbers can be expected to develop an upper limb overuse injury. (Wright, Royle, & Marshall, 2001, para. 1)

While many artificial structure climbing providers focus their risk management efforts on reducing the probability that staff and equipment contribute to injuries, the data describing causes of climbing injuries indicates that current accident prevention guidelines seem to lack recognition of the events that contribute to the majority of climbing injuries.

Joe Lackey, the President of Alpine Towers International, who has been a professional in the climbing industry for many years and receives data on the safety reports for over 200 outdoor artificial climbing structures, shared some of his insights about climbing related injuries during a telephone interview. The facilities described in Joe's data may be considered quite different in structure and use than many indoor climbing walls. Despite differences, these systems all primarily use top rope belayed climbing equipment, the safety policies, employee characteristics, and user populations for indoor climbing walls and these outdoor climbing structures are comparable. The only equipment related injury that Joe recalled in our conversation was a cable breaking on a specific outdoor ropes course component, called a zip-line, which is not similar to any top rope belayed climbing structures (personal communication, April 20, 2005). The majority of injuries reported in the Alpine Towers' 10 year safety study were due to participant complacency (not paying attention or disregarding safety policies). Of the 55,336 people who participated on some type of Alpine Towers equipment during the 10 year study period, there were 179 near misses, 78 minor accidents, and 18 serious accidents reported (Alpine Towers, 1999).

Although data describing the national number and type of injuries or contributing factors related to top rope, artificial structure climbing are largely unavailable, sources of information that allow inference to be made about the events related to human injury are the risk management and legal protection policies that are followed by climbing system providers. The Affiliation of Risk Management for Outdoor Recreation (ARMOR) is an agency that has collected data about the types of liability suits that are filed against many types of adventure recreation providers. Though recommendations provided by ARMOR are not specific for climbing, they do represent some of the internally generated legal protection policies that exist within the adventure recreation industry. This list of recommendations is in order of the areas of risk management to monitor most closely, based upon the claims that are filed against adventure recreation providers most often. This data is based upon legal claims, not necessarily human injury. The intent of the list is to describe, in order of frequency, the reasons people file suits against agencies, presumably due to injury, and then to use this information to prevent or reduce the events that result in injury and/or litigation.

ARMOR's list of reasons liability suits are filed against adventure providers

1. Failure to adequately inform participants of risk
2. Participants did not receive proper instruction

3. Instructor error
4. Equipment failure
5. Programming at the wrong place/wrong time
6. Inadequate rescue and evacuation. (Leverette, 2001)

A set of similar data was generated by the law firm of Hoisington and Morrisey.

> Over time, the types of accidents that are certain to occur in climbing gyms and that are certain to generate claims will probably fall into the following general categories: inadequate supervision, wall failure, negligent instruction, and equipment failure. (Hoisington, 2005, para. 9)

Generalizations about the accidents that are occurring within the adventure recreation provider industry can be made from these liability reduction strategies. The apparent emphasis on instructor actions and supervision being mentioned in four of the ten statements (participants did not receive proper instruction; instructor error; inadequate supervision; negligent instruction) and lack of emphasis on participant responsibilities, only mentioned once (failure to adequately inform participants of risk), indicates that agencies may be placing more emphasis on staff actions and equipment than is appropriate for effectively reducing injuries. What is needed to close the gap between existing safety practices and existing or foreseeable injuries is a method for the identification of root causes and contributing factors that have the greatest probability for resulting in human injury The next section of this chapter describes the procedure used to analyze climbing systems in the preliminary phase of this study.

Fault Tree Analysis

The reason for using fault tree analysis in this study is its common use in analysis of safety systems and the data display format which allows organized recording and analysis of events which may contribute to injury in climbing systems. I have worked with commercial climbing and belaying programs for over five years. Experience in this industry is needed for accurate development of fault tree models because, "construction of a fault tree...requires an intimate knowledge of the manner in which a system is designed and operated" (Barlow & Lambert, 1975, p. 5). The review of literature for this research indicates that fault tree analysis is used frequently to determine gaps in safety policy. "Fault tree analysis is one of the principal methods of safety system analysis...It can identify potential accidents in a system and can predict the most likely causes of system failure" (p. 19). Because climbing wall operations are typically quite structured; are often conducted in environments that may be difficult to control; and involve great variance in skill levels among participants; fault tree analysis seems the best method for analysis of these systems.

> A fault tree is a graphical representation of logical combinations of causes that may lead to a defined undesired event. Examples of types of final events are an injury to a human being, or failure of equipment. It can be questioned whether the method is appropriate for common safety work outside high-risk sectors. But a general knowledge of Fault Tree analysis can be beneficial even for those who will not use the method directly. (Harms-Ringdahl, 1993, p. 8)

The procedure used in this report follows the six steps to develop a fault tree written by Kolarik (1995) in his text about creating quality. The steps are as follows.

1. **Identify the top event...** that is desired to be avoided
2. **Identify the second level events** ...that could lead to the top event
3. **Develop the tree logic** ..use the And, Or, gates to show the relationship of subsystem failures that produce the top event
4. **Identify lower level events** ...determine the logical sequential relationship between this level and the levels above
5. **Proceed to the desired level of detail** ...repeat steps three and four until the desired level of detail has been attained
6. **Quantify the tree logic** ...Compute the probability of failures described in the fault tree. (Kolarik, 1995, p. 12)

Quantification of events listed in the fault trees are based upon estimates given by survey respondents for their opinion about the probability that events displayed in these models lead to human injury. At this time, there is no widely accepted set of data quantifying or identifying the reasons that lead to injury in permanent structure, human operated, top rope belayed climbing systems.

Review of Existing Climbing Injury Data

Existing climbing injury data was analyzed to determine if the conclusions based upon the data collected in this research could be validated through comparison with actual injury statistics. One shortcoming of fault tree analysis is that it assumes all contributing factors which may result in an undesired event can be identified and accurately quantified. While analysis is helpful, it is unrealistic to assume that all contributing factors for any event can be identified without exception. It is recognized that some of the factors which lead to injuries in climbing systems may be missing from this report. This report does not propose that all factors which result in climbing injuries can be identified and prevented. This report does propose that through scientific application of documented analysis procedures, recommendations can be made to increase safety that are based upon a more thorough understanding of the characteristics of permanent structure, man-made, human operated, top rope belayed climbing systems.

Because "overuse syndromes account for over 80% of injuries at indoor climbing walls" (Wright, Royle, & Marshall, 2001, para. 2) this research makes the assumption that 5-10% of injuries can be attributed to climbers making errors that result in injury due to personal actions that are not related to overuse. Between 1-5% percent of injuries identified in the literature review were caused by equipment failure. The remaining 5-10% of injuries are attributed to belayer errors. Safety and risk management guidelines within this industry are primarily focused on the events of equipment and belayer actions. This research demonstrates that if reduction of injuries related to climbing is an objective of artificial climbing structure providers, safety policies must be revised to address climber actions which are responsible for the majority of injuries associated with participation in these activities.

The estimate that the majority of climbing injuries are caused by climbers is supported by the data in Ten Year Safety Study conducted by Alpine Towers International (ATI). While the ATI data accounts for many injuries that do not fit within the research model used for this study, it gives support for the claim that the majority of injuries that are associated with climbing result from climber actions. The ATI data separates human injuries into the categories of: near misses, minor injuries, and serious injuries.

> Near Miss Incidents accounted for 46% of all incidents and accidents between 1989 and1999. Of the 83 reported, these were categorized into the following areas:
>
> - 27 incidents in the "other/unknown" area - made up of near miss situations such as 11 incidents of organizations reporting trespassers, and cases of people not wearing helmets or being properly equipped
> - 23 near misses occurred while people ascended the Tower
> - 14 occurred while belaying
> - 7 as a result of participating in the Swing
> - 6 while descending
> - 4 during initiatives
> - 2 on or around the base rails. (Alpine Towers, p. 3)

Forty of these incidents do not relate to climbing. Of the remaining 43 near misses, 29 occurred while ascending or descending. These 29 climber-related near misses account for 67% of those reported in this section. Fourteen near misses occurred while belaying, which account for 17% of climbing related near misses. No near misses were attributed to equipment failure.

Minor Accidents was the second most frequent type of incident. 78 minor accidents were reported, accounting for 44% of the total. Of the 78 reported, these were categorized into the following areas:

- 19 of them happened while participants ascended the Tower
- 18 occurred as people participated in the Swing
- 15 during both non-activity periods near the base rails (socializing) and in the other/unknown category
- 21 as a result of participating in ground initiatives
- 4 while descending
- 1 occurred while participants belayed. (Alpine Towers, p.3)

Fifty-four, or roughly 70% of minor injuries reported in this study are not due to climbing activities. Of the remaining 24 climbing related minor injuries, 23 or 96% of these injuries could be classified as being climber-related. Only one injury was related to belaying. No minor injuries were related to equipment failure.

Of the 18 serious accidents reported in the ATI study, seven injuries were not related to climbing activities. Of the 11 remaining injuries, two climbing injuries were related to climber error - not following directions. Two participants injured themselves while showing off on a climbing structure. Three participants suffered heat and exhaustion related injuries (Alpine Towers, p.3). These seven injuries would be considered climber related in the models used for this study, and account for 64% of the serious climbing injuries. Three participants suffered equipment related injuries and would account for 27% of serious climbing injuries in this report. No serious climbing injuries were reportedly due to belaying.

Of the 179 injuries and incidents described in the ATI report 101 are not related to climbing. Of the remaining 78 climbing related injuries, 59 or 76% are climber related, 15 or 19% are related to belaying, and three or 4% are due to equipment failure. With between 75%-90% of injuries being caused by climbers, and only a few injuries being reportedly due to equipment failure, but recognizing Hoisington's prediction that as indoor wall use continues injuries related to equipment failure will invariably increase, I estimate that at least 1%-5% of injuries should be attributed to equipment failure. This leaves an estimated 10%- 20% of injuries being due to errors in belaying.

In another report that is related to ropes course related injuries, the causes of unexpected deaths on ropes courses was analyzed for the years 1986-2000. Of the 17 deaths recorded in the time period, two were considered to be outside of the time-frame ropes course staff was responsible for, and 10 were attributed to sudden cardiac death. Only five of the deaths were associated to ropes course related trauma.

> Four of the five victims were actually staff members, not participants. While programs may have stringent safety requirements for participants, these may not extend to the individuals running the courses. In each of these five circumstances, it appeared that a standard installation or operating procedure was not being followed correctly. (Welch & Ryan, 2002, p. 143)

This data demonstrates the need for a system of detailed analysis that aids staff in identifying key problem areas and using this information in a manner that contributes to a reduction in factors that contribute to injury.

Conclusion

The literature on climbing accidents demonstrates a need for consistent organizational focus on the various aspects of climbing systems that can be monitored and controlled.

> The importance of collecting data on accidents, incidents, and near misses takes on more significance when we think in terms of the High Reliability Theory. This theory proposes that safety can be achieved through the implementation of appropriate organizational design and management techniques: leadership safety objectives, need for redundancy, decentralization, culture, and continuity, and organizational learning. (Leemon & Merrill, 2002, p. 8)

Leadership safety objectives refer to the practice of having organizational leaders and managers be knowledgeable and ensure that safety practices are correctly followed. Leadership must set the standard for safety compliance. In order to establish safe climbing practices, managers must be knowledgeable in both safety practices and methods for collecting and analyzing safety related information. Need for redundancy refers to the climbing safety practice of always having a back-up system in place to ensure safety in the event that the primary system fails. Organizations can maximize the application of redundancy through identification of problem or high-use areas and the design of accident prevention strategies with redundant qualities. Decentralization, culture, and continuity as aspects of the organizational safety system mean that every person that is involved in the organization must feel supported and willing to shut down or suspend the system if an irresolvable safety deficiency is identified. Management policies which intend to empower staff are not sufficient to prevent accidents if employees do not receive daily support and recognition of their responsibility to act in the best interests of participants.

The fourth aspect of High Reliability Theory, Organizational Learning, is key in maintaining safe climbing systems. "Organizational learning simply means that the organization learns from its experiences and mistakes" (Leemon & Merrill, 2002, p. 9). "Organizational learning should be embraced. The discussion, analysis, and evaluation, of accidents are important and necessary tools to use if we are to learn how to reduce accidents" (p. 9). Through application of fault tree and survey analysis, climbing facility staff can become more aware through detailed analysis of the aspects of their facilities which are perceived as likely to contribute to an accident and address these issues in a manner that promotes organizational continuity.

Chapter III: Methodology

Introduction

Artificial climbing structures are becoming increasingly popular and available to inexperienced participants. The safety systems that regulate these facilities need to be assessed and updated to reduce future injuries. This study identifies root causes for potential increases in climbing related injuries through analysis of: professional literature, perceptions of professionals that work with these systems, and observation of climbing systems in use. Sections addressed in this chapter include: subject selection and description, instrumentation, data collection procedures, data analysis, and limitations.

> Meyer and Williamson developed a matrix that identifies the principle causes of accidents in outdoor pursuits. Their model is based on the Dynamics of Accidents Theory, and accounts for environmental and human factors, but divides human factors into the two categories of unsafe acts and errors in judgment. (Leemon & Merrill, 2002, p. 5)

In an effort to identify factors which contribute to injury within organizations, this study uses algorithms, which account for the same factors, but has assumed that the interrelationship of human factors which are most likely to result in an accident can be observed and charted. This study does not specifically address environmental conditions through an algorithm because, according to the Dynamics of Accidents Theory, "environmental factors are usually the factors we cannot control and human factors are usually the ones we can" (Leemon & Merrill, 2002, p. 4). Many artificial climbing structures are offered in regulated climate areas, and the participants may be more closely observed in these settings than in wilderness experiences. It is important to recognize that environmental conditions do play a significant part in accidents. The purpose of this study is to analyze the human factor component of safety systems with the intent of understanding what can be controlled and then learning what errors can be identified and reduced.

Subject Selection and Description

Subjects were selected by identifying organizations known to this researcher and through Internet research, then by contacting representatives of these organizations to determine their willingness to participate in the survey. Surveys were either emailed or hand delivered to the respondents and returned either by fax or surface mail. Three sets of surveys were collected by visiting the agency and personally collecting the surveys. This research intends to capture data from professionals in this field that represents a wide range of experience levels. If generalizations about the perceptions of people in this field are to be accurate, then wide representation of people in this field is needed.

Organizations were selected on the basis of my experience or connection with them, a willingness to participate in this study, and/or due to their reputation of professionalism in climbing operations. It is the intent of this project to collect data from facilities that represent the use of best practices in their operations. The characteristics which I consider to be representative of best practices include: the use of approved medical forms and liability waivers, well maintained equipment, recognition from other known climbing centers, adherence with the national standard of care, and the availability of helpful information in promotional media. The determination of the presence of these conditions was conducted through prior experiences with these organizations, referral by other recognized professionals, and analysis of information about the organization that was available through the Internet.

Instrumentation

The survey used in this study was developed by the researcher and is based on fault tree diagrams constructed during the initial phase of this project. After conducting observation and literature review, the assumption was made that all climbing injuries can be associated with four root causes: belayer actions, climber actions, equipment function, and environmental conditions. Because environmental conditions represent the array of factors that are outside of the control of the safety system, it was decided that thorough analysis of these factors would be highly situational and too lengthy for the purpose of this study. Each of the remaining three root causes were developed through the process of fault tree construction (see Appendix A). After validating these fault tree models, surveys were constructed from the data, into a format that would allow estimations to be made for the events identified in the fault trees.

After the first phase of data collection, which included validation by professionals, the researcher made changes to the set of responses being evaluated by respondents, which were not present in the original fault tree models. The original set of options that was evaluated in the first phase of this study can be identified in the table found in Appendix C. The changes which were made during the development of the survey models used in data collection are as follows:

- All models were reformatted to allow for easier tracking of the algorithm

- On the climber error model, in the first tier under *follows facility policy* the event *random occurrence* was changed to *slips/falls* to provide a more accurate description of the event which may contribute to injury.
- In the bottom tier under *follows facility policy,* the event *climber falls attempting new level of difficulty* was changed to *slips/falls* to differentiate more clearly from the previous event which seemed too similar to the opposing choice of *climber lacks ability*
- On the equipment failure model, in the third tier under *faulty installation,* the event *negligent vendor installation* was changed to *improper vendor installation* to avoid improper use of the legal term, negligence.

The survey contains four background questions which will allow more detailed analysis of survey data to be conducted. The belayer error section of the survey has nine statements with two to four events per statement which require estimation. The equipment failure section of the survey has nine statements with two to three events per statement which require estimation. The climber error section of the survey has eight statements with two to three events per statement which require estimation.

Data Collection Procedures

A 30 question survey was administered by emailing, surface mailing or hand delivering the consent form and survey instrument (see Appendix B) to agencies that indicated their willingness to participate in this study during a telephone conversation. Respondents completed the survey and returned it either by fax, surface mail, or in person. The goal of this research is to receive at least 30 completed surveys from no less than four separate agencies representing both ropes courses and climbing gyms.

Data Analysis

A number of statistical analyses were used in this study. The Statistical Program for Social Sciences, version 10.0, (SPSS, 2002) was used to analyze the data according to characteristics identified in the background information. Analysis of survey responses was conducted in groupings of amount of experience, type of facility, and position within the organization. T-tests were used to determine if there was a significant difference in the survey responses between the different groups in each of these categories.

Standard deviation and mean were calculated across all surveys for each statement that requested estimation. The purpose for calculating these figures is to determine common characteristics and trends in the perceptions of climbing professionals, and to determine the validity of the response data.

Limitations

- Research subjects may be estimating probability for events with a different understanding of the event than that which is presented in the survey.
- Differences between the work environment and facility structure of the organizations participating in this study may decrease the applicability of these recommendations at any single organization.
- Respondents completed the surveys without supervision which may result in incorrect interpretation of statements, or sharing of answers among respondents who work at the same agency.
- The instrument asks participants to evaluate conditions which are subtle within the safety systems and therefore responses may be based on unclear understanding or hurried completion of the survey.

- The survey used in this study is an original document and has not been validated through other studies.
- Respondents' perceptions about the conditions that contribute to injuries may not reflect the actual or all of the conditions that result in injury.

Chapter IV: Results

The response goal of this study was to receive 30 completed surveys from at least four different agencies. As is evident in Table one, a total of 47 surveys were returned, which represented eight agencies. Four agencies are in Wisconsin, three in Illinois, and one in Georgia. The table below provides more information about the agencies and the number of surveys returned for this study. The remainder of this chapter will display and analyze the data gathered and trends identified in this study.

Table 1

Description of Respondent Agencies and Participation

Respondent group number and facility description	Response Frequency	Valid Percent
1. University recreation program with indoor climbing gym and outdoor ropes course	12	25.5
2. Community college program with outdoor ropes course	7	14.9
3. For-profit indoor climbing gym	3	6.4
4. Community recreation center with indoor climbing gym	7	14.9
5. For profit indoor climbing gym	5	10.6
6. University program with outdoor ropes course and indoor climbing gym	9	19.1
7. University program with outdoor ropes course and indoor climbing gym	2	4.3
8. For profit program with outdoor ropes course	2	4.3
Cumulative response	**47**	**100%**

Further analysis of the respondents shows that approximately 64% or 30 of the 47 respondents work within a university setting while the other 36% or 17 people work within a for-profit agency. Review of the types of equipment that respondents were working with at the time data was collected shows that 19% of respondents work only with a ropes course, 32% work only with a climbing wall, and 49% work at a facility where both a ropes course and climbing wall are present. Approximately 60% of the respondents have less than three years of experience working with top-rope belayed climbing systems. Twenty people or 43% of the response group have worked one to three years. Employee/belayers make up 76% of the response group with the remaining 23% being either managers or owners.

The survey responses indicate several trends or tendencies in the perceptions of the study group. The summary provided in the item analysis refers to the entire study group. Differences between sub-groups in the study will be discussed later in this chapter. Appendix B displays the median responses on the survey for the entire study group. Later in this report when specific items on the survey are referenced, the coding system divides each section of the survey numerically and then by statement number. The demographic information on page one of the survey starts the coding with item 101. Item 201 refers to belayer error section statement one. Item 301 refers to equipment failure section statement one. Item 401 refers to climber error section statement one.

The representation of data gathered through the survey, shown in the following section, is displayed by combining the survey questions and dominant responses into positive statements that represent the majority perception of the study group and are presented in the same order as the statements appear in the survey.

Item Analysis for Belayer Error

1. When belayer error contributes to injury this can mostly be attributed to belay technique.
2. The piece of belay equipment that is most likely to be misused is the belay device.
3. Improper belay technique can mostly be attributed to belayers that were properly trained but do not follow the technique they were trained in.
4. When belayers are properly trained but do not follow the technique they were trained in, the two factors of distraction and complacency are equally likely.
5. When belayer error results from distraction this can mostly be attributed to belayer complacency.
6. When belayer error results from an error in belay method this can mostly be attributed to belayer complacency.
7. When climbing injuries are related to improper use of belay equipment this can mostly be attributed to the belayer not using the equipment in accordance with facility policies.
8. When climbing injuries are related to equipment use that is not in accordance with facility policy this can mostly be attributed to belayer being properly trained but does not follow facility policy.
9. When climbing injuries are related to belayers' use of equipment that is in accordance with facility policy this can mostly be attributed to climber actions being responsible for the injury.

Item Analysis for Equipment Failure

1. When climbers are injured as a result of equipment failure this can mostly be attributed to faulty usage of equipment.
2. When climbers are injured as a result of equipment failure that is due to faulty installation this can mostly be attributed to equipment failure after not being properly installed and inspected.
3. When climbers are injured as a result of equipment failure that was not properly installed and inspected it is the installation and inspection procedures that most likely to contribute to injury.
4. When climbers are injured as a result of equipment failure that is due to installation defect it is the installation procedure that most likely contributes to injury.
5. When climbers are injured as a result of equipment failure that is due to faulty maintenance this is most likely attributed to maintenance procedures not being followed by staff.
6. When climbers are injured as a result of equipment failure that occurs while maintenance procedures are followed by staff this can most likely be attributed to oversight during maintenance.
7. When climbers are injured as a result of equipment failure that occurred due to oversight this can be attributed equally to inadequate maintenance training and inadequate tracking and recording of maintenance history.

8. When climbers are injured as a result of equipment failure that is related to usage this can mostly be attributed to the equipment not being used in accordance with facility policies.
9. When climbers are injured as a result of equipment usage that is not in accordance with facility policy this can mostly be attributed to staff not following policies for equipment usage.

Item Analysis for Climber Error

1. When climber actions result in injury this can mostly be attributed to climbers not following facility policy.
2. When climbers are injured while following facility policy this can be attributed equally to overuse injuries and staff or belayer error.
3. When climbers are injured while not following facility policies this can mostly be attributed to climbers knowing the policy but not following it.
4. When climbers are injured as a result of overuse this can mostly be attributed to insufficient warm up prior to climbing.
5. When climbers are injured due to climbing an unfamiliar route this can be equally attributed to lack of ability or simple falls and slips which cause injury.
6. When climbers are injured while not knowing facility policy this can mostly be attributed to policies being available but not understood.
7. When climbers are injured with facility policies that are available but not understood this can be equally attributed to climber and staff complacency.

8. When climbers are injured while knowing facility policies but not following these policies this can be equally attributed to staff not enforcing policies and climber complacency.

It should be recognized that there was disagreement between sub-groups on which option was perceived as being more responsible for contributing to injury. The next section of this chapter will address discrepancies identified by T-test to determine a significant difference between sub-groups in the way each survey statement was answered. Only statements with a significant difference of .01 or greater and/or when the dominant option for contributing to injury was different from the study group are addressed.

The sub group comparison that showed the greatest number of discrepancies was between respondents with less than three years or more than three years of experience working with these climbing systems. The importance of identifying these differences in perception is that people are likely to pay attention to the aspects of a system which they feel are most likely to result in injury. Knowing where differences in perception exist, in reference to safety concerns, may allow managers to achieve a more congruent safety system by addressing these differences. Table two displays the study group median responses and responses for survey items which were significantly different between people with more than three years or less than three years of experience. The level of significance listed in the table only refers to the difference between more than three or less than three years of experience and describes amount of separation between the ways in which the two groups answered specific survey statements.

Table 2

Response Differences of People with More or Less Than Three Years of Experience

Item Number	Median Response	More than Three	Less Than Three	Significance
	N=47	N=19	N=28	
203	A 60; B 40	A 43; B 56	A 67.5; B 32	.01; .01
302	A 20; B 80	A 10; B 90	A 33; B 67	.001; .001
303	A 20; B 80	A 15; B 85	A 30; B 70	.01; .01
404	A 40; B 25; C 33	A 49; B 16; C 34	A 37; B 33; C 31	B .001

Item analysis for table 2

A general trend in the response patterns seemed to show that the more than three years group responded with less deviation within their group and greater separation between choices for a single statement. This pattern could be explained by having greater confidence in deciding which option among available choices is the most likely candidate, possibly attributable to having more experience. The less experienced respondents seem to perceive that conditions which contribute to injury are less distinguishable, which may result in overlooking factors that are more likely than others to result in injury.

Item 203. This is the only statement in which these two groups did not agree upon the option that is most likely to contribute to injury. The more than three years group responded that belayer not properly trained and does not know technique is more likely to contribute to injury. The less than three years group responded that belayer was properly trained and does not follow technique is more likely. This pattern seems to indicate that the people with less experience feel that training is adequate and human error at the belayer position is responsible for injury. People with more experience seem to perceive that training tends to be inadequate, or perhaps that the trainers themselves are not delivering an appropriate level of instruction or supervision. This response may also show that less experienced staff members have more faith in the trainers than their peers. This difference may also be due to more experienced staff, having greater confidence in their personal abilities, and that training is at fault when things go wrong.

Item 302. Although the two groups agreed that equipment failure is most likely to contribute to injury after not being properly inspected, the disparity between the ways they weighted each response tends to indicate a difference in perception. The fact that 1/3 of respondents with less than three years of experience felt that equipment fails after proper inspection may reveal either a lack of confidence in equipment quality or a lack of ability to identify deficiencies through inspection.

Item 303. The two groups agreed that equipment failure after improper inspection is most likely due to the faulty inspection as opposed to defective equipment. Because twice as many less experienced people responded that defective equipment could be the cause of injury this may reveal either a lack of confidence in equipment quality or a lack of ability to identify deficiencies through inspection.

Item 404. The two groups agreed that insufficient warm up is the most likely cause of injury in cases of overuse injury. The less experienced group weighted the three responses almost equally, putting far more emphasis on injury being due to climbing a new route than the more experienced group. This seems to indicate that less experienced climbers may consider injury to be less preventable or that warming up prior to climbing is not as important to preventing injury.

Table 3 displays the study group median responses and responses for survey items which were significantly different between people with that work at university programs and people that work at for-profit programs. The level of significance listed in the table only refers to the difference between the two sub groups and describes the amount of separation between the ways in which the two groups answered.

Table 3

University Employees' and For-Profit Employees' Response Differences

Item Number	Median Response N=47	University N=30	For-Profit N=17	Significance
204	A 34; B 20; C 35	A 34; B 24; C 42	A 45; B 26; C 29	C .05
407	A 50; B 50	A 46; B 54	A 66; B 34	.01; .01
408	A 33; B 30	A 41; B 27	A 19; B 30	A .001

Item Analysis for table 3

The purpose in comparing response patterns between these groups is to gain a better understanding of the way differences in organizational structure may impact how employees within these two groups perceive safety factors. Overall, the groups were very similar in the way they responded on the survey with only the three statements displayed in Table three showing significant differences in perception. One aspect that stands out in these three statements is that the two groups perceive the factors most responsible for contributing to injury in opposing ways.

Item 204. University program employees responded that belayer distraction is most likely to cause injury when properly trained belayers do not follow proper technique. For-profit employees responded that belayer complacency, as opposed to distraction was most likely to contribute to injury in the same situation. Complacency is defined on the survey as an act of negligence or carelessness, while distraction refers to a simple loss of attention in an otherwise attentive person. This response pattern seems to indicate that for-profit employees perceive loss of attention as being more present in the work place than university employees. The fact that university employees perceived distraction to be more prevalent than complacency may imply a greater sense of safety consciousness, possibly due to their involvement with higher education, or perhaps a more forgiving environment where mistakes are not perceived as intentional.

Item 407. The difference in response patterns on this item was particularly interesting. The median response for the study group showed these items to be equally responsible; however analysis of these sub groups shows significant disparity in perception. University employees perceived staff complacency to be most significant when policies are available but not understood, but the two options were closely weighted by this group. For-profit employees strongly responded that they perceived climber complacency to be responsible for injury in this situation. This incongruity may be attributable to differences in program format. For-profit programs generally offer more open enrollment programs with higher autonomy for a given participant who is self directed within the for-profit facility. This would support the perception that climbers would be more responsible for their own injury. University programs tend to be more regimented, explaining why employees would perceive a lack of understanding among participants to be staff complacency. This difference could also be examined in reference to the response pattern in item 204. If university employees have more education and feel more responsibility for the safety of their participants, this would also explain the difference in response patterns. For-profit programs typically involve more participant autonomy, which may contribute to a reduced sense of responsibility for participant actions, by employees.

Item 408. This item addresses the same disparity as in the two previous statements, between staff responsibility and climber responsibility for supporting safety policies. University employees responded that the condition of staff members not enforcing policies is most responsible when policies are known but not followed. For-profit employees responded that the responsibility is with the climber. Another possible explanation for the difference in responsibility for safety may be in the relationship with participant populations in these two facility types. In university programs it is likely that the greatest percentage of participants come from the university. Employees may feel a greater sense of responsibility for the safety of their participants due to the shared university culture. For-profit programs tend to have less homogeneity in their user populations and may feel less connected or similar to their participants, contributing to greater feelings of independence and assumption that individuals are responsible for their own actions.

I recognized another interesting trend in the survey responses, which I do not understand completely, and which seemed deserving of further examination. Of the three groups that were compared for differences in response pattern by T-test, one group had a significantly greater number of variations in response patterns than the other three. The greatest number of differences in responses was identified by amount of experience in the more than three year and less than three year, and was not similar to the response patterns of managers and employees. Table 4 displays the sub groups which were analyzed using a T-test and the number of significant variations, by statement, in the response patterns for that group.

Table 4

Identification of differences in response patterns between sub-groups

Sub groups compared for response pattern	Number of statements with response difference at .05 significance or greater	Statements in which significant variation occurred
Less than 3 years	19	201 A,B 203 A,B
experience/more than 3 years		205 A,B 209 A,B
Less than 3 years- n=28		302 A,B 303 A,B
More than 3years- n= 19		304 A,B 305 A,B
		309 A,B 402 C 404 B
University/ For-profit	10	202 B, 204 C
University- n= 30		304 A,B 305 A,B
For-profit- n= 17		407 A,B 408 A, C
Manager/ Employee	2	209 B, C
Manager- n= 10		
Employee- n= 36		

It would seem logical that the Manager/Employee group would be quite similar to the Less than 3 years experience/more than 3 years group, but they are not. I can only speculate about the reasons that there were less differences between perceptions based on organizational status than there were differences in perception based on experience. I anticipated great difference in response pattern based on experience. Why this difference is not paralleled between managers and employees is a curiosity. It is possible that managers in my study groups were not the most experienced staff within their facilities and so shared similar perceptions with employees. The data supports the notion that managers perceive their environments in a way that is similar to their staff. This trend may imply that managers are communicating with their staff, perhaps through training, or other means which align perception. The responses for these three survey statements indicate that university employees tend to perceive employees as contributing to injuries more than climbers while for-profit employees tend to see this responsibility belonging primarily to climbers. The reason for this difference in perception is still open to speculation; however I believe that it mostly lies in the difference between program format and the general degree of autonomy for participants in these two program types. For-profit climbing programs typically offer more autonomous activities, and university programs tend to be more structured.

Before moving into the summarization of data and formation of recommendations, it is important to recognize that the models, upon which the surveys are based, may be missing events which contribute to injury. Because the models could be missing potential factors, the survey asked respondents to list events or conditions which may contribute to injury but were not available as a choice in the survey options.

Below is a list of write-in responses which respondents felt contribute to injury but were not available as choices in the survey.

Write in responses for conditions which may contribute to injury

- Facility policy too lengthy to remember
- Survey difficult to complete
- Age and lack of practice
- Route difficulty
- Human error
- Climbing beyond known abilities
- Improper climbing technique
- Horseplay while climbing
- Lack of familiarity with specific belay devices
- Climber unaware of own physical limitations

After reviewing these comments, I felt that the majority were intended to provide clarity, or specify the nature of events that were described more generally in the survey. It is acknowledged in the limitations section of this report that respondents may be responding to the questions in the survey with a different understanding of the events, than that which underlies the models. None of the write-in comments stated or seemed to imply strong disagreement with the options provided in the survey; these were suggested as additions. High response rate and a low rate of erroneous survey completion seem to imply general agreement with the survey options. In the following chapter, I acknowledge that the models I have created may not be applicable to all climbing facilities in a specific way. However, the process of fault-tree construction and survey research are useful tools to be used for understanding and aligning employee perceptions. I suggest that this study be used as a process for conducting risk management research and that the data collected in this study is useful as a baseline for future research.

Summary

Recognizing that there are some significant differences in the perception of safety factors among climbing staff implies that some portion of staff may not be making the best decisions to support safe operations. It would seem that more sharing of information and supervision of less experienced employees would be prudent to increase safe climbing in the agencies that participated in this study. The current method for understanding and preventing future accidents is to analyze incidents that occurred in the past and then attempt to figure out why they happened. While this approach is useful for understanding why accidents happen, it seems to omit the internal perceptions of the people involved as a contributing factor. The strength of this research is that it seeks to understand the perceptions of climbing professionals before accidents happen in the hope of identifying incongruities that may lead to accidents and injuries. Although it is difficult to regulate participant actions, studies like this one, which strive to understand what is happening before accidents happen, may be useful in improving safety policies and contribute to greater safety within the climbing industry.

Chapter V: Discussion

In this chapter it is my intent to deliver the most applicable and significant points of learning that I gained through the process of completing this research. In hoping to communicate what I have spent the last nine months developing, it seemed most useful to divide my conclusions into a review of what I have learned, and suggestions for looking forward, through a new lens, at a method for aligning employee perceptions and reducing organizational hazards. I feel a responsibility to recognize that the models presented in the research may not be applicable for every agency. Differences in program structure, equipment, and facility design may present potential events different from those in my models, which contribute to injury; thus reducing the usefulness of the specific responses recorded in my research. In recognition of these limitations I feel that this research has potential as a tool for identification of differences in perceptions about the conditions which lead to injury. In the looking forward section of this chapter I describe methods for potential applications of this research as an assessment tool for the identification and analysis of perceptions about the conditions that contribute to injury. Identifying this information in organizations may lead to more alignment in perceptions through sharing of information about varied environmental factors and their potential to contribute to injury.

In Review

During the research and data collection for this study I gained awareness of the need for shared incident statistics throughout the climbing community. All of the agencies I worked with agreed that the climbing industry would benefit from a shared set of accident data, but that a recognized source of this data does not exist. Reasons for the lack of this data were centered on the points of: people are afraid to share internal accident information, data collection is too varied, and there is no place to send or share data that is convenient and affordable for everyone. Analyzing industry wide data on accidents would allow best practices to be developed and the identification of trends in technique and equipment use, which may contribute to a greater occurrence of accidents. The Association for Challenge Course Technology (ACCT) collects data about equipment specifications, and recommends risk management and operational policies for use as the industry standard. This organization is considered to be one of the top regulatory standards for ropes courses and climbing gyms. Although ACCT does help to establish best practices, they do not have an interactive data collection program which would allow for ongoing research of accident factors.

The Wilderness Risk Management Conference (WRMC) is another agency that works to improve climber safety. WRMC collects incident data for outdoor climbing, ropes courses, and many other adventure recreation activities. They have developed a standardized reporting form that allows for better analysis of data and is available for not cost to any agency that wishes to contribute data. The WRMC incident reporting form is a relatively new initiative and depends on independent reports to be submitted voluntarily for data gathering. The report was designed to be used across all adventure industry activities and is intended for use primarily in a wilderness environment. The WRMC report asks people to identify objective conditions which seem to have contributed to injury and then write a short narrative about the situation. This approach lacks analysis of the interaction between events, and does not allow for sharing of perceptions about which factors contribute to accidents more than others.

The strength of the methodology used in this research is in the potential to develop increased understanding about the differences in perception of accident factors among employees. Alignment of perceptions about environmental factors may lead to greater consistency in application of risk management actions and maximization of best practices. People view things differently, based on their experiences and perspective. There are certain conditions which are more likely to contribute to accidents than others. Experience teaches which conditions need to be watched more closely, but accident prevention should not rely on preventing only those accidents that have occurred before and are now better understood. In his article *Human Nature Prepares for a Momentous Leap,* Graves, et.al. write

> A new psychological theory holds that human beings exist at different 'levels of existence.' At any given level, an individual exhibits the behavior and values characteristic of people at that level; a person who is centralized at a lower level cannot even understand people who are at a higher level
>
> (Graves, et.al., 1974, p.1)

This difference in perception may lead to inconsistency in safety practices and greater error. Graves' research shows that people at different levels of human development are unable to perceive environmental conditions in the same way. Because people perceive their environments differently, risk management must develop employees to perceive events in the most appropriate manner to ensure that they may respond effectively when accident potential is high.

> An individual can respond positively only to managerial principles appropriate to that person's level of existence, or psychology, and will respond negatively to a managerial style not appropriate to the level (Graves, 1970, p.2).

The significance of Graves work is that because people have varied perceptions, managers need to understand what employees perceive and then provide guidance on how to move from the existing, assumedly erroneous, perception to the desired perception. Using research like fault-tree analysis and surveys can provide managers with information about employee perceptions, while simultaneously providing the means by which perceptions can be aligned. Using this method to gather data to determine differences in perception also provides information which can be used to reduce these differences. The following section in this chapter describes recommendations for using this methodology as an organizational learning tool.

Looking Forward

It is possible that more injuries are occurring in the climbing industry than the public is aware of. Forty percent of the respondents in this survey reported that they had witnessed a climbing injury. This statistic far exceeds the rate of occurrence that is accepted as the standard for climbing related injuries. Reducing differences in perception about the occurrence of and contributing factors for accidents is a key process in improving the safety for climbing providers. A method is needed to teach awareness of how accidents happen and how to prevent them. I propose that agencies use the process and models I have described in this study as a template for developing their own fault-tree models.

Following the specific rules of creating a Fault Tree Model is not as important as completing the process with participation from all employees related to maintaining safe operations. The activity should be described as an attempt to create common understanding about environmental factors within the climbing facility. The process should emphasize understanding of relationships between factors without attempting to place blame. Managers could use my models as a baseline which was added to or revised; or develop completely new models to analyze other aspects of their organizational environment. Training like this would provide the opportunity to teach less experienced employees about predictable and random occurrences that contribute to injury. Approaching this training through the creation of a model allows employees to understand the interaction between conditions, how the interaction contributes to accidents, and how to interrupt interactions to prevent accidents. This type of training is also useful in its ability to inform managers about possibly incorrect perceptions of employees which they may not ask about, or realize to be incorrect. Using this process as a training tool facilitates greater understanding about accident factors, through interaction and personal analysis. The final sections of this chapter describe conclusions of my research and recommendations for improving safety within climbing facilities.

Conclusions

- The probability that the events listed in the fault trees will contribute to injuries at climbing centers will vary within specific climbing organizations based upon the characteristics of the business and its participants.

- Of the injuries recorded in the Alpine Towers study and the factors identified in this research on artificial climbing structures 75%-90% of injuries result from climber actions, 10%-20% are related to belaying, and 1%-5% are related to equipment failure
- Research collected during this study suggests that many injuries related to artificial wall climbing are due to factors that are not directly associated with climbing, for example, horseplay, tripping while walking, or weather related injuries.
- Of the injuries that are directly related to ascending and descending a climbing route, climber error is the event most likely to result in human injury
- The risk management guidelines examined in this report seem to demonstrate that injury prevention actions and policies within this industry are primarily focused on staff behaviors, when it would seem that directing more attention to participant behaviors would be more effective for reducing climbing related injuries.
- Data on the total number of injuries per hour of participant exposure related to artificial structure climbing suggest that the sport is quite safe in comparison to other extreme sports and that artificial structure climbers have a low probability of experiencing a serious injury.
- Increases in the number of people that participate in top rope belayed climbing are likely to be accompanied by increases in the number of injuries experienced by participants.

- Analysis and identification of factors that are perceived to contribute to injuries in this sport will be useful for reducing or preventing human injuries and related liability claims
- Understanding the perceptions of employees, and the way these perceptions may contribute to accidents, may be under-used as a method for increasing safety.

Recommendations

The following recommendations for improving safety and risk management policies for permanent structure, man-made, human operated, top rope belayed climbing systems are based upon data collected during this study.

- The process of conducting fault tree analysis can be used by climbing experience providers as a valid method of internal analysis for identification of undesired events in their facilities.
- Climbing experience providers should provide and/or require more training for participants about how to reduce overuse, and other types of climber generated injuries.
- When participants demonstrate a tendency to not follow safety guidelines, the actions should be documented for legal purposes, and the participant should be removed from the facility or sanctioned with immediacy.
- Because most belay related injuries are believed to be caused by some type of complacency, refusal, or inability to follow facility procedures for belaying, belay training and operation should be standardized, and regularly tested or inspected.
- Artificial structure climbing facilities should record the types of random occurrence injuries that are happening in their facilities, and make generalizations

about their causes. This analysis should lead to understanding characteristics of facility policies that may not be visible otherwise. Identification of these characteristics should lead to policy revision and reduction of injuries and contributing factors.

- More information should be shared between climbing agencies about safety policies and best practices for maintaining successful safety records.
- National or regional standards should be developed to regulate and ensure appropriate safety practices among climbing provision agencies.
- The majority of base events in the fault trees can be attributed to complacency or simply not following policies. In order to decrease this occurrence, managers should place a higher emphasis on ensuring that staff and participants are following policies, and rotating staff duties to help prevent boredom and related decreased awareness problems.
- In facilities where participants are allowed to belay, regular retraining and retesting should be a part of the risk management program regardless of experience level.
- The level of predicted complacency in trained staff indicates that allowing participants to belay themselves without supervision or thorough training may be unnecessarily risky.
- Gathering more data using models similar to those used in this study will be useful for establishing a base line of perceptions about the factors which are most perceived as contributing to injury.

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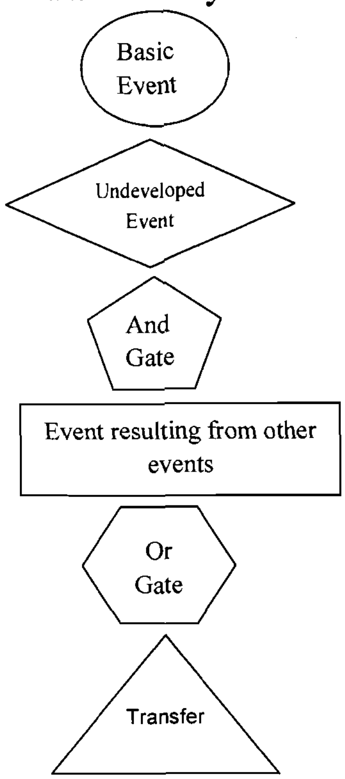
Appendix A: Fault Tree Diagrams

The below listed symbols will be used to create fault trees for the purpose of analyzing the belay and safety procedures used by the facilities described in this report.

Fault Tree Symbols



Basic events represent causes and events that inherently result in system failure

Undeveloped events represent events where the causes are not developed further

And Gates connect events which must all occur in order to result in the following event

An event box represents events resulting from other events and primary events

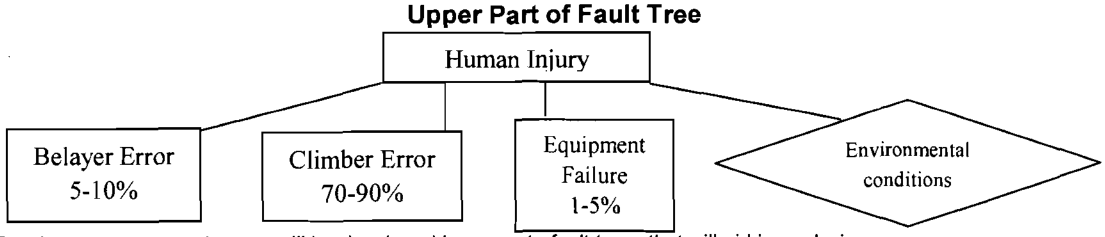
Or Gates connect events of which any could occur which would result in the following event

Transfer symbol represents events resulting from a lower order event which transfers to a higher order event in a non sequential manner

It should be noted that because the system being analyzed is largely comprised of human behaviors, this fault tree will be more simplified than typical applications for which this method of analysis is tradtionally used. Simplification should not be assumed as limited or incomplete analysis of the system characteristics

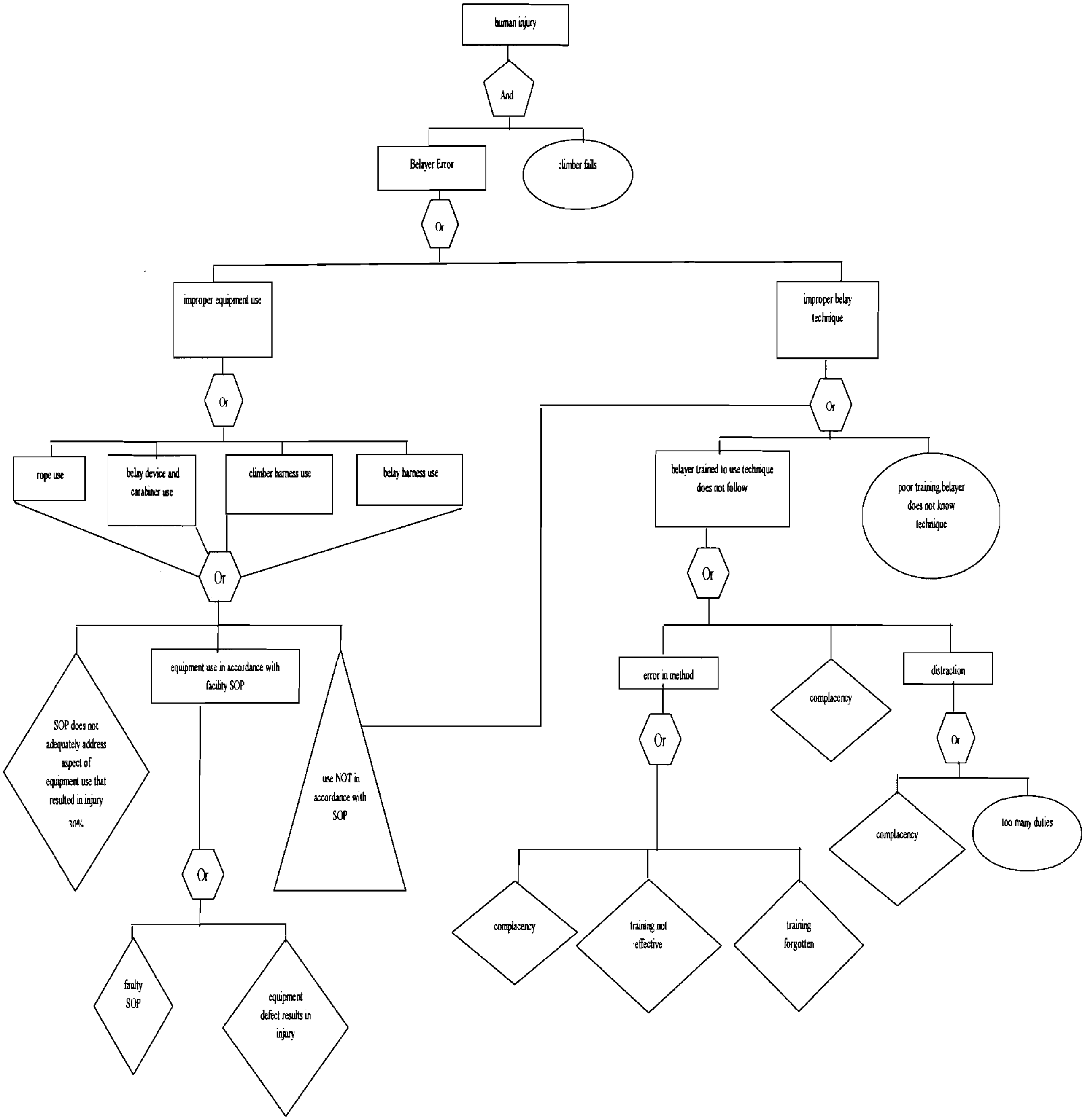
This report will develop the potential causes that would result in human injury during normal operating procedures for climbing and belaying on an artifical climbing wall. There are three sources of potential system failure; they are belayer error, climber error, and equipment failure. Failure at any one of these system levels would be consider a primary system error because any of these events alone would result in the occurrence of the top event

Upper Part of Fault Tree

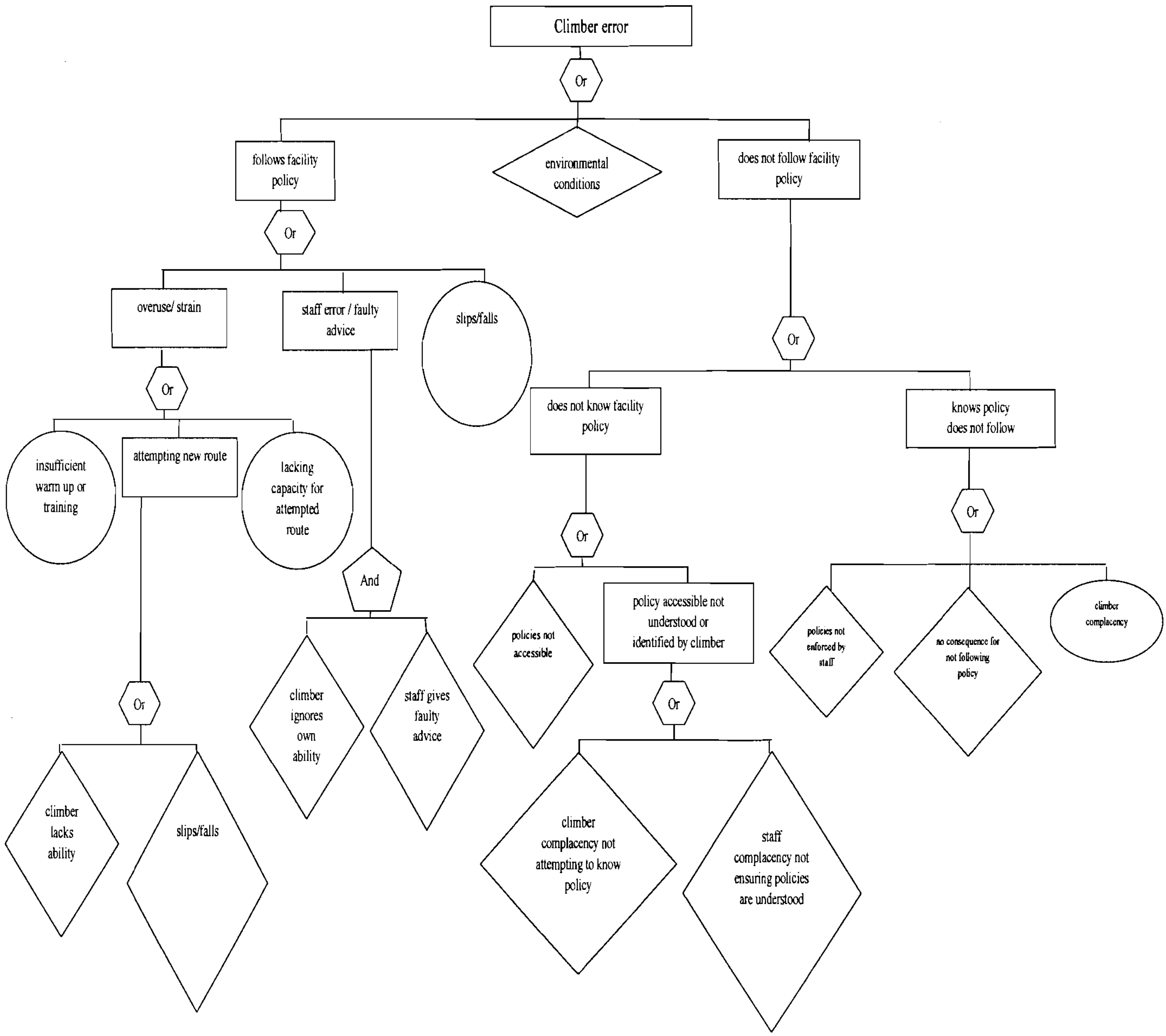


The three system event errors will be developed in separate fault trees that will aid in analysis which results in the potential for reduction or elimination of these errors. The event of environmental conditions represents the understanding that factors outside of the physical limits of the climbing facility and/or human actions caused through intention or negligence could result in injury but are typically too random to control, for example, the weather. Environmental conditions require more analysis than is appropriate for the scope of this report and will not be analyzed further within this report.

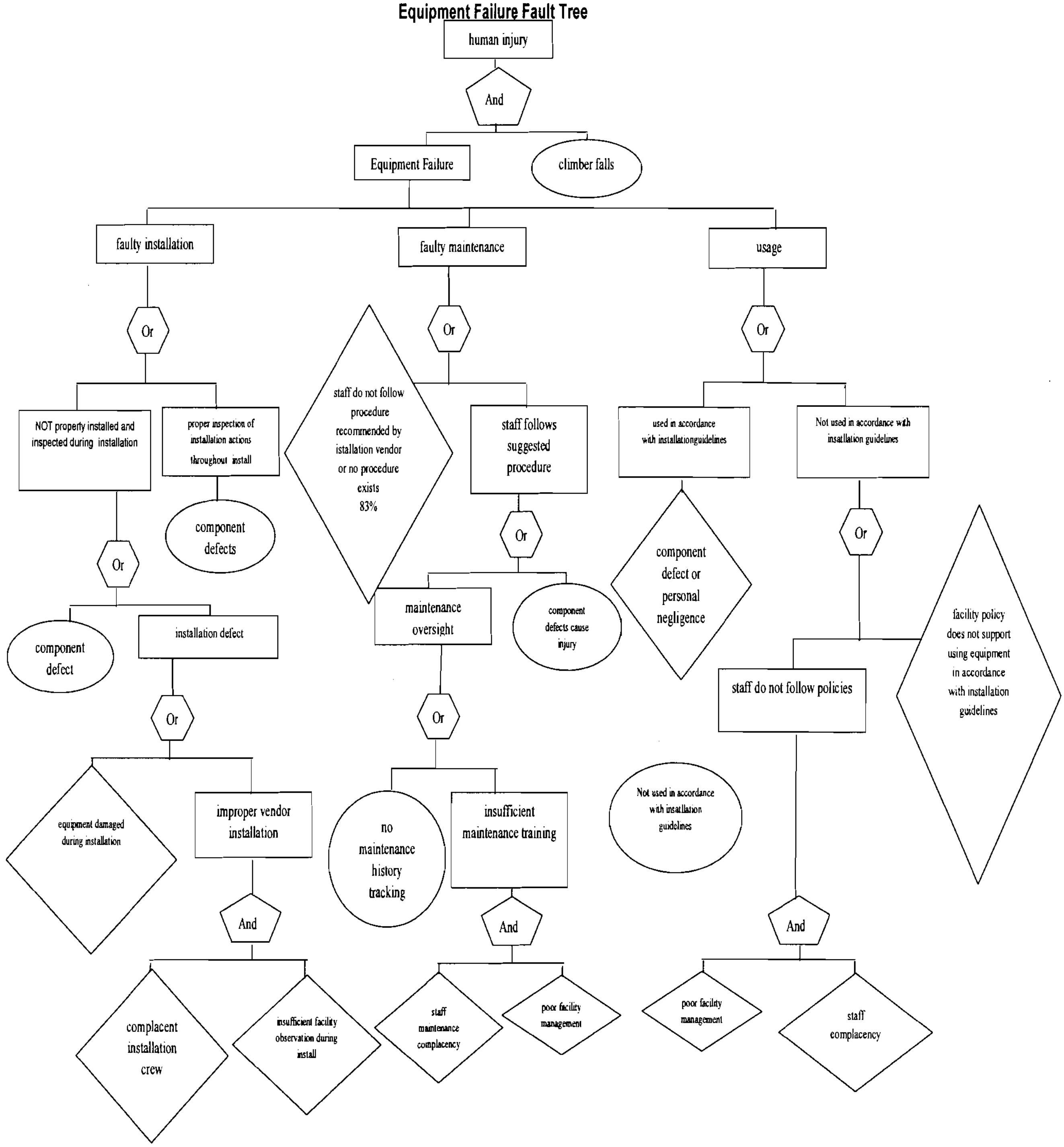
Belayer Error Fault Tree



Climber Error Fault Tree



Equipment Failure Fault Tree



Appendix B: Survey Instrument showing study group responses and Consent Form

This research has been approved by the UW-Stout IRB as required by the Code of Federal Regulations Title 45 Part 46.

This survey is being conducted for the purpose of identifying the perceptions of ropes course and climbing wall professionals, about the conditions that are related to human injury on stationary, artificial structure, top-rope belayed climbing systems.

This data will be used to make recommendations for revisions in climbing facility policies based on the perceptions of professionals that operate these systems. The data is being collected in conjunction with the researcher's completion of the requirements for a Masters Degree in Training and Development at the University of Wisconsin Stout. The survey asks you to make estimates about the conditions that are related to injury during the use of these climbing systems.

The statements you are evaluating in this survey were developed in a previous study which identified the conditions that contribute to injury on stationary, artificial structure, top-rope belayed climbing systems. In this phase of my research I am gathering the perceptions of professionals who work with this equipment. By collecting the perceptions of many professionals I may be able to validate the conclusions developed in my earlier research, and use this data to make recommendations on how to prevent and reduce injuries related to the use of these types of climbing facilities.

In appreciation of your efforts to complete this survey, you are entitled to a copy of the research findings of this study when it is finished. You may contact the researcher by email or phone at: barkert@uwstout.edu or 715-232-5623

There are three terms in this survey that may require clarification. Please use the following definitions for the below listed terms while completing this survey.

Complacency- refers to acts of negligence or carelessness of responsibility that are due to attitudinal or other similar conditions

Facility Policies- refers to all staff and participant policies that are intended to guide the use of equipment and facilities

Distraction- temporary loss of attention in an otherwise attentive person

Overuse- injuries related to excessive bodily wear and tear due to climbing

Back ground information

1. What is the name of the facility where you work? ______________________________

2. How much experience do you have working with artificial structure top-rope belayed climbing systems? (circle your answer)

   0-6 months 6-12 months 1-3 years 3-5 years more than 5 years

3. Have you ever witnessed an injury on an artificial structure top-rope belayed climbing system?
   Yes **No**

4. What is your level of responsibility at the place where you work with artificial structure top-rope belayed climbing systems? (circle your answer)

   Manager/Supervisor Owner Employee/Belayer

This survey asks you to assign percentages to the conditions that contribute to injury on artificial structure, top-rope belayed climbing systems. These conditions have been categorized into the three areas of: belayer error, equipment failure, and climber error. I have left out environmental conditions like weather, horseplay on the ground, and other random occurrences that can not be consistently anticipated.

To the right of the below listed statements there are 2-4 choices for you to choose from to make estimates of the probability for each condition which is related to injury. Divide a total of 100 points between all of the conditions for each statement. The greater the likelihood for a choice that you feel contributes to injury, the larger a portion of the 100 percent you should assign to that choice. Use whole numbers only, no fractions please. Write your estimate of percentage on the blank line to the left of each statement.
Be sure to write a number on every blank line in the row to the right of each numbered statement.

Belayer Error- The statements in the left column refer to actions taken by a belayer that contribute to climber injury

	Use the choices in the rows below to make estimates for the probability that these conditions relate or contribute to injury **Estimate the percentage for the conditions related to the statements on the left, with the total of all estimates in each row equaling 100.**			
1. When belayer error contributes to injury this can be attributed to two conditions. Estimate the percentage for each condition.	__20___ Equipment use		_80____ Belay technique	
2. Improper equipment use by belayers potentially involves four types of equipment. Estimate the probability for misuse which results in injury for each piece of equipment	__15___Rope	_40____ Belay device	__20___ Climber harness	_10__ Belayer harness
3. Improper belay technique can be attributed to two conditions. Estimate the percentage for each condition.	__60___ Belayer was properly trained and does not follow belaying technique		_40___ Belayer was not properly trained and does not know belaying technique	
4. When belayers are properly trained, yet do not follow proper belaying technique, this can be attributed to three conditions	__34___ Belayer complacency	__20_ Error in belay method	__35___ Belayer distraction	
5. When belayer error results from distraction, this can be attributed to two conditions.	__70___ Belayer complacency		_30____ Too many duties	
6. When belayer error results from an error in belay method, this can be attributed to three conditions.	__50___ Belayer complacency	__20___ Training forgotten	__20__ Training not effective	
7. When climbing injuries are related to improper use of belaying equipment (rope, belay device, harnesses) this can be attributed to three conditions	_5____ Belayer is using the equipment in accordance with facility policies	__80_ Belayer is not using the equipment in accordance with facility policies	_10__ Facility policy does not address the use of equipment in the situation that resulted in injury	
8. When climbing injuries are related to equipment use that is not in accordance with facility policy this can be attributed to two conditions.	__75___ Belayer was properly trained and does not follow facility policy		__25__ Belayer was not properly trained and **does not know** facility policy	
9. When climbing injuries are related to belayers use of equipment that is in accordance with facility policy this can be attributed to three conditions	_10___ Facility policies support improper use of equipment	_13____ Equipment defect is responsible for injury	_60____ Climber actions are responsible for injury	

Equipment failure- This set of statements refers to the conditions that contribute to injury which are related to the failure of equipment.			
	Use the choices in the rows below to make estimates for the probability that these conditions relate or contribute to injury **Estimate the percentage for the conditions related to the statements on the left, with the total of all estimates in each row equaling 100.**		
1. When climbers are injured as a result of equipment failure this can be attributed three conditions. Estimate the percentage for each condition.	__10___ Faulty installation	_31.5____ Faulty maintenance	__45__ Faulty usage
2. When climbers are injured as a result of equipment failure that is due to faulty installation this can be attributed to two conditions. Estimate the percentage for each condition.	__20___ Equipment failed after being properly installed and inspected	_80____ Equipment failed after **not** being properly installed and inspected	
3. When climbers are injured as a result of equipment failure that was not properly installed **and** inspected this can be attributed to two conditions.	__20___ Equipment failed as a result of component defect	__80___ Equipment failed as a result of faulty installation and/or inspection	
4. When climbers are injured as a result of equipment failure that is due to installation defect, this can be attributed to two conditions	_30____ Equipment failed due to being damaged during installation	_70____ Equipment failed due to being improperly installed	
5. When climbers are injured as a result of equipment failure that is due to faulty maintenance, this can be attributed to two conditions	__10___ Facility maintenance procedures are followed by staff	_90____ Facility maintenance procedures are not followed by staff	
6. When climbers are injured as a result of equipment failure that occurs while maintenance procedures **are** followed by staff this can be attributed to two conditions.	__60___ Oversight during maintenance	_40____ Equipment failed as a result of component defect	
7. When climbers are injured as a result of equipment failure that occurred due to maintenance oversight this can be attributed to two conditions.	__50___ Facility maintenance training for staff is inadequate	_50___ Inadequate maintenance records do not support accurate tracking of maintenance issues	
8. When climbers are injured as a result of equipment failure that is related to usage this can be attributed to two conditions.	__10___ The equipment was used in accordance with facility policies	_90____ The equipment was **not** used in accordance with facility policies	
9. When climbers are injured as a result of equipment failure that is related to equipment usage that is **not in accordance** with facility policies this can be attributed to two conditions	_80____ Staff do not follow policies for equipment usage	__20___ Facility polices support the use of equipment in the manner that contributed to the injury	

Please use the space below to describe any conditions which may contribute to climber injury that you feel are not represented in this survey. ____

____

____

____

Climber error- This set of statements refers to actions taken by climbers that contribute to their own injury.			
	Use the choices in the rows below to make estimates for the probability that these conditions relate or contribute to injury **Estimate the percentage for the conditions related to the statements on the left, with the total of all estimates in each row equaling 100 percent.**		
1. When climber actions result in injury of the climber this can be attributed to two conditions. Estimate the percentage for each condition.	__20___ Climber was injured while following facility policies	__80_ Climber was injured while not following facility policies	
2. When climbers are injured while following facility policies this can be attributed to three conditions. Estimate the percentage for each condition.	__40___ Overuse injuries	_40____ Staff or belayer error	__10___ Equipment malfunction
3. When climbers are injured while not following facility policies this can be attributed to two conditions.	__40___ Climber does not know facility policies	_60____ Climber knows facility policies and does not follow them	
4. When climbers are injured due to overuse, too much climbing, this can be attributed to three conditions.	__40___ Insufficient warm up prior to climbing	__25___ Injury was due to climbing a new route on which the climber was unfamiliar	_33____ Injury occurred because the climber lacked the ability to complete the attempted route
5. When climber injuries are due to climbing an unfamiliar route this can be attributed to two conditions	__50___ Climbers lack of ability caused the injury	__50___ Climber simply fell or slipped which resulted in injury	
6. When climbers are injured while not knowing facility policy this can be attributed to two conditions. .	__30___ Facility policy is unavailable	__70___ The policy is available but not understood	
7. When climbers are injured with facility policies that are available but not understood, this can be attributed to two conditions.	__50___ Climber complacency	_50___ Staff complacency	
8. When climbers are injured while knowing facility policies but not following these policies this can be attributed to three conditions.	__33_ Staff are not enforcing policies	_30_____ Consequences for not following polices are perceived as insignificant	_33_____ Climber complacency

Please use the space below to describe any conditions which may contribute to climber injury that you feel are not represented in this survey. ____

____

____

____

Thank you for completing this survey

Implied Consent Statement for Research Involving Human Subjects

Title: *Analysis of factors which contribute to injury on artificial climbing structures*

Investigator:
Timothy Barker
Ph# 715-232-5623
Email: barkert@uwstout.edu

Research Sponsor:
Kat Lui
Ph# 715-232-5634
Email: luik@uwstout.edu

Description: The objective of this study is to identify the characteristics of artificial structure, top-rope belayed, climbing systems that contribute to human injury. In the initial phase of this project, the researcher used Fault Tree Analysis to develop diagrams which display conditions that contribute to human injury in these systems. In this phase of the study, validation of the original research is being conducted through surveys which asks respondents to estimate the probability for the events which contribute to injury.

Risks and Benefits: There is some risk to the survey respondents being identified and held responsible for having participated in a study that resulted in changes being made within their job or facility where the respondent works or climbs. Misunderstandings about data in this study which describe events that contribute to injury could be used to justify unfounded or experimental changes to existing safety systems which could result in injury.

This research seeks to identify gaps in the safety and risk management policies of artificial structure climbing systems. Analysis of these gaps and identification of events that contribute to human injury in these systems can result in fewer injuries to climbing system participants and fewer liability claims filed against artificial climbing system providers.

Special Populations: This research does not involve data collection from any special populations. **If you are under 18 years of age and have been given this survey, do not complete this survey.**

Time Commitment: This survey should take no more than 10 minutes to complete.

Confidentiality: Your name should not be included on any documents. You can not be identified from any of this survey information.

Right to Withdraw: Your participation in this study is entirely voluntary. You may choose not to participate without any adverse consequences to you. However, should you choose to participate and later wish to withdraw from the study, there is no way to identify your anonymous document after it has been turned into the investigator.

IRB Approval: This study has been reviewed and approved by The University of Wisconsin-Stout's Institutional Review Board (IRB). The IRB has determined that this study meets the ethical obligations required by federal law and University policies. If you have questions or concerns regarding this study please contact the Investigator or Advisor. If you have any questions, concerns, or reports regarding your rights as a research subject, please contact the IRB Administrator

IRB Administrator
Sue Foxwell, Director, Research Services
152 Vocational Rehabilitation Bldg. UW-Stout
Menomonie, WI 54751
Ph# 715-232-2477 Email: foxwells@uwstout.edu

Statement of Consent: By signing this form you agree to participate in the project entitled *Analysis of factors which contribute to injury on artificial climbing structures*

***Signature*____ *Date*______________**

Appendix C: Original Fault Tree Validation by Experts in Phase One of the Study

Task Analysis Data Summary

Belayer Error			
Belayer Error	20,35,40	equipment use	m=32
	80,65,60	belay technique	m=68
improper equipment use	1,30,20	rope	m= 17
	10,50,60	belay device	m=40
	90,10,10	climber harness	m=37
	1, 10,10	belayer harness	m=7
improper belay technique	50, 80,70	trained does not follow	m=67
	50,20,30	poor training not know	m=33
trained properly does not follow	75,80,20	complacency	m=58
technique	15,15, 30	error in method	m=20
	10, 5, 50	distraction	m=22
distraction	20,80,40	complacency,	m=47
	80,20,60	too many duties	m=53
error in method	20,60,40	complacency	m=40
	40,30,30	training forgotten	m=33
	40,10,30	training not effective	m=27
faulty use of rope, belay device,	30,80,70	use not in accordance	m=60
climber harness, belayer harness	1, 20,10	use in accordance	m=10
	70,1,20,	training not address	m=30
use not in accordance with SOP	50,80,70	trained does not follow	m=67
	50,20,30	poor training not know	m=33
use in accordance with SOP	50,90,70	faulty SOP	m=70
	50,10,30	equipment defect	m=30

Climber Error			
Climber injury	90,10,20	follows policy	m=40
	10,90,80	does not follow policy	m=60
Climber follows facility policy	70,10,45	overuse	m=42
	5,60,20	staff error	m=28
	25,30,35	random occurrence	m=30
Climber does not follow policy	10,50,30	Does not know policy	m=30
	90,50,70	Knows policy does not follow	m=70
Overuse	35,30,40	insufficient warm up	m=35
	5, 30,30	attempting new route	m=22
	60,40,30	lacks capacity	m=43
Injured attempting new route	95,50,60	lacks ability	m=68
	5, 50, 40	climber falls	m=32
injured not knowing policy	99, 30,25	policy not available	m=51
	1, 70, 75	policy available not understood	m=49

policy available not understood	40,50,70	climber complacency	m=53
	60,50,30	staff complacency	m=47
Climber knows policy does not follow	33,40,20	staff not enforcing	m=31
	30,60,30	no consequence for non compliance	m=40
	33, 0, 50	climber complacency	m=28
Equipment Failure			
Equipment Failure	1, 10, 50	faulty installation	m=20
	80, 60 ,30	*faulty maintenance*	m=57
	20, 30, 20	faulty usage	m=23
Faulty installation	1,5,10	properly installed and inspected	m=5
	99, 95,90	not properly installed and inspected	m=95
Not properly installed	50,80,30	component defect	m=53
and inspected	50, 20, 70	installation defect	m=47
Installation defect	90, 10, 30	damaged during installation by other	m=43
	10, 90, 70	negligent installtion	m=57
Faulty maintenance	90,80,80	staff does NOT follow vendor maint. procedure	m=83
	10, 20,20	staff does follow vendor maint. procedure	m=17
Staff does follow vendor	95,80,80	maintenance oversight	m=85
maint. procedure	5, 20,20	component defect	m=15
Maintenance oversight	50,10,40	no maint.records	m=33
	50,90,60	insufficient maint. training	m=67
Faulty usage	10,20,20	used in accordance with installation guidance	m=17
	90,80,80	NOT used in accordance with installation guidance	m=83
NOT used in accordance	50,50,60	staff do not follow guidelines	m=53
with installation guidance	50,50,40	facility policy does not support use in accordance with guidelines	m=47

Appendix D: Response Agency Locations