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A Retrospective Study of Amusement Ride Restraint and Containment Systems: Identifying Design Challenges for Statistically Rare Anthropometric Cases

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A RETROSPECTIVE STUDY OF AMUSEMENT RIDE RESTRAINT AND CONTAINMENT SYSTEMS: IDENTIFYING DESIGN CHALLENGES FOR STATISTICALLY RARE ANTHROPOMETRIC CASES

by

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ABSTRACT

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Paula M. Stenzler
Old Dominion University, 2016
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The intent of this project was to conduct a retrospective study of amusement ride restraint and containment systems' failures to identify the challenges associated with existing design criteria to safely accommodate statistically rare groups that fall outside amusement industry standards. Innovations in ride technology provide an opportunity for injuries to occur if restraint and containment systems cannot properly accommodate unique patron anthropometry. It is paramount to understand how anthropometric features contribute to the patron's ability to defeat ride restraint and containment systems. A systemic perspective was used based on industry accident data to frame the problem associated with restraint and containment systems failures. This project examined how ergonomics, applied across anthropometric characteristics, affected guest safety, how cognitive ability influenced patron judgment, and how non-compliant patron behavior increased the risk for injuries. This retrospective study governed data management efforts that collected, organized, and evaluated accident data which yielded measures for patron characteristics, ride features and accident events. A design methodology was developed that incorporated statistical tests that established group differences between the project accident data and industry control data. Chi-square and Fisher's Exact Tests were used to determine statistical significance for ride and patron categorical variables. Independent tests for physical limitation, cognitive ability and behavior showed a positive association for type of failure mode. A Kruskal Wallis non-parametric test for the mean age across ride types was performed that showed a positive association. A logistical regression model was constructed combining predictor dummy variables for anthropometric mismatch, diminished capacity and behavior for the binary dependent variable for not-secured or ejection/fall failure mode. The outcome of this project produced retrospective statistical data and provided a forcing function design guidance matrix to overcome amusement ride restraint and containment design challenges associated with unique patron anthropometry.

This Doctoral Engineering Project is dedicated in memory of my parents
Angela and Robert.

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There are many people who have contributed to the successful completion of this doctoral project, and I extend my sincere gratitude to my internal and external committee members, my colleagues, friends, and most of all – my family.

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And finally, words cannot express how blessed I am to have three wonderful children who are always there for me and for the love and support I get every day without fail from them. *Thank you, Sonja, Michael, and Rachael.*

NOMENCLATURE

AIMS	Amusement Industry Manufactures' Association
ANOVA	Analysis of Variance
ASO	Amusement Safety Organization
ASTM	American Society of Testing and Materials International
CDC	Center for Disease Control
CPSC	Consumer Product Safety Commission
DDI	Data Documentation Indicatives
DIN	German Institute of Standardization
DMP	Data Management Plan
EN	European Norm
FET	Fisher's Exact Test
HFE	Human Factors Engineering
HSE	Health & Safety Executive
HSL	Health and Safety Laboratory
IAAPA	International Association for Amusement Parks and Attractions
ISO	International Standards Organization
NAARSO	National Association of Amusement Ride Safety Officials
NAFLIC	National Association for Leisure Industry Certification
NAPHA	National Amusement Park Historical Association
NCHS	National Center for Health Statistics
NEAPA	New England Association of Amusement Parks and Attractions
NEISS	National Electronic Injury Surveillance System

NJAA	New Jersey Amusement Association
NGO	Non-government Organization
NSC	National Safety Council
NSGA	National Sporting Goods Association
NSRF	National Standard of Russian Federation
OABA	Outdoor Amusement Business Association
ODU	Old Dominion University
RCS	Ride Control System
R²CS©	Ride Restraint and Containment Systems
TSSA	Technical Standard Safety Authority Canada
TUV	Technischer Überwachungsverein (translation) Technical Inspection Association
WHO	World Health Organization

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CHAPTER 1

INTRODUCTION

1.0 Introduction

Amusement rides have a long and glorified history that continues to grow in popularity. The National Amusement Park Historical Association (NAPHA) traces the first roller coaster to 15th century Russia where ice blocks were used to descend 70-ft snow laden hills. By the late 1780s the first roller coaster on wheels was built and installed in St. Petersburg, Russia. A century later the first American-built coaster was located at Coney Island in New York State, thrilling guests at a maximum speed of 6 mph. In the 1950s, Walt Disney transformed the theme park industry, and by the turn of the millennium, coasters soared over 400 feet at speeds greater than 100 mph.

Amusement rides have resulted in more complex systems to meet the public's demand for more thrilling ride experiences. As ride systems technology advances and ride systems become bigger and faster, new hazards emerge and risk mitigation strategies are implemented to ensure patron safety. However, patrons rarely consider the consequences of noncompliant behavioral interaction with amusement ride restraint and containment systems (R^2CS). Patrons assume that R^2CS are fail-safe in all situations. While amusement park accident data from the industry indicate that the chance of injury associated with restraint and containment is low (IAAPA, 2014), hazards do exist, especially for select groups with unique anthropometric features.

1.1 Background

U. S. safety standards for the amusement industry are developed and maintained by the American Society of Testing and Materials (ASTM) International. ASTM F24 nomenclature signifies the committee designation responsible for standards development for amusement rides and devices, which governs the design, manufacture, testing, operations and maintenance for ride systems safety. The ASTM F2291 design standard considers the biodynamic component of the ride design to accommodate the vast majority of the patron population; however, there is a select group of patrons that elude and fall outside industry design criteria due to unique anthropometry.

A report published by the Health and Safety Laboratory (HSL) that studied patron accidents related to amusement rides carrying passengers concluded that the lack of basic ergonomic design principles were the major contributor noted in the incident data and that the deficiencies were common across many ride types (Milnes, 2007). Additionally, the report noted that passenger age played a part in contributing to the incident but could not quantify to what degree. Other studies, such as those conducted by the U.S. Consumer Product Safety Commission (CPSC) have drawn the same conclusion (Smith, 2005).

Most rides use height as a gauge for ridership based on anthropometric data. Generally, ridership qualification is determined by height requirements based on the 95th percentile anthropometric data for adult or child physical characteristics depending on ride classification. Ridership qualification based on height does not preclude patron falls, ejection or mis-positioning on amusement R^2CS. Those at greatest risk of encountering a hazard are small children (Milnes, 2007), individuals with limitations (Saferparks, 2009c) and recalcitrant patrons (Farley, 1986). Each ride system has unique features that include size, acceleration, onset, geometry, g-forces, and moments (Mikol, 2007) that contribute to the ride experience. When combined with human factors such as age, height, weight, physical shape, emotional development, inability to assess risk and wanton behavior, the result may produce an unwanted outcome (Stenzler, 2013).

1.2 Problem Statement

The amusement industry is limited in its understanding of amusement R²CS failures associated with statistically rare anthropometry cases because of the lack of published empirical data. For this reason, advanced work to obtain data that supports a better understanding of the limitations of R²CS design to safely accommodate statistically rare anthropometric cases is of particular interest for the amusement park industry. Therefore, for this project, a retrospective study was performed to identify accident data sources, collect data, and conduct a forensic analysis to determine how 1) ergonomics applied across anthropometric characteristics affects guest safety; 2) cognitive ability influences patron judgment; and 3) wanton behavior increases the risk for injuries. Figure 1 is a visual representation of the project domain mapping that bounds the problem statement for this study.

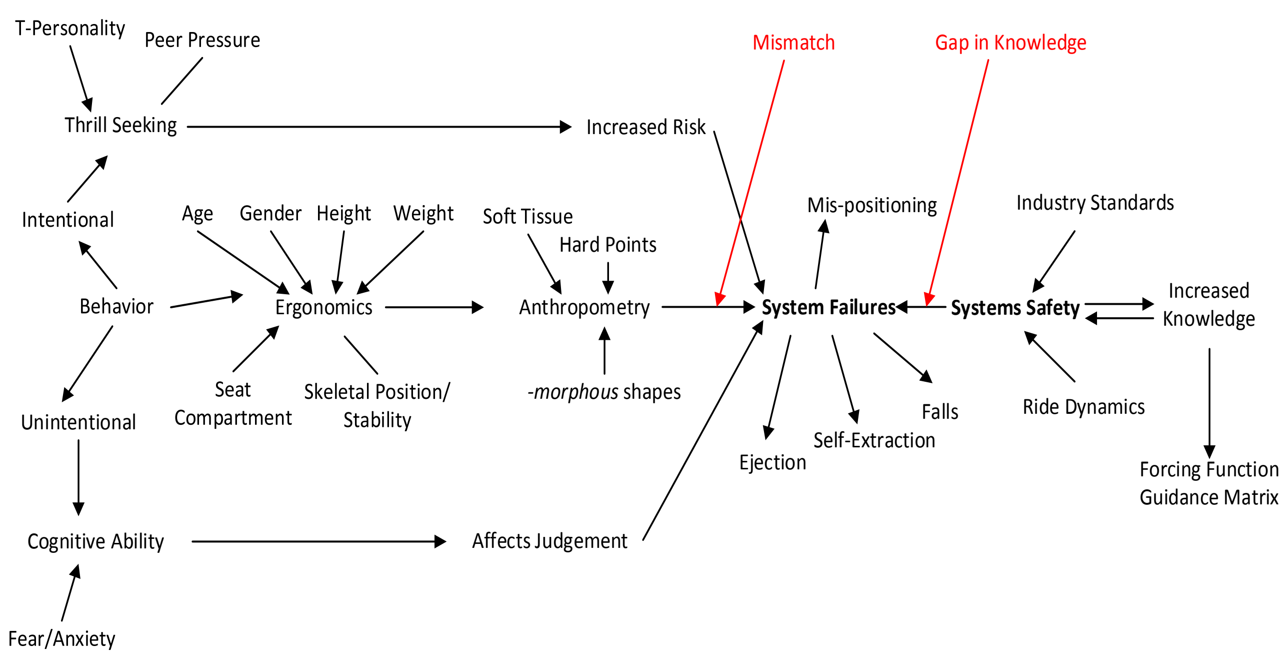


Figure 1. Project Domain Mapping of Problem Statement

1.2.1 Operational Definitions

For the purpose of this study, operational definitions for cognitive ability and wanton behavior are given to establish the boundaries of these two concepts as they pertain to this study.

1.2.1.1 Cognitive Ability

Cognitive ability assumes reasoning development widely accepted for the four development stages defined by psychologist, Jean Piaget. He categorized the four stages as sensori-motor (0-2 years), pre-operational (2-7 years), concrete operational (7-12 years), and formal operational (12-adult). Each stage serves as a critical component as part of this retrospective study. See section 2.8, *Cognitive Ability* for an in-depth operational definition.

1.2.1.2 Wanton Behavior

The term wanton, as used herein, takes on the operational meaning as defined by West's Encyclopedia of American Law (2008):

> …implies a reckless disregard for the consequences of one's behavior. A wanton act is one done in heedless disregard for the life, limbs, health, safety, reputation, or property rights of another individual. Such an act is more than negligence or gross negligence; it is equivalent in its results to an act of willful misconduct.

When the operational definition for wanton behavior is applied to the amusement industry, it refers to a patron's willful disregard of any and all warning signs, instructions, and procedures conveyed by the amusement park.

1.3 Project Description

According to industry reports, nearly all containment failures associated with amusement R^2CS fall into two categories: 1) young riders that are not able to comprehend the severe consequences and risks associated with their behavior (Milnes, 2007), and 2) patrons that purposefully engage in unsafe behavior (Smith, 2005). Although behavior can be intentional or unintentional, the outcome is the same; serious injury including death may result. While small children are likely candidates for falls, ejections and mis-positioning in amusement R^2CS, at the other end of the spectrum, adult patrons with unique –*somatotype* shapes (body shapes) are likely candidates as well.

There are three basic somatotypes based on skeletal frame and body composition. Ectomorphs' body types are long, lean, and shapeless; endomorphs have a lot of body fat and muscle and tend to be rounder in shape but not necessarily overweight; and mesomorph body types are solid and strong and offer good skeletal "hard point" connections for stability. There are also variations to the basic somatotypes which include ecto-endomorphs, pear shaped with high fat content in the hips and thighs. The inverse of the ecto-endomorph is the endo-ectomorph, an apple-shaped individual with high fat content in the mid-section and thin lower bodies. Figure 2 depicts the basic somatotype shapes and the variations.

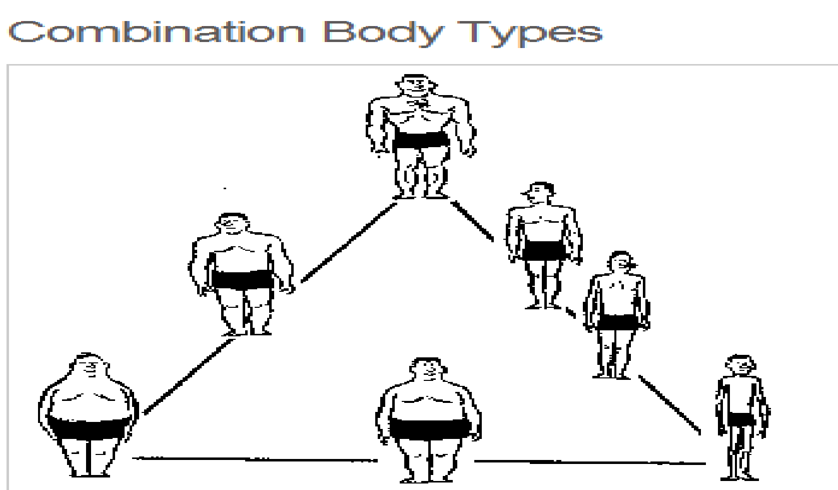


Figure 2. Classical Somatotype Shapes (Arraj, 1988)

There are a few documented studies in the public domain that identify test cases where child patrons that meet the height requirement were able to defeat restraint and containment systems due to unique anthropometric features. Ride designers have observed that it is a natural instinct for children to want to get out of containment devices even without prompting, as noted in Collins' article titled *Consider the wiggle-factor* (n.d.). Children and individuals without a certain level of cognitive reasoning cannot comprehend the risks associated with their actions; thus, extra measures are required to prevent willful patron extraction. Likewise, there are opportunities for patron mis-positioning that can lead to a fall or ejection. Therefore, a systems design solution is required to prevent a containment environment that allows for mis-positioning, ejection or extraction.

1.4 Method and Procedure

Since amusement R^2CS failures are rare and investigative secondary data were inconsistent and lacking in the public domain, the phenomenon and root cause is not very well understood, but some event indicators captured by various sources offered insight for the execution of this retrospective study. Therefore, the first phase of this study focused on data selection strategies to assure quality data collection and to avoid introducing bias into the study.

The second phase of this project performed comparative tests as part of the forensic analysis using existing industry data as a control to determine if significant differences exist for the R^2CS data and relational analyses to identify trends, relationships, patterns, and themes. The objective of the forensic phase of the project was to provide better understanding of R^2CS failures related to cognitive ability, behavior motivations, and patron anthropometry based on accident data and exposure data. Since there may be several contributors related to design deficiencies associated with amusement R^2CS failures, it is important to examine failures by evaluating the whole system. The forensic analysis considered how systems are used, the operational environment, the technologies employed and the emergent behavior of the systems integration.

Figure 3 identifies the block flow diagram of the design methodology.

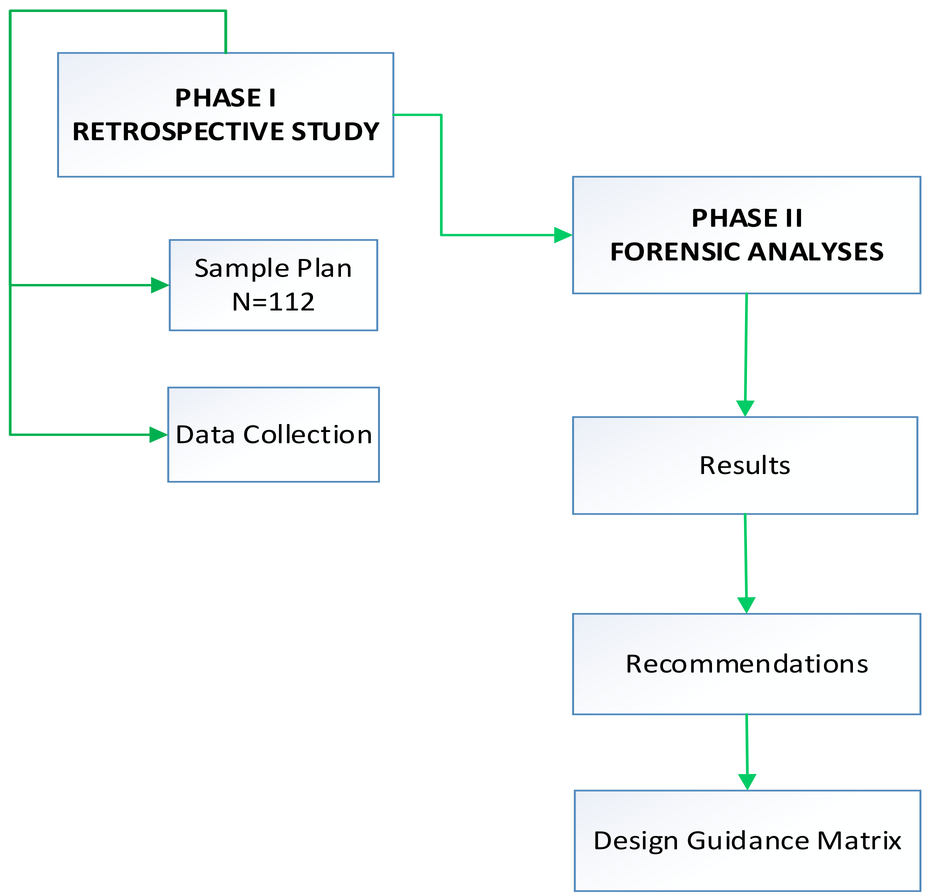


Figure 3. Proposed Design Methodology Block Flow Diagram

CHAPTER 2

BACKGROUND OF THE STUDY

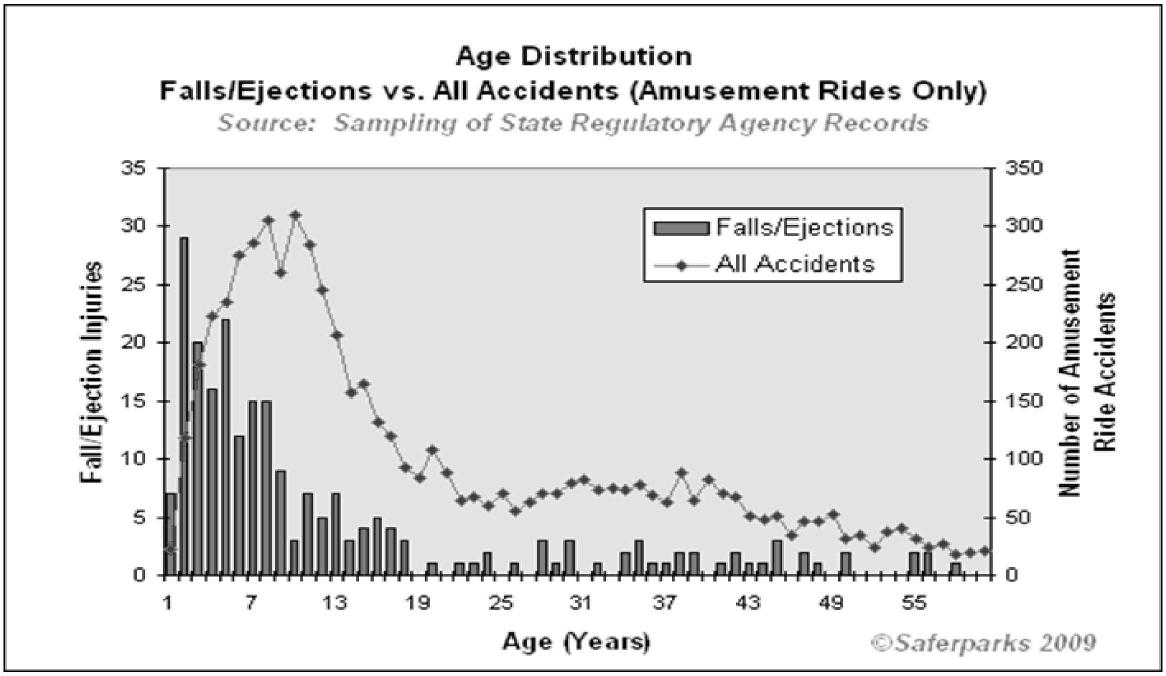
2.1 Literature Review of Amusement Park Safety

Amusement rides and devices have become representative of the amusement industry and are highly influential regarding the advancement and development of the tourist industry. With fierce competition and rapid growth of the amusement industry, fixed-theme parks are developing all over the world, and innovation is driving the advancement of larger and more thrilling rides. This is a dream come true for thrill-seekers and ride enthusiasts. The industry is largely self-regulating and maintains one of the highest safety records for recreational activities according to several sources including the International Association of Amusement Parks and Attractions (2014), Health & Safety Executive (2007) and National Safety Council (2015). The public's confidence in the industry's ability to provide safe experiences is reflected in its safety record. Ride accidents are a rare occurrence (Woodcock, 2010); however, one occurrence will produce a media frenzy, resulting in an adverse response from the public which will extend well beyond the accident venue; rippling through the entire amusement industry. This includes incidents that occur for fixed-site rides and mobile rides for carnivals, fairs and other traveling organizations. The summer of 1999 realized an increase in fatal accidents over a six day period; two of which were related to falls resulting from patrons defeating the restraint and containment systems (Braksiek and Roberts, 2002). These accidents are an example of (R^2CS) failures that reside in databases that will be used as part of this retrospective study.

It is estimated that approximately 1.4 billion safe rides are produced a year as a result of an estimated 315 million patrons visiting over 357 fixed-site amusement parks in the United States (NSC, 2015). The International Association of Amusement Parks and Attractions (IAAPA) is a leading industry organization that is committed to safety and has made safety the highest priority for the amusement industry. The organization's mission "is to be the voice for safety, advocacy and government relations" (2014). Injury estimates reported by the National Sporting Goods Association indicate the amusement park industry offers the safest form of recreation in the United States (IAAPA, 2014), and the probability of being injured on an amusement ride is less than 0.9 in one million (NSC, 2015). Similarly, the Outdoor Amusement Business Association (OABA) plays a major role in the safety of travelling carnivals and mobile rides. A summary of recreational activities in Appendix A compares injury rates per million for spectator sports relative to amusement industry accidents per million for 2013 (NSC, 2013).

Various studies have been performed to quantify variables associated with amusement ride accidents. Data retrieved from state regulatory agency records for 2009 by SaferParks compare falls/ejections and age to that of all amusement ride accidents (Graph 1- *Frequency Distribution- Falls/Ejection: Age vs. All Amusement Accidents*). The graph suggests most falls/ejections occur in the younger demographics. Children between the ages of two and 13 represent the greatest number of falls/ejections. Other studies by the U.S. Consumer Product Safety Commission (Smith, 2005) and Health & Safety Laboratory (HSL, 2007) have drawn the same conclusions.

The vast majority of amusement ride injuries are linked to patron actions based on a study that reviewed 37 amusement ride accident reports for the state of California which spanned from 1998 to 2005 (Woodcock, 2013). Earlier studies concluded that accidents result from patrons either seeking enhanced sensory experiences (Woodcock, 2010) or the desire to communicate with others in their party (Milnes, 2007). Woodcock's (2010) research leads to the idea that ride design can help shape behaviors of patrons resulting in an experience that is safe and enjoyable.



Graph 1.Frequency Distribution: Falls/Ejection, Age vs. All Amusement Accidents (Saferparks, 2009)

From 1972 until 1981, the U.S. Consumer Product Safety Commission (CPSC) had jurisdiction over fixed-site amusement rides. However, in 1981, Congress concluded that customers buy the services or experiences of amusement rides; therefore, they elected to remove control of fixed-site amusement rides from the CPSC arguing that it is the facility that buys the product. Even though the CPSC has no direct authority over fixed-site rides, it does issue annual ride injury reports regarding national statistics on fixed rides. IAAPA also collects injury data for rides and analyzes industry trends. Of the three hundred and fifteen million people that visit U.S. amusement parks each year, it is estimated that there are fewer than 1250 ride related injuries each year (NSC, 2015).

The CPSC National Electronic Injury Surveillance System (NEISS) derives its information from hospital emergency department data for fixed-park injuries. The CPSC looked at injury trends for fixed-site rides from 1997 through 2001 and concluded that ride injury rates were statistically insignificant (2001). Another report by the CPSC concluded that younger patrons had the highest incidence for falls/ejections and were at greatest risk because they are not able to comprehend the severe consequences and risks associated with their behavior (Smith, 2005). The report also concluded that there were two types of restraint failure modes based on collected data. The failures were due to unintended opening of the R²CS or an act of defeating the systems. Unintended opening of the R²CS is extremely rare and data collection agencies all agree that cases that involve the defeat of restraint systems accounts for 40-60 percent of failure modes (Amusement Safety Organization, 2011).

Other studies examined the usefulness of restraint systems for dual ridership and the effectiveness of containment based on the dissimilar anthropometric features of the riders. Scrambles had the highest rate of ejections in 2009 (Saferparks, 2009b), and industry data indicate that the major contributor is associated with the diverse size and shape of the two or more riders that share a common containment device as illustrated in Figure 4 below.

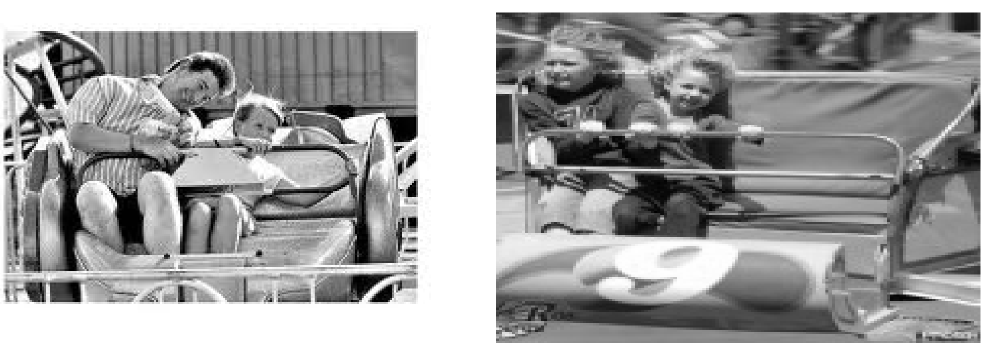


Figure 4. Collective Restraint: Large and Small Riders (a). Two Small Patron Riders (b) Photo: Dave Burton

Additional databases that capture amusement industry accident history were investigated as part of the data mining effort to further explore key drivers for systems failures. Other principle repositories that store data are the National Safety Council (NSC) and the National

Electronic Injury Surveillance System (NEISS). The HSL has been collecting accident data and ride accelerations since 1995 and has generated a database of accident facts. They have also performed field studies to understand patron behavior and motives.

The National Safety Council's revised report in 2015 estimates rider based injuries for 2013 were 0.9 per million (p. 5). Statistical data compiled by the CPSC indicate ride related injuries are extremely low but recognize restraint and containment hazards exist. The NSC provides public access to high level summary data. The most recent amusement park accident data were collected from this source as part of the literature review process and data mining efforts.

The NEISS database is in the public domain and is readily accessible by anyone inclined to review the information. NEISS was developed in the fall of 1970 based on census data and a survey of hospital emergency department inventories across the United States and falls under the CPSC. After several updates to the hospital emergency department sampling selection process, the current sampling is reflective of a probability sample as outlined in the 1997 and 2000 revisions. There are four levels of engagement practiced by NEISS to capture the full magnitude of accident injuries as noted below:

1. Ongoing routine surveillance of emergency department injuries;
2. Special emergency department surveillance activities;
3. Follow-back telephone interviews with the injured person; and
4. More comprehensive on-site investigations with the injured person and other witnesses.

Figure 5. NEISS U.S. Hospital Locations (NEISS, 2011)

To maintain consistency, the data collected by hospital emergency departments from the sampling lot is dictated by the NEISS and the following is a list of the information captured:

- Date (one year range; e.g., how many injuries were treated in 1996)
- Product (e.g., how many bicycle injuries occurred)
- Sex (e.g., how many injuries occurred to women)
- Age (e.g., how many injuries occurred to people aged 35-55)
- Diagnosis (e.g., how many lacerations occurred)
- Disposition (e.g., how many people were admitted to the hospital)
- Locale (e.g., how many injuries occurred at a school)
- Body part (e.g., how many injuries involved the knee)

NEISS data collection serves as a tool for researchers to study specific hazards and accident trends associated with specific products. Table 1 is an example of the format and data extracted as a result of querying the NEISS database. Studies like this set the stage for standards development, both voluntary and mandatory (CPSC, 2011).

Table 1. Query of Hospital Department Data Entry for Amusement Park Injuries (CPSC, 2011)

National Electronic Injury Surveillance System
(NEISS) Sample Case Detail

Glossary
PSU = Primary Sampling Unit (Hospital) Weight = Statistical Weight
Stratum = Size/type of hospital (S= Small, M=Medium, L=Large, V=Very Large, C=Children's Hospital) **Total Records: 789**

CPSC CASE #: 130127750 TREATMENT DATE:01/03/2013 PSU: 37 WEIGHT: 5.7324
STRATUM: C
AGE: 5 • 5 YEARS SEX: 2 - FEMALE RACE: 0 - N.S. RACE OTHER:
DIAGNOSIS: 57 - FRACTURE DIAG OTHER:
BODY PART: 36 - LOWER LEG
DISPOSITION: 1• TREATED & RELEASED, OR EXAMINED & RELEASED WITHOUT TRTMNT
LOCATION: 0 - UNKNOWN
PRODUCTS: 1293 - AMUSEMENT ATIRACTIONS (INCLUDING RIDES) NARRATIVE: 5 YO F FELLIN BOUNCY HOUSE AT A PARTY. DX: L LEG FX
FIRE INVOLVEMENT: 0 - NO FIRE OR NO FLAME/SMOKE SPREAD

CPSC CASE #: 130148439 TREATMENT DATE: 01/19/2013 PSU: 73 WEIGHT: 76.7142
STRATUM: S
AGE: 11 - 11YEARS SEX: 2 • FEMALE RACE: 0 • N.S. RACE OTHER:
DIAGNOSIS: 55 - DISLOCATION DIAG
OTHER: BODY PART: 92 - FINGER
DISPOSITION:1- TREATED & RELEASED, OR EXAMINED & RELEASED WITHOUT TRTMNT
LOCATION: 9 • SPORTS OR RECREATION PLACE
PRODUCTS: 1293 - AMUSEMENT ATIRACTIONS (INCLUDING RIDES)
FIRE INVOLVEMENT: 0 - NO FIRE OR NO FLAME/SMOKE SPREAD
NARRATIVE: LLYOF SUSTAINED A RIGHT THUMB DISLOCATION CAUGHTIN THE METAL DOOR OF AN AMUSEMENT PARK RIDE AT THE F

Based on the literature review of patron safety, design questions associated with ride features such as seating configuration, restraint type, and ride type were constructed for the forensic analysis to establish relevant significance among industry control data and other R^2CS variables.

2.2 Ride Site Classification

Amusement rides are classified as either fixed-site or mobile-rides. The classification between fixed-site versus mobile-rides is distinctive in that they are not regulated the same. The Authority Having Jurisdiction (AHJ) is different; therefore, what information and how it is reported is highly dependent on what agency, if any, has jurisdiction.

2.2.1 Fixed-Site Rides

Fixed-site rides are permanent structures that once installed operate in the same location for an extended period of time and are not intended to be dismantled and relocated as part of the operational strategy. Both amusement and theme parks fall into the “fixed-site” category. While amusement and theme parks have many of the same rides as carnivals and fairs, they are home to larger attractions. For the fixed-site rides, the amusement industry is largely self-regulating. A handful of states in the U.S. have jurisdiction over accident investigations, ride inspections, and in some cases, operational procedures. Regardless of whether or not there is a government agency that has jurisdiction, all states look to the ASTM F24 suite of amusement ride design, maintenance and operational standards for guidance.

2.2.2 Mobile-Rides

Mobile-rides refer to temporary ride structures and carnival rides that get assembled, disassembled and transported to another location for operation on a regular frequency. These sites are referred to as traveling fairs or carnivals. Their origin evolved out of the trade industry and was intended to mark the opening of trade markets (Roberts, 2001). Today these traveling venues stand on their own with the primary objective being to provide entertainment. In the U.S. only mobile-ride or transportable rides are federally regulated (Smith, 2005). The scope of the CPSC is so vast that a concentrated effort on safety regulation for amusement rides and devices is not feasible. An equivalent regulatory agency for the United Kingdom is the Health and Safety Executive (HSE) which is responsible for the enforcement of safety regulation for fairs and carnivals. The HSE has conducted extensive amusement accident investigations and has contributed heavily to safety in the industry through their research.

Design questions were formulated that looked at differences that existed between the study data and industry data associated with ride classification related to injury severity.

2.3 Safety Consensus Standards

Understanding the hazards associated with restraint and containment design is critical for ride designers of the theme park industry. For the last 30 years, amusement industry experts world-wide have come together to develop the most successful and comprehensive set of safety consensus standards for the design of amusement park ride systems that make up the F24 standards for the *American Society of Testing and Materials-International*. While there are amusement ride standards in Europe, Russia, and China, the ASTM F24 standards are the only recognized standards for amusement ride design in the United States (ASTM, 2011). Extensive work is being conducted by the F24 standards committee to harmonize amusement ride standards with other countries.

In the absence of federal legislation, consensus standards are also known as *customary law* that are not directly enforceable in courts but nonetheless are commonly practiced and are widely accepted and have an impact on industry compliance. Due to the growing number and influence of such standards, customary law is quickly becoming a major source law. Standards continue to be the main driver regarding amusement industry compliance for design, operation, inspection and maintenance of ride systems.

In the United States, the standardization system incorporates government and non-government agencies and classifies standards into two categories: mandatory and voluntary. The distinction between voluntary and mandatory standards is rooted in the development nature of the specifications. Mandatory standards are the development efforts of government agencies which largely adopt private sector standards by reference. When mandatory standards reference voluntary standards in regulations, that reference promulgates the standard and becomes federal, state and local law and shall be adhered to. The Environmental Protection Agency (EPA) and the Occupational Safety and Health Administration (OSHA) are regulatory agencies that reference voluntary consensus standards under their jurisdiction and are examples of government standards.

Voluntary consensus standards are developed by all sectors that have an interest and need for the use of a standard. Consensus standards are considered by many as the most technically sound and most credible documents (ASTM, n.d. a). The U.S. National Technology Transfer and Advancement Act (Public Law104-113), which requires government agencies to use privately developed standards whenever possible, has increased the use of voluntary consensus standards (ASTM, n.d. a).

Standards consensus is established by an eclectic group of experts from around the world with intimate knowledge of the technology governed by the standards. The exception to this statement is when the technology is so technically advanced that it has no peers. In this case these standards are recognized and have international acceptance no matter how they were developed (ASTM, n.d. b).

The ASTM F24 Committee for Amusement Rides and Devices is the foundation of the theme park industry. ASTM F24 is a world standard and has representation from over 23 countries providing scientific and technical expertise that draws upon authorities in the industry, including leaders in academia, the private sector, government, and citizen representation. At the forefront of the ASTM F24 standards is F2291, the most comprehensive standard for the amusement industry today (ASTM, n.d. b). Development of F2291 defined the g-force limits and was reviewed by 14 industry experts from around the world. The standards, in their entirety, resulted from the work of a global group of cross-industry experts from the medical, astrophysics, bio-dynamics, and biomechanical fields, who came together to meet the need for a single, universally accepted design standard for amusement rides (ASTM, n.d. a).

Most of the same experts that developed the F24 standards are working to harmonize these standards with international standards such as ISO, EN, and NSRF. Understanding the value of standards and how to effectively influence industry standardization that one day may be adopted into legislation makes for the greatest opportunity for success in the global market place. According to Bothe, "*when standards are based on quantitative data and facts- not misconceptions; standards influence practice- and practice influences law"* (1980, p. 392). Technical experts, who are active participants in standards development, are the ones to shape issues that impact the industry (ASTM, July/August 2011).

2.4 Human Factors

Human Factors Engineering (HFE) emerged as a discipline concerned with the design of devices, equipment, systems and the environment to assist with human competencies and limitations of everyday tasks. While HFE has been around for over half a century, over the past decade, knowledge that derived from research within the HFE community has been effective in solving unique ergonomic problems. However, it requires a systems approach that considers both human behavior as well as the cognitive component in developing a design solution to meet the performance requirement of amusement R^2CS for patrons with unique anthropometry. The use of behavior-shaping constraints is a recognized technique with foundations in cognitive systems engineering and systems theory (Vicente, 1998).

Each ride has unique features and a dynamic profile that when combined with human attributes such as age, size, weight, and physical shape in statistically rare cases, may produce an unwanted outcome including rider ejection. ASTM F2291-14 industry standard for the design of amusement ride systems requires that a patron containment analysis shall be performed in accordance with Section 6, and section 5.1.1 states:

> A patron suitability assessment shall describe the suitability of the design of the amusement ride or device for the intended patrons, including anthropometric factors related to age and physical size (ASTM F2291-14, p. 5).

Consideration of the human factors component is reflected in the design questions developed to look at the significance associated with cognitive ability and behavior motives regarding interaction with the containment device.

2.5 Patron Restraint and Containment

The ASTM F2291 standard identifies the appropriate patron coordinate axis system (Figure 6) to provide optimal patron containment during the ride experience and is the guideline for restraint type determination based on assumed ride dynamics and acceleration profiles during the design phase. The appendices of ASTM F2291 (2014) summarize restraint design criteria based on restraint determination selection (See Appendix B). The anthropometric data referenced by ASTM F2291 used during containment design and analysis is published by the Center for Disease Control (CDC) and the Dreyfuss charts for human factors (see Appendix F).

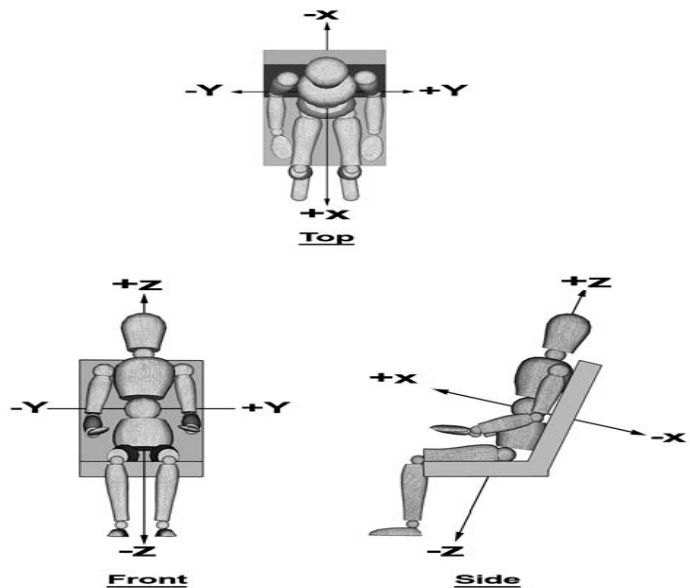


Figure 6. Patron Coordinate System. (ASTM F2291-14 Standard, 2014)

Guidance for restraint selection during the design phase is provided by the ASTM F2291 standard wherein assumptions about acceleration limits and sustained durations are determined by the ride designer/engineer. This information is used in patron restraint and containment analysis in accordance with Section 6 of the standard. For the purpose of this study, the operational definition for patron containment shall adopt the definition of Section 6.1.1 of F2291-14 as follows:

> The amusement ride or device shall be designed to support and contain patron(s) during operation. This support and containment, that is, the patron containment, shall be consistent with the intended action of the ride or device (ASTM, 2014, p. 7).

The operational definition shall extend to include containment systems as defined by the HSL (Milnes, 2007) as: *“The seating, handrail, lap bar, and foot-well structures which contain the passenger and / or enable them to support themselves and remain stable by being able to resist acceleration forces”* (p. v).

In addition to acceleration limits and sustained duration, the nature of the amusement ride or device as well as the intended adult and child anthropometry shall be considered based on growth charts from the Center for Disease Control (CDC), the Dreyfuss Human Scale and the Society of Automotive Engineers (SAE). Ride designers/engineers use these data charts to establish height requirements for ridership eligibility. Ridership eligibility is provided by the manufacturer's ride designer and is enforced by park owners/operators. The patron restraint and containment analysis also considers the value of seat features such as seat contour, apertures and other attributes that shall prevent patrons from mis-positioning, falling out or being ejected from the restraint.

ASTM denotes five restraint classes to consider based on acceleration limits and duration of sustained accelerations when conducting a containment analysis. Classes 4 and 5 restraint systems have the most stringent design requirements. The requirements are based on ride accelerations over a sustained period of time. A Class 4 restraint requires a redundant design locking device function and is only allowed to be opened by the operator. Redundancy of a locking device for Class 5 restraints requires two independent restraint systems or one fail-safe system, and only the operator shall unlock the restraint (ASTM F2291, 2014).

In some cases, defeat of a restraint system is not deliberate. Containment analyses show that a child patron that meets the ridership height requirement can defeat the restraint and containment system by performing self-extraction (Collins, n. d.) because children have excess free movement space due to lack of correlation between their girth and height. Children slip out of the restraint by maneuvering legs enough to push out of the top of the restraint. This is an example of anthropometric data that does not align with ridership eligibility based on height rather than on a holistic anthropometric association. Restraint design and ride type vary in degree, but the containment design is based on male/child anthropometric profiles, losing sight of the “guests whose physical attributes fall outside the design parameters due to size, disability or other factors” (IAAPA, 2011).

It was also noted by HSL that focus needs to consider static, dynamic and psychological factors in the design of suitable containment to ensure passenger safety (Milnes, 2007). During the containment analysis, the desired height restriction is evaluated based on anthropometric tables referenced by industry standards and then converted to a minimum height requirement. However, the containment analysis may indicate that the height restriction under consideration relative to age may not be appropriate and other containment strategies need to be implemented to align height requirement to age. Studying the impact of static, dynamic and psychological factors independently offers little value during the analysis and must be considered as a systems problem. This requires a holistic approach where the three factors are examined simultaneously.

In some cases, different somatotype shapes afford either excess containment space or not enough resulting in patrons not being secured. Both scenarios directed a series of questions that were examined as part of the logistic regression analysis.

2.6 G-Forces

Studies of accident data conclude that while g-force is one of the components considered in the accident investigation, its importance is considered secondary when taken in aggregate regarding the ergonomics of restraint and containment systems and passenger behavior. The data set investigated by the HSL (2007) showed that containment incidents occurred on rides with measured accelerations that met allowable g-forces. The principle contributors were due to passenger behavior, patron containment design, and whether patrons had the ability to brace themselves. In these cases, the accident related causes had little to do with the biomechanical response to ride g-forces and point to a root cause associated with poor containment design and patron interaction with the containment system (Jackson, 2007). The analysis report also asserted that in a low g-force environment, *"where the g-force tolerance is acceptable, the effect of the analysis may hinge on a treatment that acceptable g-force tolerances rely on passengers to stay seated"* (p. 34). The German code DIN 4112, provides guidance for *"sizing passenger seats and cabins which specify details that need to be given to the height and upholstering of back rest and arm rests as well as for bracing"* (p. 29).

2.7 Anthropometry

CDC growth charts were developed based on data extracted from international health examination surveys and supplemental data. Initial growth charts were released in 1977 by the National Center for Health Statistics (NCHS) for use in the United States. In 2000 the Center for Disease Control (CDC) revised growth charts with the intent that they supersede the 1977 NCHS growth charts. The NCHS 1977 charts were revised due to limitations and procedures used to develop the charts due to inadequate representation of ethnic, genetic, socioeconomic, environmental, and geographic variability (Kuczmarski, Ogden & Gus, 1977). As more recent body measurement data became available, development of the 2000 charts improved statistical smoothing procedures, used more representative survey data, and augmented charts to include body mass index in addition to weight-for-age and stature-for-age. The CDC growth charts were developed for primary use for health care professionals for the purpose of assessing the anthropometry and growth of infants, children and adolescents. The amusement industry adopted these and other growth charts to provide direction to ride designers/engineers. Industry standards point to growth charts associated with the CDC, SAE, and the Dreyfuss Human Scale for guidance when conducting the containment analysis. As ride manufacturers' products reach well beyond their traditional market locations, they find themselves designing for cultural areas that have diverse somatotype shapes and variable average sizes.

The World Health Organization (WHO) recognized the ethnic and cultural diversity in international markets and recommended the use of normalized growth charts that considered body measurements in terms of z-scores which allows for insight into the anthropometry at the two ends of the distribution spectrum. Normalized data charts serve as a tool that allows for the comparison of growth status of an individual or group based on the reference population. There is a distinction between a growth reference and a growth standard. The WHO defines a reference as “what is” and a standard as “what should be” (CDC, 2002). However, growth references are often used interchangeably in terms of standards; unfortunately, references were not intended to be an independent tool on which decisions are made. Moreover, the growth reference serves to monitor growth in individuals or populations. The main reason for the distinction between reference and standard resides in the development of the 2000 CDC growth charts where some data exclusions ensued. The two data exclusions were very low birth weight (VLBW) and National Health and Nutrition Examination Survey (NHANES III) body weight data for children and adolescents. The decision to leave out this data in the development of the reference growth charts impacts the curve on both ends; fewer children are identified as being well below the norm or at risk for being overweight. Therefore, a ride designer/engineer should take into account which anthropometric characteristics are not being captured by the growth charts used during the containment analysis.

Six of the ten cases noted in the CPSC Annual Report (2005) were associated with R^2CS failures due to patron behavior and were the result of patrons squirming out of the containment compartment (Smith, 2005). Three of the six cases resulted in death. In cases where riders were able to extract themselves from restraint containment compartments, the supposition is that accepted industry standards for anthropometric data are not aligning with the physical attributes of select groups which are considered statically rare. ASTM F2291-14 design standards require the containment analysis to consider the relationship between the intended ride dynamics and the physical characteristics of adult and child anthropometric data. In the six cases noted by the CPSC report, riders were able to get out of the restraint due to the available space between the patron and containment compartment (Smith, 2005).

The Amusement Safety Organization (2011) accident report identifies falls and ejections that can be attributed to failure modes associated with containment designs that could not adequately accommodate unique patron anthropometry. A 31 year old woman died after falling from a ride due to her size at a Dublin fair. The investigation concluded she was thrown from the ride because she was too large for the restraint system to adequately secure her in the device (ASO, 2011). This is an example where the ride analysis failed to match up the ride containment and patron's physical anthropometry. In another case, a 29 year old male amputee who lost both his legs lacked the gripping capacity required to stay firmly contained which resulted in being ejected out of a coaster and killed (ASO, 2011, RideAccidents.com, 2011). Twelve years earlier, a 37 year old man was ejected from the same coaster due to his large size (ASO, 2011). In 2004, a large man was killed due to ejection on the same version of this coaster because his restraint could not be securely fastened. In another incident, after slipping out of the harness, a 12 year old boy fell 129 feet to his death on a free fall ride (RideAccidents.com, 1999). These are examples of cases where a mismatch of anthropometric data and the results of the ride analysis failed to discover the risk for statistically rare patron outliers based on restraint and containment systems' design criteria.

Based on the conclusion of some investigations, a series of questions related to patron stature and type of failure mode were generated and evaluated during the forensic phase.

2.8 Cognitive Ability

Cognitive science is becoming an important part of the field of design; it studies the mind, awareness, decision making, difficulty and related issues (Dreyfuss, 2002). Many of the containment failures associated with defeating restraint systems involved very young riders who were unable to comprehend the severe consequences and risks associated with their actions due to limited cognitive development. The following sections clarify the operational definition of the different stages of cognitive development (see Figure 7) and how it applies to this study.

The first stage of development starts at birth and matures to age two based on the child's perception of objects they can see in their space in real time. Learning is through trial and error, and towards the end of this phase they are beginning to realize that objects exist even if they cannot see them.

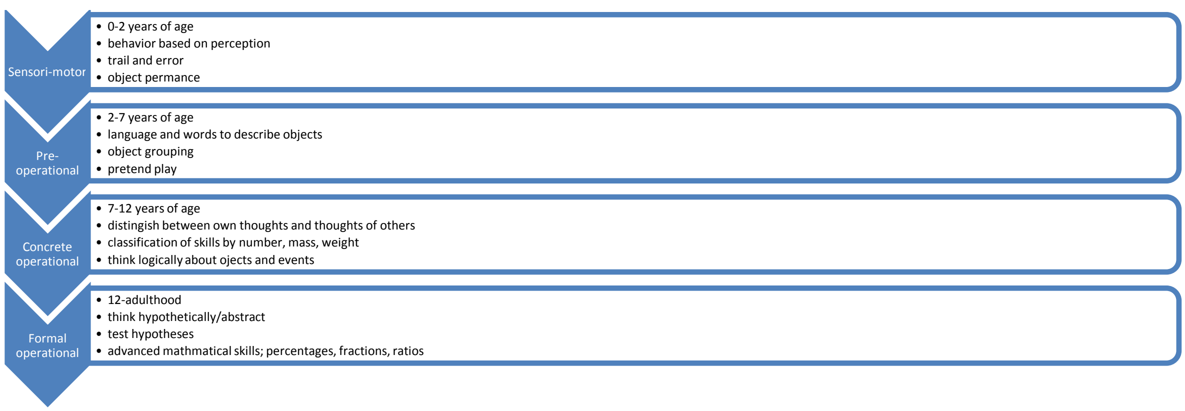


Figure 7. Cognitive Development (created based on Piaget's cognitive development concepts)

As children advance to the pre-operational stage, cognitive development is advancing rapidly, and the ability to think is by a priori association but not in terms of logical reasoning. Some of the advancements in this stage are recognized by the child's ability to construct words and use language as the primary tool to describe the environment, objects, images, and experiences. Grouping things based on similarity is also prevalent. The ability to describe their environment and group properties can be seen as children interact and role play. Role playing is very common at this level of cognitive development; however, it is limited to the association of their experience and not rational thought. Logical thinking doesn't start to develop until the concrete operational stage.

At this point children are starting to show signs of logical reasoning ability similar to adults but are still limited to a priori situations. This phase is sometimes referred to as middle childhood, and according to Wood (2001) Piaget asserts that children are advancing in the developmental process for sustained understanding of logical and concrete information. While children in middle childhood are able to understand things from several points of view, they are still challenged to grasp abstract concepts and future consequences of their actions and their environment. It is not until the final stage of Piaget's theory of development, when children are around the age of 12, that they start to develop reasoning skills.

In the formal operational stage, milestones for logical reasoning and abstract processing skills continue well into adulthood. Development is characterized by having the ability to think hypothetically in the abstract, challenge hypotheses, and possess advanced computational skills to perform mathematical functions associated with fractions, ratios, and percentages. This stage of cognitive development presents some challenges due to the velocity at which children advance through this stage. To provide delineation among the overlapping ages for each of Piaget's cognitive development stages, an adjustment in the age range for this study is defined in Table 2.

Table 2. Modified Age Ranges for Piaget's Cognitive Development Stages

Cognitive Development Phase	**Age Range**
Sensori-motor	0-2
Pre-operational	3-7
Concrete-operational	8-12
Formal operational	13-Adult

In 13 cases analyzed by the CPSC, the riders were between two and eight years of age and were able to access the restraint locking mechanism and open it (Smith, 2005). The level of cognitive development of riders needs careful consideration and is highly relevant when determining the appropriate restraint class.

Cognitive development is contingent upon interaction with others such as family, friends, peers, teachers, and media. These interactions shape the cognitive development process and may result in reasoning conflicts associated with opposing views. How these conflicts get resolved depends primarily on the level of cognitive maturity achieved. Others argue (Habib, 2011) that some adults never really achieve the full state of cognitive development for the formal operational stage, as in the case of adults who have attained full formal operational development but willfully elect to engage in risk taking behavior anyway. This is indicative of Farley's (1986) concept of the Big-T personality where the experience of the adrenaline rush is the reward for sensation seeking tendencies. It is also possible that adult thrill-seekers may be able to manipulate the cognitive area of their brain to rationalize that a ride experience is safe and thus negate the fear response (Patione, 2009) leading to risk-taking behavior.

Children under the age of eight years old have limited capacity to understand safety measures and assess risk (Mikol, 2007). Nine of the thirteen incidents referenced above by the CPSC happened to riders with cognitive development normally seen in children less than eight years old (Smith, 2005); therefore, they were unable to recognize the hazards of releasing the restraint locking mechanism.

Injury severity associated with cognitive development and sensation-seeking experience was crafted into a succession of design questions for the analysis; design questions were also constructed that looked at associations for ride category associated with cognitive development.

2.9 Patron Behavior

Patron behavior is a major factor in restraint and containment injuries. Behavior can be intentional or unintentional, but the outcome is the same; serious injury including death may occur. There are several reasons why patrons engage in unsafe behavior when experiencing rides and are in an unfamiliar setting. In many cases, risk taking behavior is the result of one of two things: peer pressure/acceptance or enhanced thrill-seeking experience.

2.9.1 Peer Pressure

Just as parents influence children's behavior and social development, so does the interaction with peers and friends. Children learn communication skills and certain attitudes reflected by peer groups (Mikol, 2007). The attitude of peer groups is highly influential and is closely linked to peer-acceptance. Quite often acceptance of peers is so compelling that it causes a child to disregard parental values and acceptable behaviors and engage in risk taking activities (Bradbury, 1998). Acceptance or rejection by peers has been associated with various social and self-affirmation attributes, many resulting in injury (Engstrom et al., 2005). Risk-taking behaviors are also taken to become part of the group, maintain status, prove loyalty or even reduce the threat of bullying (Mikol, 2007).

2.9.2 Thrill Seeking Behavior

Lack of cognitive development is not the only cause of risk-taking activities. The CPSC Project Report on the *Human Factors Review of Restraint Failures on Mobile Amusement Rides* (Smith, 2005) examined two cases in which two adult males deliberately extracted their legs from under the restraint and placed them on the seat in order to ride unencumbered by the restraint. It is doubtful that these men possessed diminished cognitive capacity and therefore were able to recognize the risks associated with defeating the restraint but still elected to engage in this behavior (Smith, 2005). Through his research, psychology professor, Marvin Zuckerman, determined that men have a higher desire for sensation-seeking experiences than women, and this desire is at its height during the late teens to early twenties (1980). Even though high-sensation-seeking is associated with risky behavior, Zuckerman argues it is a normal personality trait (Munsey, 2006). Dubbed the Big-T nation, Farley suggests that the U.S. is built on risk takers and that thrill-seekers are more inclined to engage in thrill-seeking activities. The intense popularity of extreme sports that emerged in the last decade; high risk occupations such as test pilots, firefighters and emergency responders; stock car racing; and the popularity of roller coasters are just a few examples of the ways people attempt to satisfy this need.

2.10 Summary

The amusement industry has fueled the imaginations of so many, from young to old, spectators to thrill-seekers, small to big. Since the first roller coasters were built, the demand to design bigger and faster rides has been at the forefront of the ride designers' imaginations. Advancements in technology have yielded highly sophisticated engineering systems at the heart of a fully integrated experience, where restraint and containment analysis is a key component in ride design. For the most part, the amusement industry is self-regulating and focuses heavily on the safety of amusement rides and devices through the development of safety consensus standards for design, maintenance, operation and inspection of ride systems. While it is rare that patrons are injured due to R^2CS failures, the literature review indicates there are cases where there is a mismatch in ridership eligibility and unique patron anthropometry. In such cases, there is an inherent risk for falls, ejections, and mis-positioning resulting in injury for patrons with limited cognitive development and patrons willing to engage in wanton behavior. To this end, a host of design questions (Table 3) were generated. The questions looked at anthropometric mis-matches associated with ride event, patron characteristics, and ride features. A retrospective study of R^2CS failures to identify the gap in knowledge and a forensic analysis was performed to advance understanding of the problem in order to augment existing containment design guidelines.

Table 3. Design Questions and Analysis Method

DQ	***Question Type***	**Independent**		**Analysis**	**Questions**
		#	**/ data type**		
1	Is there an association between two variables?	1	categorical	Cross tabulation Chi-square Fisher's Exact	Is the ***age distribution*** observed for HSE industry data comparable with the doctoral R^2CS data?
2	Is there an association between two variables?	2	categorical	Cross tabulation Chi-square Fisher's Exact	Is the ***distribution of behavior*** type observed for HSE industry data comparable with doctoral R^2CS data?
3	Is there an association between two variables?	2	categorical	Cross tabulation Chi-square Fisher's Exact	Is there an association between type of ***failure*** (R^2CS vs. NSC overall industry) ***ride*** related injuries and ***ride type***?
4	Is there an association between two variables?	2	categorical	Cross tabulation Chi-square Fisher'sExact	Do R^2CS injuries for ***fixed-site and mobile rides*** differ from CPSC overall industry injury rates?
5	Do differences exist between two groups?	2	categorical	Cross tabulation Chi-square	Do ***males*** display more ***non-compliant behavior*** than woman?
6	Is there an association between two variables?	2	categorical	Cross tabulation Chi-square	Does ***injury severity*** differ between ***ejection/falls and not secured*** for patrons in doctoral R^2CS failure data?
7	Is there an association that exists between two variables?	2	categorical	Cross tabulation Chi-square	Is there an association between ***cognitive level and ride types*** for doctoral R^2CS failure data?
8	Is there an association that exists between two variables?	2	categorical	Cross tabulation Chi-square	Is there an association between ***cognitive level and severity of injury*** for doctoral R^2CS failure data?
9	Is there an association that exists between two variables?	2	categorical	Cross tabulation Chi-square	Is there an association between ***diminished capacity and non-compliant behavior*** for doctoral R^2CS failure data?

DQ	*Question Type*	Independent #	/ data type	Analysis	Questions
10A 10B	Is there an association that exists between two variables?	2	categorical continuous non parametric	Cross tabulation Chi-square Kruskal Wallis	A) Is there a relationship between ***age groups and ride types*** as defined by HSE industry data? B) Is there significant difference in the ***average age*** across different ***ride types***?
11	Is there an association that exists between two variables?	2	categorical	Cross tabulation Chi-square	Is there an association between the ***physical limitations vs. failure mode*** for doctoral R^2CS failure data?
11A	Is there an association that exists between two variables?	2	categorical	Cross tabulation Chi-square	Is there an association between having an ***anthropometric mis-match and failure mode*** for doctoral R^2CS failure data?
11B	Is there an association that exists between two variables?	2	categorical	Cross tabulation Chi-square	Is there an association between ***diminished capacity*** and ***failure mode*** for doctoral R^2CS failure data?
11C	Is there an association that exists between two variables	2	categorical	Cross tabulation Chi-square	Is there an association between ***behavior and failure mode*** for doctoral R^2CS failure data?
12	Is there an association that exists between two variables	2	categorical	Cross tabulation Chi-square	Is there an association between ride security strategies vs. ***failure mode and seating*** for doctoral R^2CS failure data
12A	Is there an association that exists between two variables	2	categorical	Cross tabulation Chi-square	Is there an association between ***failure mode and restraint type*** for doctoral R^2CS failure data
12B	Is there an association that exists between two variables	2	categorical	Cross tabulation Chi-square	Is there an association between ***failure mode and seating*** configuration for doctoral R^2CS failure data
13	Can we estimate the probability of a characteristic being present given the values of a set of independent variables?	3	categorical	Logistical Regression	Does having a physical limitation in terms of anthropometry, diminished cognitive ability and wanton/risky behavior make a failure event more or less likely to result in an ejection/fall?

CHAPTER 3

METHODOLOGY

3.1 Introduction

The intent of this design methodology is to present a retrospective study and a forensic analysis. Figure 8 depicts the final design methodology mapping. The retrospective phase retrieved R^2CS failure data from various industry sources. Preliminary descriptive analyses were performed to understand data structure in order to identify the type of advanced statistical analyses to perform as part of the forensic phase to address the following concerns: 1) how ergonomics applied across anthropometric characteristics affect guest safety, 2) how cognitive ability influences patron judgment, and 3) how wanton behavior increases the risk for injuries.

The intent of the forensic phase, through bivariate and multivariate analyses, was to determine goodness of fit for observed distribution counts to that of expected counts, and to examine industry control data to see if a relationship exists between two or more categorical variables. The results of the bivariate analyses led to an in-depth look at predictor variables for failure modes used to develop a containment forcing function design determination matrix intended to augment existing design criteria used by ride designers as a part of the containment analysis.

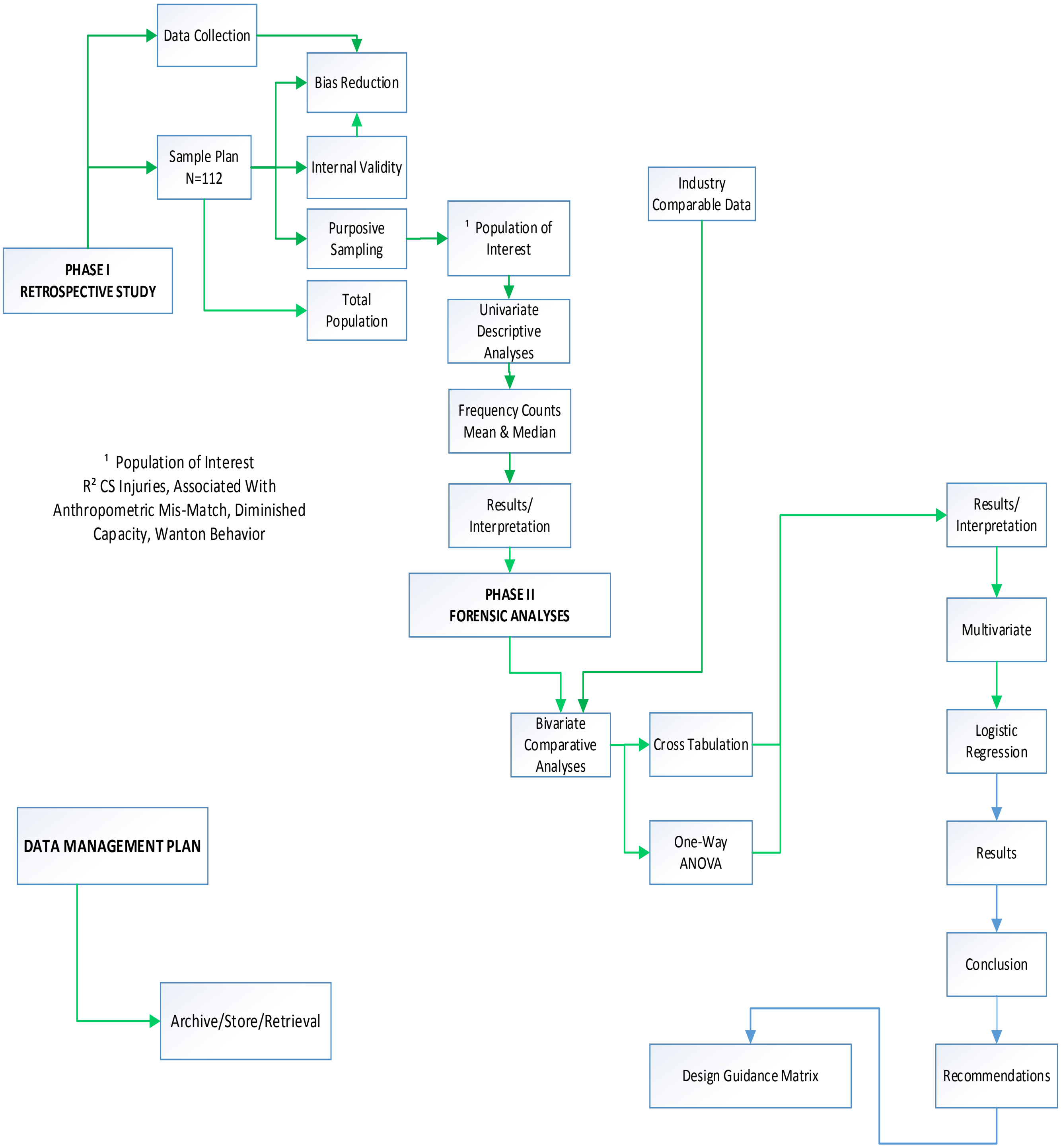


Figure 8. Final Design Methodology Mapping Diagram

3.2 Retrospective Study

Various state and regulatory agencies collect amusement ride accident and injury data as well as industry and trade organizations. Unfortunately, there is no official repository for this information in the public domain. Therefore, several queries of various government and non-government agencies, advocacy groups, non-profit, public service, and industry trade organization databases were required to retrieve raw data reports for amusement ride accidents and injury details. From these databases, reports specific to R^2CS failures were obtained for this study.

3.2.1 Sampling Bias

Careful consideration was taken to avoid introducing bias into the analysis. The entire population of identified non-mechanical R^2CS failures was used in the study. This strategy reduced the bias in the non-probability sampling scheme because the sample selection included all known R^2CS failures. Additionally, the sampling scheme was not geographically restricted. R^2CS failure data were obtained globally. Therefore, unique anthropometry for specific cultures was captured as part of the sample population. However, it should be noted that any failures not identified during the data collection process were not included in the analysis, but that is not expected to negatively skew the results because the data only represent a small percentage of R^2CS failures.

In an effort to maintain the integrity of the sample data, only accident data that resided in credible trade organization databases, government and regulatory reports, scholarly journals, public service agencies and consumer advocacy groups were used. No data that were published in media outlets such as newspapers, social networks, and blogs, etc. were used in the data collection process. Additionally, only the raw accident data were used to construct and manage accident details for analyses. In other words, previous summary data or other analyses were not used as part of the sample data which would be subject to others' accuracy and interpretation.

Very few resources existed that collected and organized industry accident data prior to the 1990s; therefore, many accident cases were not recorded, and for those that were captured, the details barely provide information beyond gender. Therefore, R^2SC accident data from 1985 to 1994 did not contribute meaningfully to the outcome of the analyses and could have introduced bias into the study thus threatening the validity of the results. Consequently, the data were not used in this study.

The area most likely to introduce bias into the data lies with the information collected from first responders to the accident site. When accident events happen, chaos ensues and the information collected may not be correct or details may be missing. Additional research was performed to locate corrections and updates to the original report. Since this study focused on more concrete and tangible details pertaining to R^2CS failures, it is not anticipated that excessive bias will be introduced that will greatly affect the outcome of the analyses. Details such as ride type, seating configuration, region, site type, injury severity, and restraint type were easily verified through polling efforts. It is likely that the qualitative data associated with the accident investigation and witness testimony are at higher risk for inaccuracies. These accounts may include the emotional state of the victim, sequence of events, patron size, actions of others, and fall distance.

3.2.2 Data Collection

The data mining effort was used to gather preliminary data from industry accident reporting databases. The approach was aimed at gaining a holistic view of how systems failures occur related to falls, ejections, and mis-positioning failure modes and to identify relationships, patterns and themes leading to a better understanding of the problem. Data mining was used as an imperative statistical tool to sort and organize information required to conduct the forensic analyses.

The National Electronic Injury Surveillance System (NEISS) is an extension of the U.S. Consumer Product Safety Commission (CPSC) that collects data from hospital emergency departments treating victims of amusement ride accidents. A query of the NEISS database for amusement accidents from 1995-2014 returned 10,659 accidents; however, no R^2CS failures were specifically noted.

The National Safety Council (NSC) is a public service organization that promotes safety in the community and collects data for a number of industries including the amusement industry. NSC collects data from regulatory agencies conducting accident investigations and from fixed-site amusement park injury surveys. The accident data are summarized at a high level in reports that are published annually. The data summarized in the NSC Annual Report (2013) were used to generate the graph in Appendix A to provide a comparison for various sporting and recreational activities based on the number of accidents per million versus amusement industry estimates for accidents per million for ridership. Summary data collected by the NSC were used as exposure data as a control for advanced comparison analyses.

RideAccidents.com (RA) is a non-profit organization which offered the most comprehensive database with investigative reports and accident details for the industry. The organization has no affiliation with government agencies, amusement industry organizations, or advocacy groups and acts as a resource to help identify the cause of amusement ride accidents and to facilitate safety awareness. There were 97 R^2CS accident reports retrieved from RA's database. Many researchers use this database to obtain information regarding amusement accidents.

The Amusement Safety Organization (ASO) is a non-profit organization that also tracks ride injury information and was used to augment the total number of accident reports used in the analyses. Other data sources came from state and local authorities, regulatory agencies such as the Health & Safety Executive (HSE-UK) and consumer advocacy groups such as SafeParks.

RA's database contained the majority of the R²CS accident reports, however, a *data polling* technique was used to capture additional information and updates to the original accident reports. Data polling is an accepted practice used by researchers to enhance data quality, wherein several sources are consulted for updates, augmentation of details, and corroboration of facts. The primary sources that participated in the data polling and contributed to the data collection effort are listed in Table 4 below.

Table 4. Data Sources: Amusement Ride Accident Reports

Analysis Code	Data Source	Description	Affiliation	website
1	RAs.com	RideAccidents.com	non-profit	RideAccidents.com
2	ASO	American Safety Organization	non-profit	amusementsafety.com
3	NEISS	National Electronic Injury Surveillance System	government	cpsc.gov
4	NSC	National Safety Council	public service	nsc.org
5	SaferParks	Safer Parks	advocacy	saferparks.org
6	HSE	Health and Safety Executive	regulatory	www.hse.gov.uk
7	OABA	Outdoor Amusement Business Association	trade organization	oaba.org
8	Misc.	Reporting Agency	authority having jurisdiction	Referenced in document

3.2.3 Sampling Plan

A critical element of the design methodology is the sampling methods used in the study. A non-probability, purposive sampling strategy was used for the sampling plan. The rationale for selecting the purposive sampling plan was to focus on specific characteristics of the population that are of interest for the study. The phenomenon being studied has specific characteristics that are not common to all amusement ride accidents; therefore, the population of interest is amusement R^2CS failures where patrons who met ridership requirements were able to defeat the R^2CS.

For more advanced analyses, additional purposive sampling techniques were used to sample events that had very specific attributes as well as very rare occurrences. After the initial analyses, an *extreme case sampling* technique was used as the basis for the development of the logistical regression model. Extreme case sampling is a type of purposive sampling technique that considers unusual events such as R^2CS failures that had notable outcomes that can lead to increased knowledge and understanding regarding the phenomenon under analysis, thereby providing direction for future studies.

3.2.4 Sample Size

Since the population was limited to the events where the physical anthropometric attributes allowed patrons to defeat R^2CS represent a statistically small patron base, the entire population of R^2CS accident events was used in the analyses. An event is defined as one documented incident involving a R^2CS failure that resulted in an injury to one or more people on a ride.

According to Gay (2003), for small populations with less than 100 units, the entire population should be sampled. The sample population of R^2CS failures retrieved from accident databases yielded 109 events for a total of 112 injuries over a 20 year period from 1995-2014. In keeping with Gay's recommendation, the researcher considered 109 events to be a small population; therefore, the entire population was used in the study.

3.2.5 Validity

Threats to validity are inherent in design constructs used in studies but were mitigated or minimized through purposeful strategies. At the core of the study were key elements associated with careful data collection, sample selection and appropriate statistical analyses. The two types of threats to the validity of this study were internal and external threats. Threats to internal validity challenge whether the researcher's conclusions are correct, while threats to external validity emerge when the researcher's inferences are incorrect based on attributes of the sample population.

This study looked at past events and provides insight into potential risks or stability aspects in relation to an outcome that was established at the start of this study. Retrospective studies are more prone to errors due to confounding and bias than other studies. Therefore, for this engineering project, every effort was made to avoid the introduction of confounding and bias that threaten internal and external validity by focusing on quality data collection, sample selection, population, repeatability, and having an independent third-party review.

An important step in the process was to make sure quality and relevant data were collected for this study. The data collected came from amusement industry databases that consolidate federal and local government investigation agency reports, emergency department accident reports and park operator accident reporting data. The collected data were organized in an Excel® workbook, re-entered three times, and checked each time against the original data reports.

Re-running the analyses several times to verify repeatability was implemented at various stages of the analysis process as well as at the conclusion of all the analyses. These measures provided repeatability of results for the study.

3.2.5.1 Internal Validity

As part of the study to determine cause-and-effect or causal relationships wherein internal validity was the primary consideration, the question that was asked was *were the changes in the independent variable really responsible for the change in the dependent variable, or is the variation in the dependent variable the result of something else?* According to

Creswell, threats to internal validity are the experimental procedures, treatments or experiences of the participants that threaten the legitimacy about the researcher's inferences. Internal validity only applies to the specific study (2009).

Table 5.Types of Threats to Internal Validity (Creswell 2009)

Types of Threats to Internal Validity			
Type	**Description of Threat**	**Applicable**	**Mitigation Strategy**
History	Over time events can occur that unexpectedly influence the dependent variable?	No	
Maturation	Changes in dependent variable due to development over time?	No	
Regression	Participants with extreme scores are selected for the experiment. Score change over time, regression toward the mean.	No	
Selection	Participants selected who have certain characteristics that predisposed them to certain outcomes.	Yes	Only participants that defeated R^2CS are selected for this study
Mortality	Participants drop out of the study and outcome unknown for these individuals	No	
Diffusion of Treatment	Participants in the control and experimental groups communicate with each other and influence the outcomes.	No	
Compensatory / Resentment	Benefits of experiment unequal. Experimental group gets treatment and control group gets nothing	No	
Compensatory Rivalry	Social competition motivates subjects in groups not receiving goods/services attempt to reduce or reverse effects of desired treatment.	No	
Instrumentation	Instrument changes between pre-test and post-test, impacting scores on outcome.	No	

For this project, the relevance of internal validity was concerned with the outcome associated with R^2CS failures based on independent variables obtained from the data collection process. It should be noted that in order for internal validity to exist, there only needs to be evidence to support what was done in the analysis/study that produced the observed outcome, even if it was not what the researcher wanted to observe. Table 5, *Types of Threats to Internal Validity*, summarizes the different types of internal threats (Creswell, 2009, p. 163-164) for consideration. Data/participant selection was the only applicable threat to internal validity for this study.

Therefore, great care was taken to identify the relevant criteria required for data selection to minimize the threat to internal validity. To achieve internal validity, a causal relationship needed to exist. The analyses were used to establish whether a relationship occurred among certain anthropometric mis-match contributors (predictor variables) and the likelihood of an amusement ride restraint and containment systems failure (dependent variable). The threats to the internal validity of this project were limited to data selection, treatment of data and the researcher's interpretation of the results. Since this was a retrospective study, the design controlled variables for behavior and cognition to determine if the observed relationship between R^2CS failures and anthropometry were the result of a third variable.

3.2.5.2 External Validity

Identification of potential threats to the external validity of the study were identified, and design strategies were implemented to minimize threats. When incorrect inferences are drawn from the sample data, external validity threats emerge. Threats emerge due to the characteristics selected for the sample, the uniqueness of the setting, and the timing of the experiment (Creswell, 2009). This study design was carefully constructed to ensure the sample represents the target population. A non-probability, purposive sampling plan that used a total population sampling scheme was implemented so that only data with specific R^2CS failure characteristics were selected. R^2CS failures where participants met ridership requirements that were not attributed to operator error or equipment failure related events were selected for this study. The sample method selected was intended to reduce sampling bias (error) created when differences in the sample and target population exist. While sampling errors cannot be totally mitigated, strategies were implemented that minimized sampling bias. The population-based design described herein minimized the chance of unintended outcomes associated with selection factors. All of the accident data associated with R^2CS failures that met the criteria were part of the study and the statistical analyses. The more representative the sample is to the population, the more confidence there is in generalizing from the sample to the population (Kukull, 2012).

One area of concern regarding external validity centers around the underreporting of eligible events and reports that were held in confidence and not made available in the public domain. Due to the sensational aspect of the failure mode, most R^2CS events make it into the public domain. However, omitted data include the near misses that do not make it into the public domain because they are not considered a recordable accident. Not having this data available restricts researchers from drawing correct assumptions and accurate results.

3.2.6 Data Treatment

All identified accident reports located from 1995 to 2014 were reviewed and all R^2CS failures that were not associated with equipment failures or operator error were retained for this study. Of the 109 R^2CS failure events retained, 112 injuries occurred due to more than one patron being injured as a result of one failure event.

There were three focus areas during the data mining process. For treatment of data retrieved from accident databases, the first step organized the data into manageable blocks and isolated R^2CS failure modes that fell outside this study and segregated superfluous information contained in the dataset. This approach led to the second step which was to identify the most relevant variables required for the development of statistical models.

During step 2, qualitative data were assigned quantitative values so the data could be sorted and organized; then, simple univariate analyses of frequency distributions were performed to determine themes and patterns. Preliminary analyses provided an organizational structure for the data and a basis for advanced analyses to examine relationships among variables.

More advanced analyses using bivariate and multi-variable models were conducted in order to examine relationships for two or more variables. The outcome from the study was to provide accident statistics of amusement R²CS failures and offer a forcing function design guidance matrix based on the results of the forensic analyses.

The data were organized by year into a Excel® workbook. The workbook tabs were arranged by year and category. Labels describe variables that were located in the column headings of the spreadsheet. The events were listed on the rows. Numerical codes represent categories (e.g. male=1, female=2, unknown=0) for ease of sorting and managing data. The numerical values for the continuous age variable were retained. For structure see Table 6.

Table 6. Legend: Categorical Coding: Data Format and Structure

Event item	Source		Date	Injury Severity		Failure Mode	F1	F2	Gender		Age		Cognitive Stage		Behavior	B-1	B-2	B-3
				unkn	0	unknown	0		unk	0	unk	0	unknown	0	unknown	0		
1	RAs.com	1		minor	1	ejection/fall	1		male	1	<2	1	pre-operational (2-7 yrs)	1	normal	1		
2	ASO	2		major	2		2		female	2	2	2	concrete operational (8-12 yrs)	2	drugs/alcohol	2		
3	NEISS	3		death	3	misposition /extraction	3				3		formal operational (13 yrs - adult)	3	thrill seeking	3		
4	NSC	4				dragged	4				4		mentally disabled	4	waving hands	4		
5	SaferParks	5				struck equip	5				5		sensor-motor (0<2 yrs)	5	standing up	5		
6	HSE	6				oper error	6				6		distraught	6	extraction mispositioning	6		
7	OBAB	7				pinned/crushed	7				7				unconsciousness	7		
8	Other	8									8				climbing	8		
											9				kneeling	9		
											10				facing bwkd	10		
											11				fear	11		
											.				unlatched restraint	12		
											.				rocking car/gondola	13		
											.				crossed legs	14		
											60				existing RV	15		
															Unruly	16		

Physical Limitation		Site type		Ride Type		Seating Config		Restraint Type	R-1	R-2	Restraint Class	Prev Issue		Region		Region	
unknown	0	unkn	0	unknown	0	unknown	0	unknown	0		0	unknown	0	unknown	0	NH	26
special needs	1	fixed	1	coaster	1	single rider	1	multi lap bar	1		1	yes	1	AK	1	NJ	27
too large	2	mobile	2	kiddie train	2	dual rider	2	over shoulder	2		2	similar	2	Asia	2	NM	28
too small	3			carousal	3	multi riders	3	none	3		3	no	3	Australia	3	NV	29
none	4			360 loop coaster	4			strap betw legs	4		4			Az	4	NY	30
				flume	5			seatbelt	5		5			CA	5	OH	31
				kiddie coaster	6			indiv lap bar	6					Canada	6	PA	32
				rotate in plane	7			T-bar	7					CO	7	Philippines	33
				free fall/tower	8									CT	8	SC	34
				rotating/ spinning	9									Eng/UK	9	Singapore	35
				ferris wheel	10									FL	10	southern_HEM	36
				ski lift style	11									GA	11	Spain	37
				swing chair	12									IA	12	TN	38
				bungee/sling shot	13									IL	13	TX	39
				inv coaster	14									IN	14	UAE	40
				kiddie ride	15									Japan	15	Hawaii	41
				boat/water	16									KN	16		42
				simulator	17									LA	17		43
				stand up coaster	18									MA	18		44
				cage	19									MD	19		45
				pendulum	20									MI	20		46
														MN	21	UT	47
														MO	22	VA	48
														MS	23	WA	49
														NC	24	WI	50
														NE	25	Europe	51

Preliminary descriptive analyses were performed in Microsoft Excel®. The workbook data was imported into the IBM SPSS Statistics Revision 22 analysis software package where intermediate and advanced statistical analyses were performed as part of the forensic analysis phase.

3.2.7 Data Analysis

It is important to match the design methodology to the design questions (Elliot, 2007); the statistical analyses offered the ability to systematically examine R^2CS accident data and use the results as a predictive tool to draw conclusions about the data. Therefore, 12 categorical variables and one continuous variable noted in Table 7 were selected from the R^2CS accident data reports from 1995-2014.

For the logistic regression model, failure mode was examined and set up as binary outcomes for ejection/fall or a not secured event. A not secured event refers to a state where the patron's anthropometry or somatotype shape was not adequately restrained in the containment system as opposed to ride designs that intentionally have excess containment space. In other words, when patrons were supposed to be securely fastened by the restraint containment device without excess space but due to stature were not able to be secured.

Restraint types most commonly used in the analysis were single lap bar, collective restraint (a belt or bar that restrains two or more patrons at a time for the containment compartment), and over the shoulder harness.

3.2.7.1 Univariate Descriptive Analysis

The retrospective phase utilizes descriptive analyses that calculate values for mode, mean and frequency distributions of single variables associated with R^2CS failures. The results are summarized in histograms to gauge frequency distributions, bar charts to display categorical data, and tables for cross tabulation results for multiple variables. Understanding the central tendencies of R^2CS incidents allowed inferences to be made about the data that advanced the forensic analyses. The results of the initial descriptive analyses are presented in Chapter 4, *Descriptive Analyses Results.*

Table 7. R^2CS Project Variables and Analysis Examples

Categorical Variable	**Description**	**Analysis Type**
Failure Mode	ejections/falls/not secured	Descriptive
Gender	male/female	Descriptive/Cross tabulation
Cognitive Level	sensori-motor/pre operational	Descriptive/Cross tabulation/Regression
Physical Limitation	too large/petite	Cross tabulation/regression
Seating Configuration	individual/dual/multi seating	Descriptive/Cross tabulation
Previous Issue	yes/no previous R^2CS failure	Descriptive/Fisher's Exact
Injury Severity	death/ major/ minor injuries	Descriptive/Cross tabulation
Behavior Style	standing/ self-extraction/unlatching	Descriptive/cross tabulation/Regression
Ride Type	coaster/ spinning/ free fall	Descriptive/Cross tabulation
Restraint Type	lap bar/ over shoulder/ collective/belt	Descriptive/Cross tabulation
Site Type	fixed-site or mobile ride	Descriptive/Cross tab
Continuous Variable		
Age	0-65 years	Descriptive/Cross tab/Kruskal Wallis

The objective of this analysis design is to use methods that are simple and effective in answering the questions whenever possible. According to Wilkinson (1999), the researcher should select the simplest statistical procedure that adequately answers the questions. Therefore, traditional descriptive, comparative and association analysis methods were used. Interpreting the results of the outcome was critical for understanding the problem associated with R^2CS failures bound by this study. Therefore, the question that needs to be asked is: *are the results due to random fluctuations?* According to Elliott (2007, p. 5) this question was addressed with executed statistical tests. The data types noted in table 8 identified the type of analyses used in the study.

Table 8. Data Type and Analysis Methods

Data Type	Analysis Type
Categorical/dichotomous	Descriptive/Cross tabulation/Exact tests/Regression
Continuous/non parametric	Descriptive/Cross tabulation/Kruskal Wallis

3.2.8 Limitations

This retrospective study utilized information from several sources in the public domain that was acquired during the accident investigation. Because no single entity is responsible for investigating accidents and data collection, standardization regarding what is reported and how it is reported was not consistent. Therefore, not all the accident data were accessible in the public domain and captured for this study.

3.2.9 Delimitations

Project delimitations of this study did not include ridership cases for patrons with partial or amputated limbs or casts. These cases are very complex with many factors to consider; therefore, they are beyond the scope of this retrospective study. Ridership qualifications for these cases are reserved for further studies.

Ride accidents associated with bungee jumping, zip lines and inflatable rides were not considered as part of the analysis data. These rides are considered non-traditional ride designs and lack a conventional containment environment. Further research for restraint and containment design criteria for these types of amusement rides and devices require additional research that falls outside the scope of this doctoral engineering study.

Amusement rides found at other venues such as malls, arcades, super markets, parties and events were not considered in this study.

Measurement of ride acceleration estimates were not made for this retrospective study. The intent of this project was not to determine safe g-force levels or if the cause of the accident was due to excessive g-force loads. The objective of the study was to examine the amusement R^2CS accident data for rides that were operating properly, rides within acceleration limits for the ride type with no mechanical or operational anomalies. G-force studies conducted by the Health and Safety Laboratory (HSL) since 1995 have concluded that nearly all the accidents associated with ejection from rides happened at relatively low ride accelerative forces (Jackson, 2007) and the rides were operating within the required accelerations. Therefore, the project moved forward in this spirit based on the assumption that unique anthropometry that prevaricates current design standards is more of a contributor than g-force levels.

3.2.10 Ethical Considerations

Although secondary data were extracted from public domain databases, any data that contained direct or indirect identifiers that make distinctive cases visible were treated so that the identifiers did not reveal the identities of victims, ride manufacturers, specific parks, carnivals or fairs. The researcher's objective was to protect all parties associated with the accident data. The researcher considered the analytic importance of the qualitative-secondary data collection and concluded that in some cases removing direct or indirect identifiers imposes limitations on future research that is intended to replicate or augment content. Therefore, the datasets were divided into public-use and restricted-use data files in order to maintain the integrity of the analysis. Refer to Appendix C for the complete Data Management Plan.

3.3 Forensic Analysis

All the computations associated with the retrospective phase are applied methods intended to advance understanding of the problem. The forensic analysis identified data patterns, differences, themes, relationships, and trends that established the appropriated forcing function guidance matrix for the development of amusement R^2CS that accommodate patrons with unique anthropometry. A closer examination of the data was performed using the appropriate bivariate and multivariate techniques. Several comparative analyses using industry exposure data published by NSC (2015), HSE (2005), and the US CPSC (2007) was evaluated against the R²CS accident data.

3.3.1 Bivariate Analysis

Cross tabulation analyses to compare industry data with the doctoral R²CS accident data was applied to judge whether differences between the two groups were valid or were due to chance. The same test holds true for the analyses that compared two variables within the R²CS dataset. This test allowed the researcher to make inferences about the data that were more applicable in terms of generalities.

3.3.1.1 Chi-square and Fishers' Exact Test

The statistical test that compared whether differences exist between variables was the chi-square statistic and associated *p*-value. For small values of expected numbers, the chi-square test is inaccurate; therefore, in cases where the expected value was less than five, the Fishers' Exact Test (FET) was used instead. The probability ability of rejecting the null hypothesis even if true (false positive) used a significance level of p=0.05. Cross tabulation tests were performed on design questions 1 through 12B listed in Table 3, *Design Questions and Analysis Method.*

3.3.2 Multivariable Data Analysis

With multivariate analysis, a statistical technique was used to examine the relationship among multiple variables at one time. Several iterative cross tabulation calculations for predictor variables associated with cognitive level, behavior, physical limitation, restraint type and seating configuration were performed as a precursor to setting up the logistical regression model. The confidence interval of 95% was used. Either the chi-square or Fisher's Exact Tests were performed to determine whether there are significant associations among variables.

3.3.2.1 Kruskal Wallis Non-Parametric Test

An attempt to use a one-way ANOVA model to test the statistical significance in mean for age across ride types for the dependent variable (failure type) was unsuccessful. The tests for homogeneity and normality were not accepted. Therefore, the Kruskal Wallis non-parametric test was used instead. The Kruskal Wallis model was developed to analyze design question 10B identified in Table 3, *Design Questions and Analysis Method* which asks, "Is there a significant difference in the average age across different ride types? The results of the model are discussed in Chapter 5, *Forensic Analyses Results.*

3.3.2.2 Logistic Regression Model

The forensics analysis consisted of several bivariate and multivariate models to establish the association of predictor variables to dependent variable outcomes. Bivariate cross tabulation analyses were performed for all the variables in the study. A logistical regression model was developed that evaluated multiple predictor variables to determine the impact on anthropometric mis-match associated with cognitive ability, behavior style and ride characteristics for statistical significance. The logistic model estimated the likelihood that an ejection/fall failure mode would occur based on an iterative process where the results are interpreted from the output value of the odds ratio, *Cox and Snell* (C&S) R^2 *and Nagelkerke* R^2. Both R^2 techniques are pseudo statistics that measure the strength of association of the model. More focus was placed on the Nagelkerke R^2 statistic which is a variant of the C&S R^2 statistic and was considered a better measure of likelihood and, therefore, a more suitable indicator of strength of association for the model. Chapter 5, *Forensic Analysis Results* discusses the results of the logistic analyses in detail.

For the logistic regression analysis, the model was set up to determine the probability that the categorical dependent variable for failure mode was measured on a dichotomous scale for the response based on five predictor variables. The predictor variables used in the model were anthropometric mis-match, diminished capacity, behavior, restraint type, and seating configuration.

Use of the logistic regression model was contingent upon the ability to analyze the R²CS dataset. Initial assumptions for suitability of the data for the logistic regression model was based on the measurability of the dependent variable on a dichotomous scale, independent variable data type were categorical, independence of observations, and the dependent variable has mutually exclusive categories. These assumptions were validated prior to preforming the logistic regression analysis.

The logistic regression was conducted with failure mode (ejection/fall, not secured) as the dependent variable and patron characteristics as predictor variables (anthropometric mis-match, diminished capacity, and behavior). The dependent variable binary coding arrangement (ejection/fall =0, not secured=1). The not secured failure mode was defined as a patron that could not be properly restrained due to their stature not because of the intentional design to have excess containment space. The model was set up to predict the probability of the failure mode ‘not secured’ as opposed to ejection/fall. Reference categories are normal behavior, not having diminished capacity, and not having anthropometric mis-match. The Omnibus Tests of the Model Coefficients were consulted to see if the new model improved over the baseline model. The test used the chi-square statistic to determine if there was a significant difference in the log-likelihoods between the old and new models. The variability in the dependent variable was explained by the predictor ranges according to the Cox & Snell R^2 (C&S) which is based on the log-likelihood and also takes into account the sample size. Nagelkerke R-squares adjust the C&S statistic to achieve the maximum value of 1 for a better estimate for likelihood. Finally, the Variation in the Equation output table provided the overall summary of the predictor variables in the model.

3.4 Data Management

A data management plan (DMP) was developed that identified how data were collected, organized, shared and stored. The data were stored and made accessible over a period of ten years. The format type, data structure, and meta-data generated are discussed in the DMP. A directive of how the data is made available in the future to other researchers was accounted for in the DMP in Appendix C. The objective of the DMP was to protect the integrity of the data and safe guard against loss or corruption.

The datasets were deposited with Old Dominion University's Institutional Repository, Norfolk, Virginia. They shall be responsible for the long-term stewardship, curation, protection, and availability of data. Intellectual property and data generated under this project shall be administered in accordance with both the University's and the National Science Foundation's (NSF) Engineering Directorate policies including the NSF Data Sharing Policy and *ODU policy numbers 5350 and 3504* (Appendices D&E).

3.5 Summary

The methodology was developed as a two phase approach. The retrospective study, included data collection, data treatment, data management, sampling plan, preliminary descriptive analyses, and validity. The design construct focused on strategies that maintain the quality of data selection and analysis methods, ultimately, leading to the appropriate inferences about the results; whereupon, the project advanced to the next phase.

The design methodology concentrated on applied bivariate and multivariate models. Kruskal Wallis and logistic regression models were developed to determine goodness of fit of the model and significant association for independent variables associated with patron characteristics, ride configuration and ride type for the dependent variable for failure type.

The results of the retrospective study are noted in chapter 4, and the results of the forensic analyses are located in chapter 5. Chapter 6 provides recommendations and R^2CS mitigation strategies and a forcing function design guidance matrix.

CHAPTER 4

Descriptive Analysis Results

4.1 Introduction

The purpose of this section was to examine the results of the preliminary statistics for the descriptive analyses for amusement R^2CS accident data from industry databases to gain a better understanding of the distribution of failures. As part of the retrospective phase, the study evaluates data in terms of central tendency measurements for frequencies, percentages and distribution of categorical variables that are specific to unique patron somatotype shapes and anthropometry considered challenging for existing design criteria. The results of the descriptive analyses helped guide the strategy for the advanced bivariate and multivariate analyses required to perform the forensic phase of this engineering project.

4.2 Frequency Distribution Results

Data collection yielded 109 R^2CS failure events resulting 112 injuries over a twenty year period from 1995-2014. The total sample population of R^2CS failures retrieved from industry databases was used in the preliminary statistical analyses. Graph 2 depicts the number of failure event incidences per year. The R^2CS failure data were also divided into ten year durations to determine trends. The dataset of 112 injuries yielded 32% of the incidents as fatalities. Although the middle time period inclusive of years 2002-2007 represents 30% of the total time span analyzed, it accounted for 41% (45) of the total reported failures. In the preceding seven years, there were 24 (22%) failures reported, and in the following seven years, there were 40 (37%) failures.

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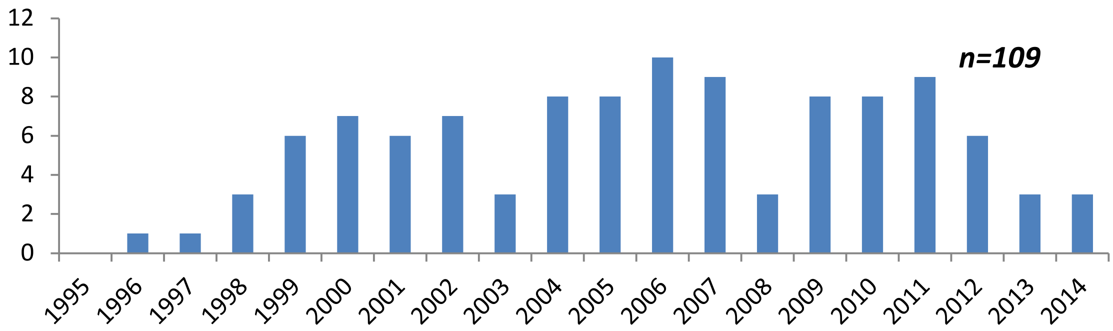


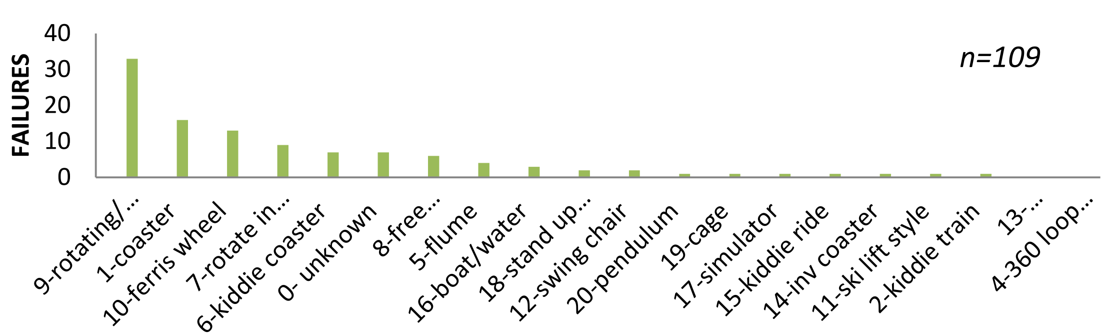
Graph 2. Failure Events: R²CS Failure Frequencies by Year

4.2.1 Failure Mode

The majority of the R²CS failure modes associated with the sample are ejections or falls from the ride system. Of the 112 injury sample size, 97 were related to ejections and falls; 15 were related to the patron not being secured; 16 patrons were struck by another vehicle or ride structure after ejecting or falling from the ride while in motion.

4.2.2 Ride Type Failures

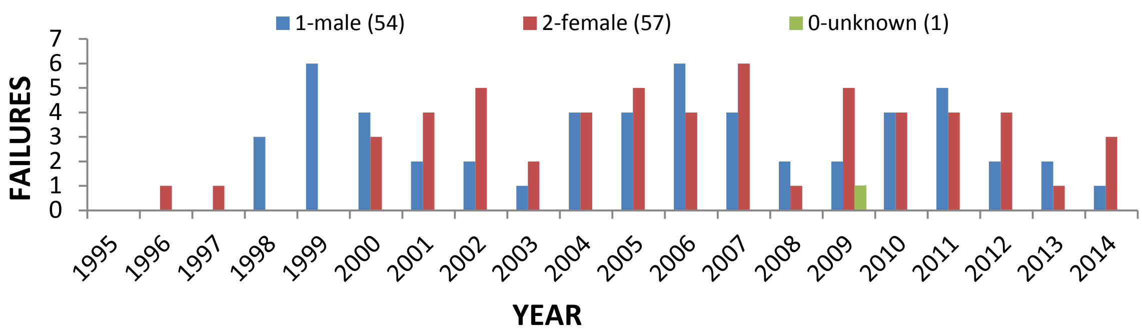
Frequency counts for R²CS failures for ride type show that rotating-spinning rides have the highest R²CS failure counts. There were 40 related failures associated with rotating-spinning rides followed by 20 failures for coasters, 13 failures for kiddie rides and 11 for vertical wheels. These four types of rides account for 77% of the total failures (Graph 3).



Graph 3. Ride Type: 20 Year R²CS Failure Frequencies

4.2.3 Gender Frequency

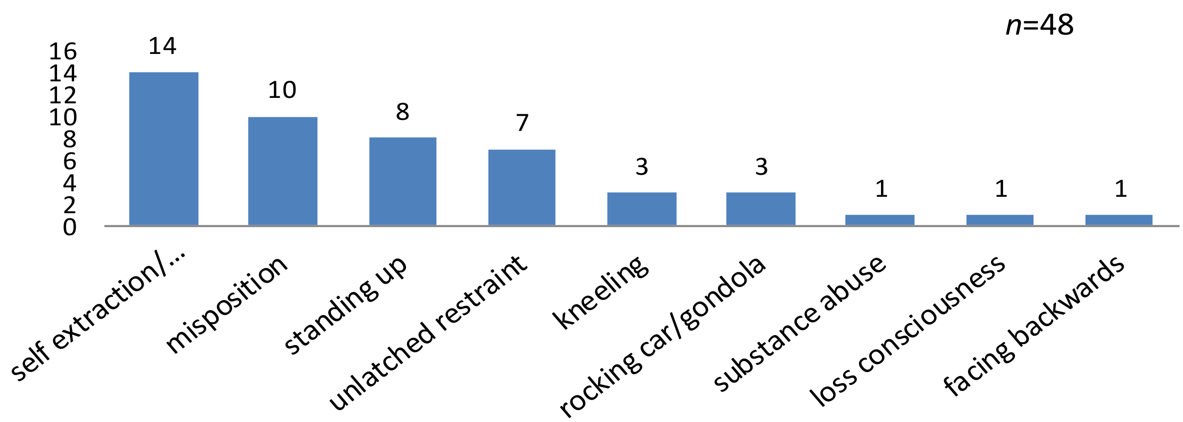
The data for gender association for failures indicated the data were nearly flat, with female patrons slightly higher accounting for 57 failures versus 54 failures associated with male patrons (Graph 4). Male incidents for R²CS failures for 1995-2004 yielded 22 events and increased to 31 events for 2005-2014. This was a 41% increase for males associated with R²CS failures. Females also saw an increase in failure related events for 2005-2014 with 36 failures versus 20 for the preceding ten years, an increase of 80%. The results indicated an upward trend for both genders for R²CS failures.



Graph 4. Gender: 20 Year R²CS Failure Frequencies by Year

4.2.4 Behavior

The sample size for non-compliant behavioral styles noted in reports was 48 with nine different types of behaviors. The balance of the other accident reports did not indicate patron behavior. Patron self-extraction yielded 14 failures, followed by patron mis-position (10) and standing up accounted for 8 failures (see Graph 5). The distribution was fairly flat for the remaining six behaviors. Although the behaviors were broken out by specific type, 29 cases were categorized as thrill-seeking behavior. Incidents considered thrill-seeking occurred in 14 cases from 1995-2004. The next ten years saw an increase of 48% in thrill-seeking behavior.



Graph 5. Behavior Style: R²CS Failure Frequency Distribution (1995-2014)

4.2.5 Injury Results

Of 109 R²CS failure events there were 112 injuries. Thirty-six injuries resulted in death, 39 injuries were major, 19 were considered minor and the injury statuses of five cases were not given.

4.2.6 Cognitive Level Versus Injury Frequency

The majority of the injuries were associated with the formal operational stage that ranges from 13 years of age to adulthood. This level of cognition accounted for 44% of the total number of injuries. A finer resolution of this cognitive group revealed that 24 injuries were associated with patrons 21 years old or under. Combined pre-operational and concrete operational cognitive levels realized 44% of the injuries and when including distraught patron (2), sensori-motor (4) and 24 injuries associated with ages 13-21, this age range represented

75% of the injuries. (See Figure 9, *Cognitive Level: R²CS Failure Frequency Distribution).* This indicates that three quarters of the injuries happened to patrons under 22 years old and points to this group as being more at risk for injuries associated with R²CS failures.

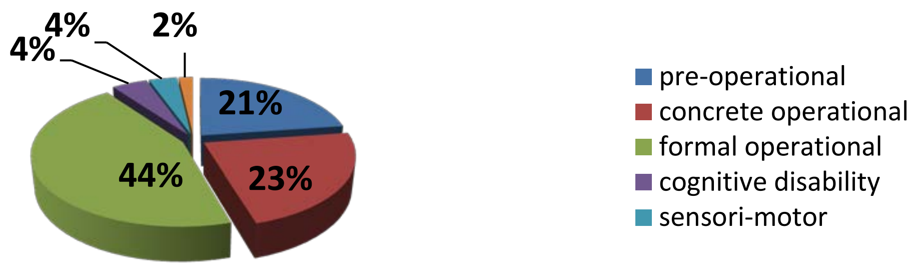
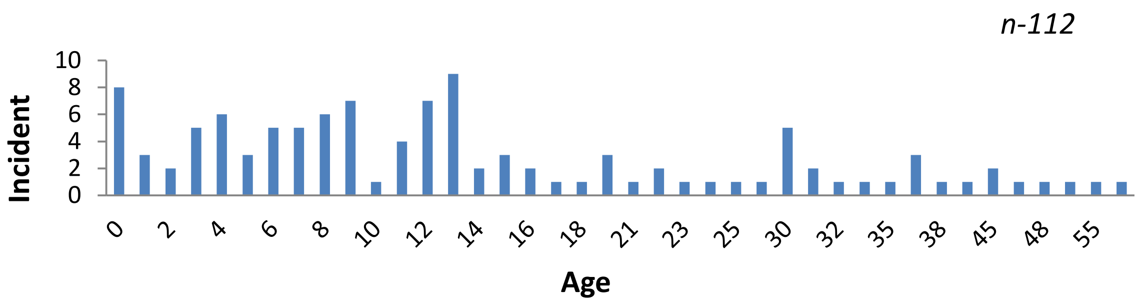


Figure 9. Cognitive Level: R²CS Failure Frequency Distribution (1995-2014)

The frequency of the raw data for ages (Graph 6) identified the highest cluster of injuries was associated with ages 8, 9, 12, 13.



Graph 6. Age: R²CS Failure Frequency. (1995-2014)

4.2.7 Restraint Type Frequency Distribution

Collective lap bar restraint sustained the most system failures at 38% (33), rides without restraints accounted for 21% (18), followed by over the shoulder restraint at 20%

(17). Failures associated with individual lap bar (11%) and seat belt restraint types (9%) had a lower frequency distribution. See Figure 10, *Restraint Type Failure Frequency Distribution*.

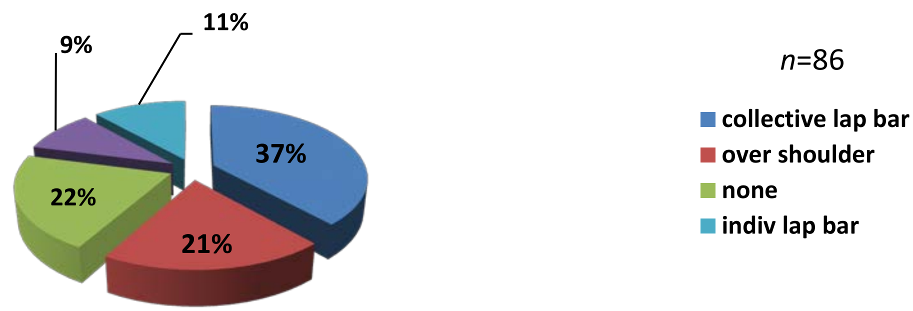
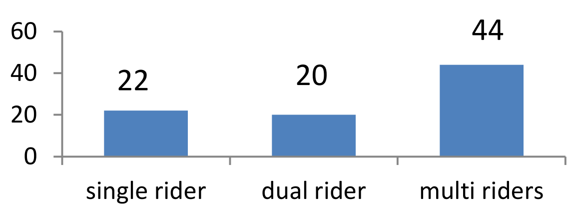


Figure 10. Restraint Type Failure Frequency Distribution

4.2.8 Seating Configuration

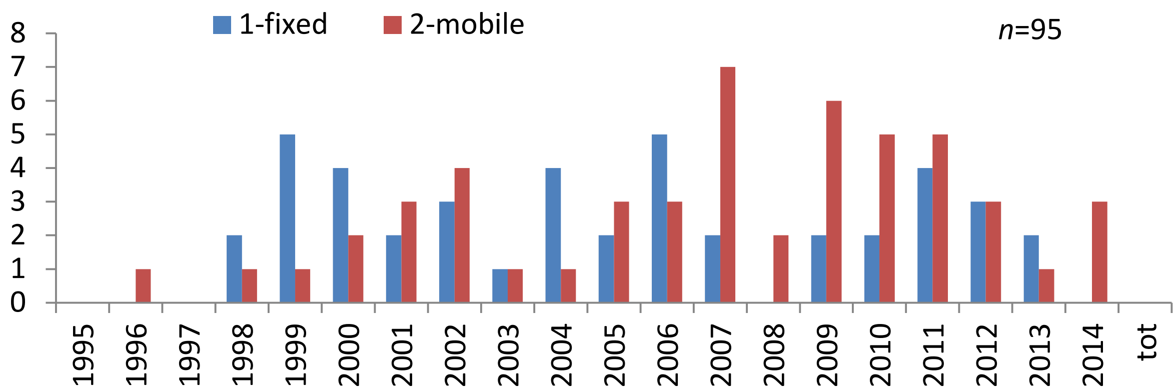
The dataset for patron seating configuration yielded a sample size of 86 where the majority (44) of the R^2CS failures occurred on systems that had multiple riders to a compartment. Single and dual rider seating configuration failures were closer with single rider incidents slightly higher at 22.



Graph 7. Rider Seating Configurations

4.2.9 Site Type

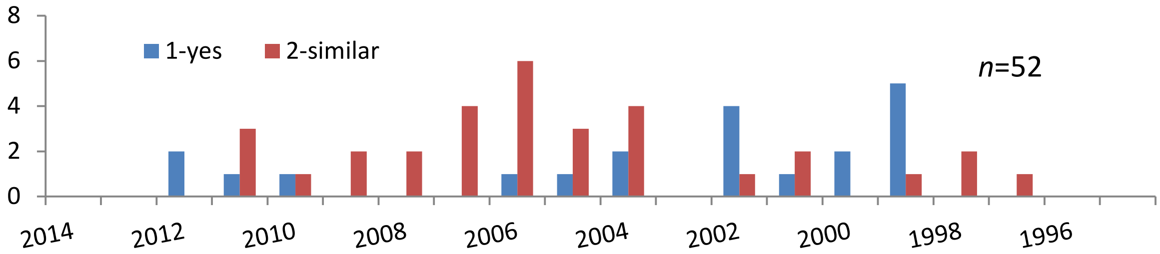
The R²CS failure data identified 95 venue site types where 43 were associated with fixed-site ride. Trend data for fixed-site type remained nearly flat for the ten year increments. The first ten years yielded 21 incidents. Mobile-site rides saw an upward trend during the last ten years when 38 of the 52 incidents occurred. See Graph 8, *Fixed-Site Versus Mobile-Site R²CS Failure Frequency*.



Graph 8. Fixed-Site Versus Mobile Ride R²CS Failure Frequency

4.2.10 Rides With Previous R²CS Issues

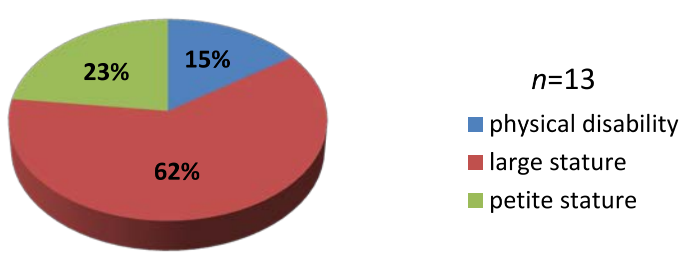
Nearly half (52/109) of the incidents happened on either the same ride (20/109) or on similar ride types (32/109). The balance of the incident reports provided no indication to conclude that an incident happened previously on the same or similar ride type.



Graph 9. Previous R²CS Issues Frequency Distribution

4.2.11 Patron Limitation

Of the 112 injury incidents 12% of patrons had a physical limitation, eight patrons were too large for the restraint, three patrons were of petite stature and two with a physical and or cognitive disability. Graph 10, *Patron Limitation Distribution Percentages*, depicts the percentages based on a sample size of 13.



Graph 10. Patron Limitation Distribution Percentages

4.3 Summary

The descriptive analyses provided insight into the frequency and distribution of 12 categorical variables and one continuous variable associated with a retrospective study for R^2CS failures over a twenty year period. The descriptive analysis helped set up the variables to be examined for significance for the forensic models. The results are located in the next chapter.

Chapter 5
Forensic Analysis Results

5.1 Introduction

The descriptive analyses offered both expected and unexpected results about R^2CS failure data that led to the development of a list of design questions for analyses. The questions were constructed so that the analyses compared the R^2CS data collected to that of industry exposure data as a control measure for injury distributions for age and behavior. Other design questions focused on the association between two variables across an event, ride features, and patron characteristics for the collected R^2CS data. Bivariate analyses were performed in advance of the multivariate logistic regression model to establish whether there was a significant association between predictor variables noted in Table 7 and the dependent variable for failure type. Table 11, *Design Questions and Associated Significance* provided the p-value for the list of the design questions and whether or not a significant association was identified as a result of the analyses performed. Six of the 18 design questions had no statistically significant association.

5.2 Industry Comparative Analyses

Industry injury data were compared to the R^2CS data in determining if differences exist for patron characteristics, ride features, and events.

5.2.1. Age Comparison Analysis

The age variable for cognitive level for the R^2CS data was recoded to align with the Health Safety Executive (HSE) Passenger behavior on amusement rides field study report

(2007) data and compared for differences. The cross tabulation analysis yielded three cells that produced expected counts less than five, therefore, the Fisher's Exact Test (FET) was used to determine whether there was a statistically significant difference between age distribution observed for the HSE data and the R²CS failure data (FET=49.4, p=.000). There was a higher percentage of age 0-10 for the R²CS data compared to the HSE data (47% vs. 33%) The percentage of age range 11-15 was lower for the R²CS data compared to HSE (25% vs. 48%). Both age groups for 31-50 and over 50 years old had a higher presence among R²CS failure data compared to the HSE observed data. See summary of the analysis in Table 9.

Table 9 Age Range Distribution Observed Data for HSE Comparison.

	Data source	-Study groups, n (%)	
	R²CS	HSE	p-value
Age Range			.000
Development phase			
0-10 yrs	51 (46.8)	946 (33.0)	
11-15 yrs	27 (24.8)	1388 (48.3)	
16-21yrs	8 (7.3)	308 (10.7)	
22-30 yrs	6 (5.5)	118 (4.1)	
31-50 yrs	14 (12.8)	105 (3.7)	
>50	3 (2.8)	4 (0.1)	

5.2.2 Behavior Comparative Analysis

Behavior was recategorized to align with the HSE Passenger behavior on amusement rides, field study report (2007) data for normal, mis-position, unlatching/interfering with mechanism, self-extraction, standing up and others and cross tabulation tests were performed. There was a statistically significant difference between the behavior distribution observed for the HSE data and the R²CS failure data (FET= 75.44, p=.000). Results of analysis in Table 10 show there was a higher percentage of normal behavior observed for the HSE data (76%) compared to the R^2CS data (50%). Behaviors standing and unlatching were also more predominant in the R^2CS data (23% and 7%) compared to the HSE data (0.5% and 1%). Misposition was slightly more common under the HSE data at 17% versus 14%.

Table 10. Behavior Type Observed for HSE Data Comparison

Data Source	Study groups, n (%)		
	Doctoral R^2CS	HSE OA injuries	p-value*
Behavior Type			.000
normal	47 (50.0)	2150 (76.3)	
miposition	13 (13.8)	480 (17.0)	
unlatch/interf w/mech	7 (7.4)	24 (0.9)	
self-extraction	0 (0.0)	14 (0.5)	
standing	22 (23.4)	126 (4.5)	
other	5 (5.3)	22 (0.8)	

5.2.3 Fixed-Site Versus Mobile Ride Comparison

Overall injury rates for fixed-site and mobile-ride venues were obtained from CPSC reports for the years 1997-2004 and compared with the R^2CS failure data for the same time frame. Chi-square tests indicated there was a significant association between data source (R^2CS, overall) and the type of site (fixed, mobile) venue (chi-square=4.2, p=0.040). Mobile sites were positively associated (53%) with R^2CS failures compared to 43% of overall injuries occurring in mobile ride venues.

Table 11. Design Questions and Associated Significance

DQ	**Questions**	**Association**	**p-value**
1	Is the *age distribution* observed for Health Safety Executive (HSE) industry data comparable with the doctoral R²CS data?	Yes	.000
2	Is the *distribution of behavior* type observed for HSE industry data comparable with doctoral R²CS data?	Yes	.000[1]
3	Is there an association between type of *failure* (R²CS vs. NSC overall industry) *ride* related injuries and *ride type*?	No	.725
4	Are R²CS injuries observed more frequently among *fixed-site or mobile rides* compared to CPSC overall industry injuries?	Yes	.040
5	Do *males* display more *non-compliant behavior* than woman?	No	.929
6	Does *injury severity* differ between *ejection/falls and not secured* for patrons in doctoral R²CS failure data?	No	.148
7	Is there an association between *cognitive level and ride types* for doctoral R²CS failure data?	Yes	.000
8	Is there an association between *cognitive level and severity of injury* for doctoral R²CS failure data?	No	.665
9	Is there an association between *diminished capacity and non-compliant behavior* for doctoral R²CS failure data?	No	.344
10A 10B	A) Is there a relationship between *age groups and ride types* as defined by HSE industry data? B) Is there significant difference in the *average age* across different *ride types*?	Yes Yes	.052[1] .001[2]
11	Is there an association between the *physical limitations vs. failure mode* for doctoral R²CS failure data?	Yes	.000
11A	Is there an association between having an *anthropometric mis-match and failure mode* for doctoral R²CS failure data?	Yes	.001
11B	Is there an association between *diminished capacity* and *failure mode* for doctoral R²CS failure data?	Yes	.012
11C	Is there an association between *behavior and failure mode* for doctoral R²CS failure data?	Yes	.000[1]
12	Is there an association between *ride security settings vs. failure mode* for doctoral R²CS failure data?	N/A	---
12A	Is there an association between *failure mode and restraint type* for doctoral R²CS failure data	No	.177[1]
12B	Is there an association between ride seating configurations vs. *failure mode* for doctoral R²CS failure data?	No	.445[1]
13	Does having a physical limitation in terms of anthropometry, diminished cognitive ability and wanton/risky behavior make a failure event more or less likely to result in an ejection/fall?	Yes	.000[3]

[1]Fisher's Exact Test
[2]Kruskal Wallis Non-Parametric Test
[3]Logistic Regression

5.3 Patron Characteristics for R^2CS Data

Patron characteristics associated with R^2CS failures were evaluated to determine significance associated with age, gender, patron limitation, and behavior.

5.3.1 Cognitive Ability across Ride Type

There were significant differences in the distribution of cognitive ability across the different types of rides (Chi-square=49.96, p=.000). See Table 12 for results. The cross tabulation showed that 75% of the failure events in coasters happened among the 13 to adults group, 41% for rotating-spinning rides, 36% in the Ferris wheels category and 18% for kiddie rides. Normally, the FET would be used to calculate the statistic, but due to the large number of cells with expected count less than five there was insufficient memory, and it was not able to be computed; therefore, the Chi-square test was used.

Table 12. Difference in Cognitive Ability Versus Ride Type

	-Study groups, n (%)					
	COASTER	KIDDIE	ROTATE SPIN	FERRIS WHEEL	OTHER	*p*-value
Cognitive ability						
Development phase						.000
pre-oper (2-7 yrs)	0 (0.0)	4 (36.4)	10 (25.6)	4 (36.4)	4 (20.0)	
concrete-oper (8-12y)	5 (25.0)	1 (9.1)	11 (28.2)	2 (18.2)	5 (25.0)	
formal-oper (13-adult)	15 (75.0)	2 (18.2)	16 (41.0)	4 (36.4)	9 (45.0)	
cognitve -disabled	0 (0.0)	0 (0.0)	2 (5.1)	1 (9.1)	5 (5.0)	
sensori-motor (0<2y)	0 (0.0)	4 (36.4)	0 (0.0)	0 (0.0)		

5.3.2 Age Range R^2CS Failures by Ride Type

A positive association existed between coaster and age groups 11 to 15 (33%) and 31 to 50 (39%). The most common age group that experienced kiddie rides was the youngest group, 0 to 10 years with 82% of kiddie ride failures falling in this age group. Failures affecting the youngest group were also the most common among the rotating-spinning (49%) and the Ferris wheels (46%). There was also a positive association between coaster and age group 31-50 (39%). Differences were considered statistically significant at just over 5%, but it should be noted that the FET could not be computed (Chi-square=31.25, p=.052). See Table 13.

Table 13. Age Range for R²CS Failures by Ride Type

	-Study groups, n (%)					
	COASTER	KIDDIE	ROTATE_ SPIN	FERRIS WHEEL	OTHER	*p*-valueƗ
Age range						
Development phase						.052
0-10 yrs	2 (11.1)	9 (81.8)	18 (48.6)	5 (45.5)	7 (36.8)	
11-15 yrs	6 (33.3)	1 (9.1)	7(18.9)	3 (27.3)	6 (31.6)	
16-21yrs	1 (5.6)	0 (0.0)	4 (10.8)	0 (0.0)	1(5.3)	
22-30 yrs	1 (5.6)	0 (0.0)	6 (16.2)	0 (0.0)	1 (5.3)	
31-50 yrs	7 (38.9)	1 (9.1)	2 (5.4)	2 (18.2)	3(15.6)	
>50	1 (5.6)	0 (0.0)	0 (0.0)	1 (9.1)	1 (5.3)	

5.3.3 Kruskal Wallis Non-Parametric Test

There were significant differences in age between the different ride types. The descriptives table results showed that the average age for a coaster is 26 years compared to the kiddie rides, where the average age was 7 years. Average ages for rotating-spinning rides and ferris wheels were 14 years old to 20 years old. See Tables 14.

Table 14. Kruskal Wallis Test: age differences between ride types

Age	df	Chi-square	p
	4	19.534	.001

Average age by ride type

				95% Confidence Interval	
Ride Type	N	Mean	SE	Lower Bound	Upper Bound
Coaster	18	25.67	3.462	18.36	32.97
Kiddie Ride	11	7.36	3.251	.12	14.61
Rotating Spinning	37	13.89	1.583	10.68	17.10
Ferris Wheel	11	20.00	6.189	6.21	33.79
Other	19	17.53	3.250	10.70	24.35

5.3.4 Gender

Over the 20-year period of analysis, females sustained 51% of the injuries; however, there are no gender differences associated with non-compliant behavior when compared to females (Chi-square=.008, p=0.929).

5.4 Association of Patron/Restraint Characteristics and Failure Mode

5.4.1 Failure Mode Versus Physical Limitation

The type of failure mode (not secured vs. ejection/fall) was highly associated with patron limitation attributes (large stature, petite stature, physical/cognitive disability, or no limitation). Patrons with physical/cognitive disability or of petite stature were all ejections and falls (comprising 2% and 3% of ejections/falls respectively), while all patrons described as large in stature were not secured, comprising 53% of all failures involving patrons not secured (FET=33.98, p =.000), as shown in Table 15.

5.4.2 Anthropometric Mis-match

There was a significant relationship with 60% of patrons involved in a not-secured failure mode described as having some anthropometric mis-match (failure in conjunction with an over-the-shoulder restraint) compared to 18% among ejection/fall failures (Chi-square = 12.94, *p*=.001), as shown in Table 15.

5.4.3 Diminished Cognitive Capacity

There was a significant association between cognitive ability and failure mode. Considering those with cognitive disabilities and ages 13 and younger as having diminished cognitive capacity, not-secured failure modes affected a higher percentage of diminished-capacity (79%) compared to ejection/fall (43%) (Chi-square= 6.34, p=.012), as shown in Table 15.

5.4.4 Association of Patron Behavior and Failure Mode

Patron behavior type and failure mode showed a significant association (FET=21.67, *p*=.000). A higher proportion of ejection/fall failures occurred with normal behavior (57%) compared to not-secured failure mode where 87% entailed a form of non-compliant behavior. Not secured failure mode showed 53% for not secured failure mode compared to 9% for ejection/fall failure mode, as shown in Table 15.

5.4.5 Association of Restraint and Seating Configuration and Failure Mode

Restraint type was described in 86 reports also describing failure mode. No significant association existed between restraint type and failure mode (FET=5.8, *p*=.177). Cross tabulation showed that among ejection/falls failure mode, the percentage of collective lap bar was higher (41%) compared to not secured failure mode (23%). Seatbelt (6.8%) and individual lap-bar (9.6%) had lower percentages among ejection/fall compared to not secured, as shown in Table 15.

There was no significant association between seating configuration and failure mode. (FET=1.66, *p*=0.445-. Multi configuration seating is more common under ejection/fall (53%) than not secured events (36%), as shown in Table 15.

Table 15. Potential Predictors of Failure Mode

Predictor [1]	Study groups, n (%) EJECTION/FALL	NOT SECURED	p-value
Patron characteristic			.000
Patron limitation			
special needs	2 (2.1)	0 (0.0)	
too large	0 (0.0)	8(53.3)	
petite	3 (3.1)	0 (0.0)	
none	91 (94.8)	7 (46.7)	
Anthropometric Mis-match			.001
yes	79 (82.3)	6 (40.0)	
no	17 (17.7)	9 (60.0)	
Diminished capacity			.012
yes	40 (42.6)	11 (78.6)	
no	54 (57.4)	3 (21.4)	
Behavior			.000
normal	45 (57.0)	2 (13.3)	
misposition	5 (6.3)	8 (53.3)	
unlatch/interf mech	7 (8.9)	0 (0.0)	
standing	17 (21.5)	5 (33.3)	
other	5 (6.3)	0 (0.0)	
Ride configuration			
Restraint Type			.177
collective lap bar	30 (41.1)	3 (23.1)	
over shoulder	15 (20.5)	2 (15.4)	
seatbelt	5 (6.8)	3 (23.1)	
individual lap bar	7 (9.6)	3 (23.1)	
none	16 (21.9)	2 (15.4)	
Seating Configuration			.445
single rider	19 (25.3)	3 (27.3)	
dual riders	16 (21.3)	4 (36.4)	
multi riders	40 (53.3)	4 (36.4)	

[1]Anthropometric mis-match comprises failures involving restraint type of over-the-shoulder.
Diminished capacity includes 13 and younger and cases described as having cognitive disability.
Non-compliant behavior includes all cases of mispositioning, unlatching or interfering with restraint mechanisms, standing, self-extraction or other behavior described as non-compliant. In this table, mispositioning and other non-compliant behavior were treated as separate variables, each compared with normal behavior.

5.5 Logistic Regression Model for Failure Mode

When analyzed independent of other variables, behavior, limited cognitive capacity, and anthropometric mis-match contributed to the type of R^2CS failure; therefore, a logistic regression model was constructed combining these three predictor variables and the outcome of not-secured or ejection/fall failure. Each predictor was created as a binary variable for the presence or absence of the factor. The model (Table 16) is significant (Chi-square= 30.46, p=.000, $R^2_{C\&S}$ = .284, $R^2_{Nagelkerke}$=.494).

Table 16. Logistic Regression Physical Limitation Predicting Failure Mode

Predictors[1]	OR	B	SE	Wald	p-value
Anthropometric mis-match	9.538	2.255	.870	6.171	**.010**
Diminished capacity	2.636	.969	.796	1.480	.224
Behavior					
misposition	36.337	3.593	1.091	10.843	**.001**
standing & other	6.565	1.882	1.046	3.235	.072

Goodness of fit

Chi-square	d.f	p-value.	Cox & Snell R^2	Nagelkerke R^2
30.46	4	.000	.284	.494

[1]Reference categories were not having any anthropometric limitation, not having diminished capacity and normal behavior.

5.6 Summary

Several exact tests with a 95% confidence interval were performed to test for significance for event, ride features and patron characteristics for R^2CS variables and industry control data. Significant association existed for age distributions observed for HSE industry data when compared to the R^2CS data. The age variable also had a positive association across ride types for the data. The R^2CS data for behavior type observed was comparable to HSE industry data, and there was a relationship between behavior and failure mode. R^2CS injuries observed had a significant association to the NSC overall injuries related to ride type. Cognitive level also had an association related to ride type. Association was established for fixed-site and mobile ride incidents for R^2CS data. Ride features such as restraints and seating configuration showed no significance as a predictor for failure mode. There were no associations noted for gender, cognitive ability across injury severity, and diminished capacity related to non-compliant behavior; see Table 11.

Strong associations emerged for anthropometric mis-match and behavior. The logistical regression model determined anthropometric mis-match and behavior are significant predictors for failure mode. While tested independent of the regression model, diminished capacity and failure mode showed a positive association, but when combined with other predictor variables such as anthropometric mis-match and behavior, the p-value for diminished capacity was no longer significant. The results of the forensic analysis identified significant factors associated with R^2CS design challenges due to anthropometry which was addressed by a Forcing Function Guidance Matrix containing recommendations for mitigation strategies that are presented in Chapter 6.

CHAPTER 6
Design Recommendations

6.1. Introduction

A series of forcing functions was incorporated into a design matrix guide based on common themes and patterns linked with significant association based on the results of the forensic analyses for this study. The most prevalent themes to emerge from the forensic analyses identified three themes associated with anthropometric mis-matches between the R^2CS and 1) patrons of large stature, 2) patrons of petite stature, and 3) excess containment space.

6.2 Forcing Function

A forcing function is a 'force' that simplifies how users interface with a design. It is an interactive design technique that prevents the user from doing something without consciously processing information first, which requires the designer-engineer to systemically anticipate the user's behavior. The use of forcing functions in design is fairly common but not very well understood, so in some cases the designs are not as effective as intended. Systems that lack good user interface cause users to commit more errors. The forcing function needs to feel natural to the user to be effective and can be achieved by observing user interaction and behavior with the system and environment.

Balancing how much force is incorporated into the design is paramount for a successful outcome and needs to be transparent to the user. Engineering systems with error prevention measures rather than error recovery are the primary objective when designing forcing functions into a system. Therefore, the Forcing Function Design Guidance Matrix only provides design mitigation strategies as part of the deliverable of this project

Within the three themes, there were several factors associated with cognitive level and behaviors that were present for which forcing functions were identified to facilitate patron behavior modification techniques, cognitive development considerations, and R^2CS ergonomic design solutions to mitigate or accommodate excess containment space. Coding of forcing function strategies that coincide with themed patterns of R^2CS failures are noted in Table 17. Table 18 provides a description of the forcing functions and the rationale for recommendations.

6.3 Mapping Quantitative Results to Qualitative Themes

The results of the bivariate and multivariate regression models produced numerical results which were mapped to qualitative R^2CS failure themes that showed significant association.

6.3.1 Mapping of Significant R^2CS Anthropometric Mis-Match Themes

Mapping of central themes that had significant association for R^2CS anthropometric mis-match failures were identified in Figure 11. Each theme had a series of specific variables that act as contributors to R^2CS anthropometric mis-match failure modes. There were commonalities among various combinations of the three themes such as ride categories, behaviors, secured, not secured, age, and mispositioning. Depending on the interaction of variables within the themes, specific forcing functions were identified as mitigation strategies.

6.4 Qualitative Assessment of R^2CS Failure Themes

All of the R^2CS failures studied in this project resulted from a patron anthropometric mis-match with the restraint and containment environment. The three central themes with significant association for failure mode were concerned with patrons of large stature, patrons of petite stature, and excess containment space. Depending on the theme, certain variables were more prevalent as a contributor for R^2CS failures.

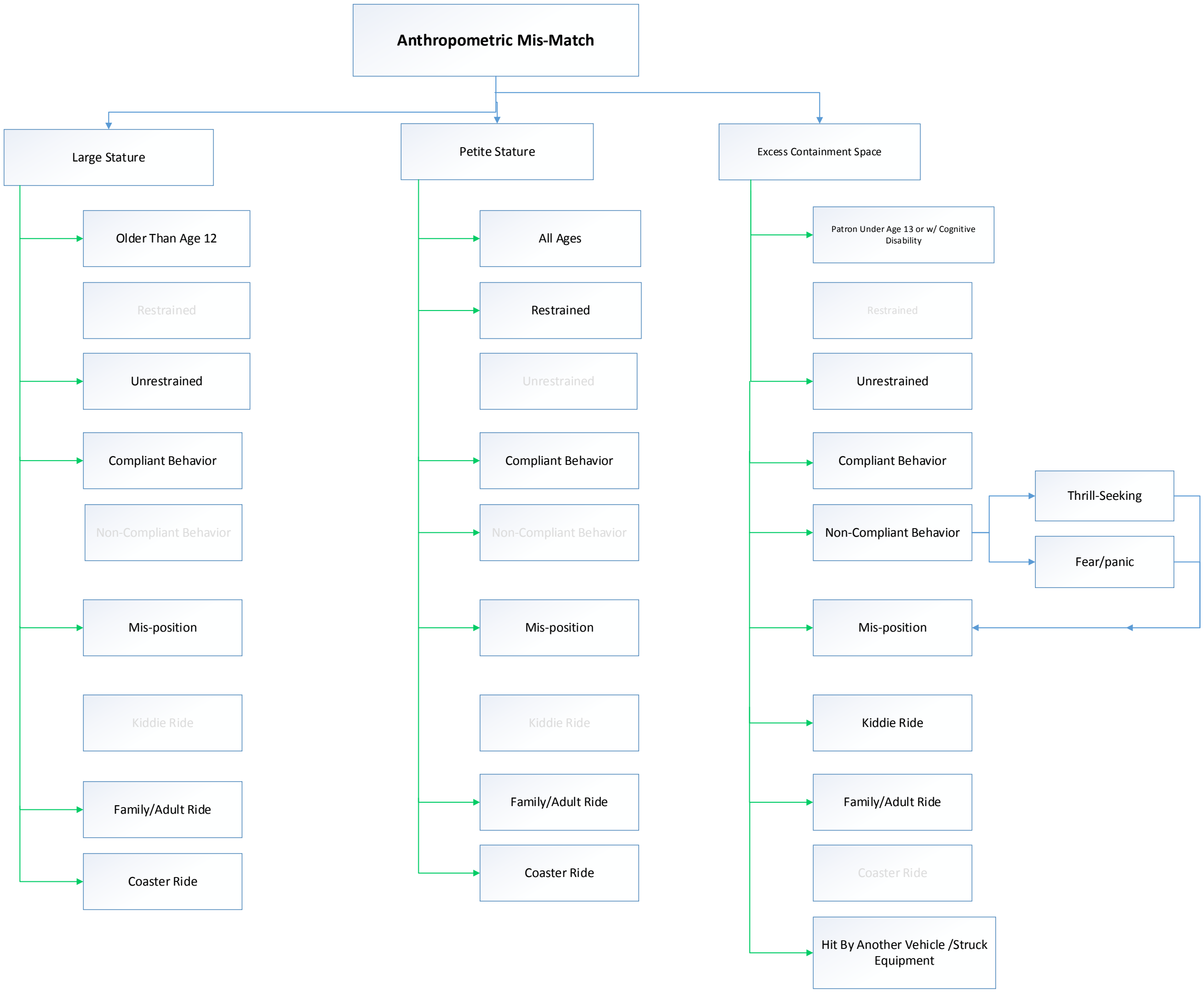


Figure 11. Anthropometric Mis-match Central Themes with Significant Association

6.4.1 Petite Stature

There were three cases where patrons of petite stature slipped out or were ejected from the restraint and fell from the ride. Two cases involved adult rides and the other a coaster. Victims ranged in age from 12 to 35. See Table 17 for specific variables present during the event for petite patron R²CS failures. There was one case not used in the analysis where a 14 year old with a physical/cognitive disability was killed when she fell from an adult ride after she panicked and escaped from her harness and fell through a 12-16 inch gap, indicating she may have been of petite stature. Since the report did not conclude the victim's stature was petite or that her size was the cause of the failure, this event was not classified under the petite stature theme but is certainly worth mentioning in this section.

Designing restraint and containment systems for extreme ends of the anthropometric spectrum is very challenging for ride designers. However, there are forcing functions that can be implemented that close the gap for patrons with unique anthropometric features that fall outside the low end of the 5^{th} percentile patron for a targeted age. Forcing functions that restrict movement of the lower leg or thighs are very effective in keeping patrons secure and prevents ejection as well as self-extraction. Redundant restraints also add to the integrity of the system and counter any measures not accommodated by the primary restraint such as small gaps and openings in the harness.

6.4.2 Large Stature

Large stature guests that fell from rides accounted for eight cases and were equally distributed across gender. All were adult victims. One victim had cerebral palsy. Five of the incidences involved coasters; the balance were on adult rides. Twice before, two different ride types had rider separation. In one case, a safety belt was added to the containment system after the second incident.

Forcing functions that are recommended to secure larger riders are noted in Table 17. Redundant restraints should be designed into the containment system and have the locking mechanism located away from the patron's reach. Other forcing function strategies should include the use of patron hard points to secure the skeletal structure in the containment device. Hard points include lower leg, thigh, and below the knee. Bracing restraint devices against soft tissue for large patrons is ineffective at keeping guests anchored in position, especially during high "G" events and sudden changes in direction. Soft tissue of the girth, shoulders and arms is malleable and can defeat conventional restraint systems.

6.4.3 Excess Containment Space

Containment systems with excess space for young riders (age<13) had the greatest number (50) of R^2CS failure incidents and were associated with kiddie and adult/family rides. Kiddie rides were primarily problematic because patrons were very young, usually riding alone, lacked gross motor skills required for physical stability, and the ride may have been void of restraints. Rides that do not have restraints allowed patrons to fall or leave the containment space unencumbered. Falls from kiddie rides were usually a short distance and in most cases resulted in minor injuries; however, in ten of the 13 cases involving kiddie rides, the victims sustained a secondary injury by being run over or hit by oncoming vehicles. There were seven cases where the patron was riding alone, five of which were on family/adult rides.

Thirty seven young riders experienced R^2CS failures on family/adult rides. There are a variety of reasons why this theme was the most prevalent regarding restraint and containment failures. Family/adult rides are intended to accommodate a larger spectrum of anthropometry, which allows greater flexibility in the containment environment. This duality requirement created a hazardous condition for child patrons.

In four cases, patrons were mis-positioned while riding, legs crossed or positioned to one side. Family/adult rides often had a collective lap bar that was shared among the party members; however, the largest patron in the group dictated the final the position of the restraint bar, leaving smaller riders unsecured and at risk of being ejected from the vehicle. This was particularly troubling when the ride abruptly changed direction which was true of rotating and spinning rides. In many cases, excess containment space also facilitated self-extraction and standing behaviors. The motive for this behavior included panic, boredom (prolonged ride interruption in operation), premature exiting of ride, and thrill-seeking experience. One of the biggest considerations when determining the containment requirement during the analysis is the intensity of the ride experience based on dynamics, theming, audio and story line. Currently, there is no specific criterion that guides this analysis.

There are ten key forcing function design recommendations to address the excess containment space environment. All or a combination of the ten forcing functions should be incorporated into the overall design strategy based on the ride analysis. Utilizing forcing functions that address ejection, falls, self-extraction, standing and misposition include should include the use of a secondary restraint with a latching mechanism located out of the reach of the patron. Anticipating rider behavior is a major consideration, so focusing on behavior modification forcing function designs to address intentional behaviors can be achieved by utilizing hard points to restrict movement. Other engineered solutions include ride systems designs that require the ride to come to a complete stop in a short amount of time, reducing the chance of a secondary impact to the guest.

One of the current requirements of the containment analysis is to evaluate the suitability of the ride design for the intended patron.

Currently there is no standardized rating system for ride experience so one of the recommendations of this project is to have a rating scale developed that rates the ride experience based on content, theming, ride dynamics, audio, video and other special effects elements that comprise an entire ride system.

From an operational perspective, there are recommendations forcing functions that are procedural in nature that can have an equally positive result for mitigating R^2CS failures that include reduced ride cycle interruptions and duration of downtime. Requiring supervising companions for young riders on family/adult rides helps assuage panic or behaviors that would otherwise spiral out of control. Awareness of the environment and full line of sight for operators allows for advanced warning when things go wrong and allows more time to respond.

6.5 Summary

Implementing as many of the forcing function strategies recommended by this study as possible will substantially reduce the number of R^2CS failures. Until more detailed accident and near miss data are made available for researchers, quantitative analysis will continue to be a challenge; therefore, any R^2CS design improvements will rely heavily on heuristics and qualitative analysis.

Table 17. Forcing Function Design Matrix Guide

Report #	[1]Family/ Adult Ride	ANTHROPOMETRIC MIS-MATCH: LARGE STATURE					PETITE STATURE						EXCESS CONTAINMENT SPACE								
		Age> 12	Not secured	Compliant behavior	[1]FA Ejection	Coaster ejection	All ages	Contained	Not secured	Compliant behavior	[1]FA Ejection	Coaster ejection	Ages < 13/cognitive	Unrestrained	N/C behavior	Thrill motive	Fear motive	Mispositioning	Kiddie ride eject	[1]FA Separation	Struck Equip/RV
	Forcing Function Codes	D-G-H-I-J-L-M					D-E-G-H-I-J-L-M						A-B-C-D-E-F-G-H-I-J-K-L-M-								
	Significant Themed Events																				
090823-4	35 yo woman fell from Coaster. Woman's stature too petite causing the fall.						√	√	√	√		√									
130719-3	52 yo woman fell 75 ft. from roller coaster, died, **too large** for ride. After accident added safety belts.	√	√	√		√															
060729-6	45 yo woman fell out of spinning coaster due to **improperly occupying 2 seats during ride**, **too large** for ride.	√	√			√															
050409-8	30 yo man died after falling 15 ft on adult ride simulator, victim **too large** for ride. Safety belt did not fit around him, only secured with over shoulder restraint.	√	√	√	√																
120314-3	3 yo girl injured after **slipping out** of adult ride while riding with 8 yr. old brother. Video shows both **legs** on left side of **pummel**. No crotch restraint. Tossed from 6-8 feet in the air once the ride reached full speed. Had lap bar.												√	√				√		√	
110903-2	9 yo boy injured when he performed **self-extraction** while swing ride in motion.												√	√	√						√
110411-4	3 yo boy falls from kiddie coaster ride, after performing **self-extraction** by freeing himself of the restraint, died at scene.													√	√			√	√		
100905-5	2 yo girl injured when she **stood up** and fell out of a kiddie coaster and was hit by 5 subsequent vehicles but escaped serious injuries												√	√	√				√		√
100727-6	9 yo girl fell from an adult ride. Witness say girl **stretch out legs underneath the safety bar** and was mispositioned.												√	√	√			√		√	
100708-7	3 yo fell from adult sky ride. **Slipped out** of restraint when hit in the head by patron shoe, knocked out and fell to ground.												√	√						√	√
130814-2	5 yo boy **slid underneath** lap bar on kiddie coaster, fell between 2 cars, large cut on leg												√	√					√		√
090310-7	12-mo old boy fell 2-3ft, kiddie coaster, **run over by oncoming vehicle**. Suffered head injuries.												√	√					√		√
080717-1	4 yo boy performed **self-extraction** and fell off slow rotating kiddie ride and was hit by 2-3 other cars, witness said boy was **scarred.**												√	√			√	√	√		√
140912-1	8 yo girls dies, slipped out of her harness on adult ride, thrown 30 ft												√	√						√	
060618-7	6 yo boy dies from 90 ft fall while performing **self-extraction** from adult Ferris wheel when he panicked and tries to exit the gondola, riding alone, no seat belts or safety restraints,												√	√	√		√			√	√
060609-8	4 yo boy injured from 20 ft fall from adult ride, child met height requirements.												√	√						√	
050803-5	7 yo boy died from blunt force trauma when he fell from a boat on adult dark tunnel ride, witness saw the boy standing in the water, mother heard **boy crying,** no water in lungs, insufficient number of operators working, no video of tunnel, boy exceeded height requirements. **Riding alone.** Mother thought he would be put with other guests.												√	√			√			√	
040522-2	7 yo girl elude restraint bar and was **kneeling and waving** on adult whirling ride when she was thrown out and died of massive head injuries. She met 48 inch height requirement and riding alone**.**												√	√	√			√		√	

Table 18. Legend: Forcing Function and Rationale Coding

Mitigation Rationale		Forcing Function	
1	Redundant restraint safe guards against single point failure (SPF) especially for young patrons unable to assess risk or consequences associated with non-compliant behavior. Precludes premature exiting of ride	A	Design secondary restraint when using collective lap bar.
2	Non-accessible latching mechanism makes it difficult and longer to perform a patron self-extraction giving operator more time to detect non-compliant behavior. Requires operator intervention to release mechanism.	B	Design secondary restraint systems with latching mechanism or device out of patron reach on all kiddie rides and class 3 restraints.
3	Adjusting the height requirement for ridership to include the lower end of the spectrum. E. g. rather than selecting the height requirement for the 5th percentile 8 year old, adjust the height requirement to 99th percentile 7 year old.	C	Reduce anthropometric percentile range for ride type/class to avoid anthropometric mismatch due to cognitive ability based on height.
4	Indicator marks allow operators to visually inspect if the restraint is properly positioned and respond to patron mispositioning, not secured, etc, before and during the ride cycle.	D	Provide visual indication for restraint engagement status
5	Contouring of containment seat, especially for kiddie rides adds stability for young children that lack fine motor skills. Contouring of seat provides stabilization of the skeletal structure and restricts undesirable movement.	E	Design containment for patron stability via skeletal hard points.
6	The systems' ability to respond (stop) immediately reduces the chance of patron being hit by oncoming vehicles and the severity of injury may be less. Many young riders fall a short distance and are not seriously injured but are hit by oncoming vehicles and consequently suffer major injuries as a result.	F	Design system to reduce time for ride system to come to complete stop upon Emergency stop (E-stop)
7	Evaluation of the ride dynamics for sudden changes in direction can facilitate appropriate containment design.	G	Implement stabilizing features into the restraint and containment design. Based on ride dynamics for sudden change in direction
8	Petite patrons can slip through or be ejected from containment when gaps are present. Closing gaps will keep patrons contained.	H	Design vehicle containment environment to close any gaps greater than 4 inches between patron and compartment.
9	Test seat at attraction allows patrons to determine if they are able to fit properly in the containment device in advance.	I	Design secondary restraints for rides with sudden changes in direction require.
10	Containment design that anticipates intentional wanton behaviors can reduce injuries and restrict patron behavior.	J	Design behavior modification devices to preclude non-compliant patron behavior.
11	Supervising companions help mitigated non-compliant behavior and assuage fear/panic in younger patron. Young patrons on dark ride shall have supervising companion.	K	Design containment compartment to accommodate both patron and supervising companion.
12	Rating of ride experience can identify severity of ride experience so that the suitability for age appropriateness can be established. Level of cognitive development should be adequate so young riders can distinguish between ‘make believe’ and reality.	L	Develop standardized experience rating system
13	All kiddie rides shall have restraints because young children easily fall. Without restraints, young riders try and exit ride too early and currently supervising companions are not required.	M	Redundant restraints for restraint classes 3

CHAPTER 7
Conclusions

7.1 Introduction

Safety is the highest priority for the amusement park industry (IAAPA, 2010) and of the nearly 315 million people who visit amusement parks annually in the U.S., few will receive an injury. Of those, less than seven percent of injuries require an overnight hospital stay according to the U.S. Consumer Product Safety Council (2014).To continue to keep patrons safe, it is incumbent upon engineers to design solutions that are practical and simple to use. This can be achieved through the application of forcing functions. Incorporating forcing functions into containment systems performance requirements is a means to changing human behavior, reducing human error, and restricting undesirable patron behavior: *"the solutions to the problems of the 21st century absolutely require the redesign of society to change human behavior"* (Moray, 1994).

7.2 Conclusions

The descriptive analyses did not identify any increase or decrease in trends specific to restraint and containment systems (R^2CS) failures for this project, largely due to the incompleteness of the accident data available in the public domain. However, the dataset did indicate an increase in injuries for both male and female patrons. Incidents involving specific ride types associated with R^2CS failures remained constant over the twenty year period. Trends for fixed-site venues remained flat over both ten year periods, but mobile ride venues saw a steep upward trend for the years inclusive of 2005-2014 with 38 failures, up from 14 in the preceding ten years.

Three variables linked to failure mode were related to individual differences between riders: anthropometric mis-match, cognitive ability, and behavior. Variables describing ride feature for ride type, seating configuration, and restraint type did not predict the type of failure mode. If more details about the ride features were available in the accident reports, the outcome for significance may be different. While riders' individual characteristics predicted the type of failure, this analysis did not examine whether those individual characteristics predicted greater involvement in restraint failure by and large because there is no data source to provide exposure data broken down by these characteristics. Therefore, patrons with these characteristics may not be as visible in the dataset as in reality for restraint failure events when total ride exposure is taken into account.

A not-secured failure mode was associated with anthropometric mis-matches and non-compliant behavior, particularly mispositioning whereas ejection and fall were associated with normal behavior. Ride vehicles with multi-rider seats and shared restraints or no restraints comprised the majority of failure events. These ride characteristics tended to be falls and ejection failure modes rather than not-secured events; however, no significant association between seating configuration and failure mode was evident in the analyses.

The ride type that produced the most R^2CS failures was rotating-spinning rides. Although this may reflect their popularity among rides in operation, the frequency of occurrences justifies targeting these ride types in developing forcing function remediation techniques to preclude rider separation, especially for young riders.

Similarly, while diminished capacity (due to young age or disability) was often speculated as a hazard for ride exposure, and while it did predict type of failure mode on its own, it was not associated with non-compliant behavior and did not result in a significant predictor variable of anthropometry and behavioral differences in the multivariate logistic regression model of failure mode type. As previously noted in the literature review, this indicates that uniform restrictions based on disability are not warranted.

Unlike the literature and mainstream assumptions regarding risk-taking and thrill seeking behavior, the data did not find an abundance of males among riders involved in R²CS failure-related injuries. This may be the result of thrill seeking tendencies by males to engage in recreational activities in a less controlled environment such as mountain climbing, stock car driving, extreme sports and other competitive activities. It may also signal gender differences where males are not as inclined to report when injuries are sustained, causing female reports to be more prevalent.

While non-compliant behaviors need to be anticipated in the design of restraint and containment systems that avoid excess containment space and afford patrons the opportunity to stand or defeat restraints, patron size needs to be considered in the selection of rider containment systems, especially when the threat of severe injury exists. Large riders may not be adequately secured, and petite riders may be able to reposition within secured restraints. Even over-the-shoulder restraints can allow riders with unique proportions and somatotype shapes to be unsecured or ejected, and designer-engineers should consider vulnerable extremes of body size and shape. This is an area where the containment design will benefit from forcing function strategies noted in the matrix.

While R²CS injuries persist year after year for the years studied, the incidences cannot be interpreted without data on exposure. For example, there is high visibility associated with R²CS failures from secondary data sources because of the extreme outcome. Unfortunately, the level of detail needed to accurately identify all variables associated with the incident was not captured; hence, a certain level of heuristics must be applied in the development of the solution. More importantly, near miss data are not available in the public domain or shared through other repositories for researchers to access for research use. Making these data available for the academic community of the amusement industry can lead to the implementation of effective design strategies that target anomalies that challenge ride designers of R^2CS as well as other human-equipment interface designs.

Evaluating the data in smaller increments provided a clearer picture of distributions. For instance, the frequency data indicated an increase in R^2CS failures over the last ten years, but when the data was sliced into smaller durations, a six year period was identified that accounted for 41% of the failures.

Likewise, the results of the descriptive analyses for the four phases of cognitive development revealed that nearly half of the R^2CS accidents were at the formal operational development phase which supports Zuckerman's theory that high sensation-seeking behavior is at its peak between the early pre-teen years and early twenties and is examined more closely as part of the forensic analysis. While the descriptive analysis indicated women sustained a higher rate of R^2CS injuries, advanced bivariate analyses was explored to determine whether there was a significant association that males prefer sensation-seeking experiences over females; no evidence of significance was noted.

The results for the categorical variable for behavioral style supports claims by the Health & Safety Executive, U.S. Consumer Product Safety Commission and the National Safety Council that 40%-60% of amusement ride accidents are due to patron behavior. Frequency data show that R^2CS failures associated with non-compliant behavior fall into this percentage range.

7.4 Recommendations for Future Work

The work performed as part of this engineering project was the beginning effort of a long journey to understand restraint and containment systems' safety related to unique patron anthropometry. The restraint task group for ASTM F2291 Design Standard should continue the vetting process to sanction strategies mapped out by the Forcing Function Design Guidance Matrix and craft language for inclusion into the standards.

This project did not study R^2CS failures involving patrons with amputations or other special cases. Additional research to understand how legs, arms, hands, shoulders and other body parts contribute to skeletal stability during the ride experience was not examined; however, this type of research will prove very useful in establishing the proper ridership requirements. Continued research for R^2CS related to patron accessibility is a major area of focus for the industry. Studies in the area of non-conventional amusement ride containment environments such as, bungee jumping, zip lines, and inflatables implores more research as well

The biggest problem facing researchers in the amusement industry is the lack of available data and the quality of the data being captured. The information that is available for researchers does not represent the whole picture. Data quality needs to be greatly improved before meaningful contributions can be made. Near miss data is very telling but is not shared across the industry. Currently, it is very difficult to quantify industry trend data with any certainty. However, great strides have been made by a priori, so until the quality of the data improves, enhancements will be driven by qualitative heuristics rather than quantitative analyses.

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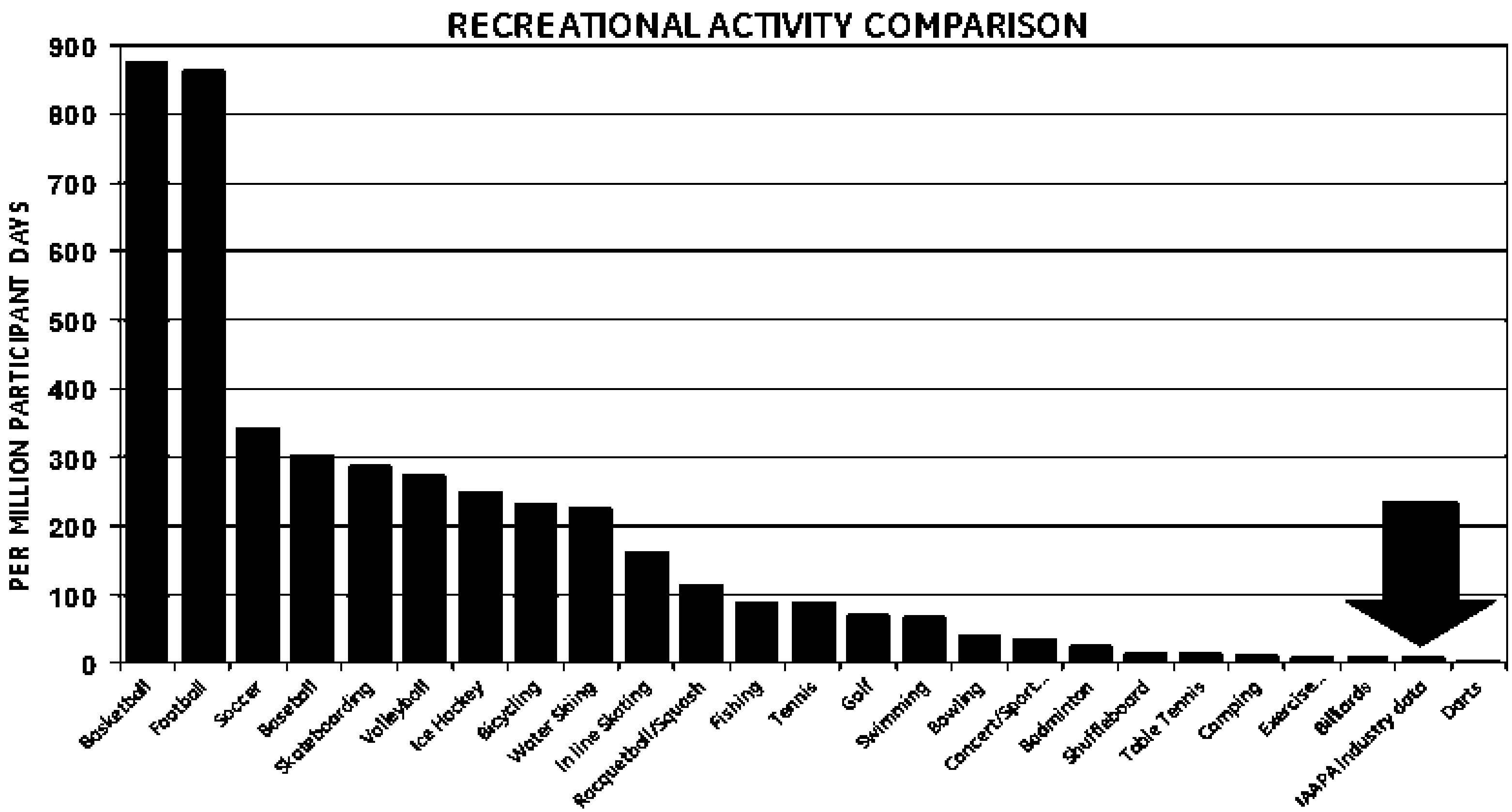
APPENDIX A



Graph. 11. Accident data comparison for sporting/recreational events versus amusement industry. National Safety Council, 2013

APPENDIX B

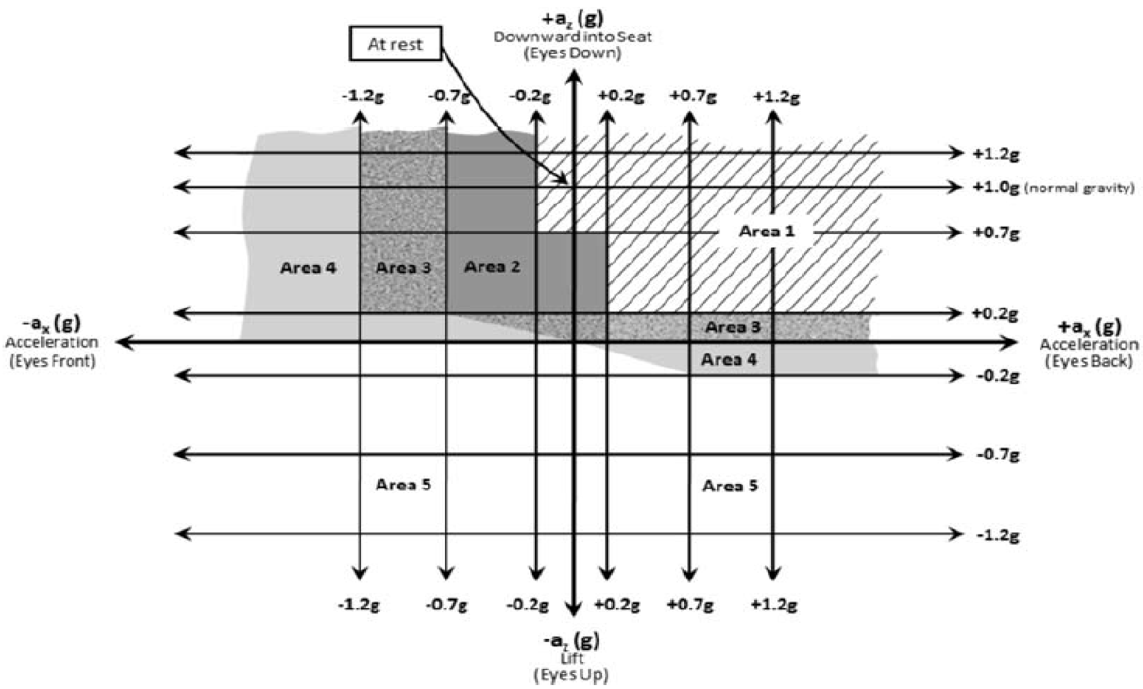


Figure 12. Restraint determination diagram-Acceleration in design stage**. (**ASTM F2291 Standard, 2014)

APPENDIX C

Data Management Plan: Old Dominion University: NSF Engineering Directorate

Background Information

Title:

Retrospective Study of Amusement Ride Restraint and Containment Systems: Identifying Design Challenges for Statistically Rare Anthropometric Cases.

Purpose of project:

The purpose of this retrospective study project is to identify amusement ride restraint and containment system failures associated with unique patron anthropometry to provide ride designers with guidance criteria when performing the containment analysis and developing the restraint and containment systems. The researcher of this project is a doctoral student at Old Dominion University and is performing this research in partial fulfillment of the requirements for the degree of Doctor of Engineering.

This proposal will categorize secondary-qualitative data for accident failures associated with non-mechanical/structural failures of amusement ride restraint and containment systems into quantitative data for statistical analysis. The data collection methodology will focus on a very specific sample population and the transformation from qualitative to quantitative data will allow for data analyses techniques that result in effective data which provide the basis required to meet proposal objectives The results from this study shall be shared with interested parties of the general public, private industry and the academic community.

1. Types of Data Produced

Secondary-qualitative data for amusement ride accidents classified as falls, ejections and mis-positioning associated with non- mechanical/structural events related to restraint and containment systems failures shall be collected from industry databases, regulatory agency reports, accident investigations, and journal publications. The secondary data collection shall span accident data records from 1997 to 2015 and is expected to yield approximately 150 records.

The qualitative raw data is converted to quantitative data by assigning a numerical value based on taxonomies of descriptive variables related to ride type, restraint and containment class, failure mode, anthropometry, injury severity, patron vital statistics, behavior, and cognitive ability. The raw data are processed and entered into an excel workbook; wherein, each year is represented in a separate spreadsheet. The data from the excel spreadsheets are imported into an IBM Statistical Analysis Software program for analyses.

2. Data and Metadata Standards

The results of the secondary data collection shall be made available in digital format through a hyperlink located in the corresponding cell of the spreadsheet workbook pointing to the source of original data. This will allow future researchers to duplicate the analyses, achieve repeatability and expand on the original findings over time. The researcher will produce metadata from raw data files, save and deposited analyzed data as SPSS files, ASCII format, tab-delimited, tables, graphs. Documentation shall be deposited in PDF, JPEG and plain text file formats in accordance Old Dominion University Institutional Repository prevailing standards, policies and guidelines

3. Access and Sharing

Secondary data collection is extracted from public domain databases; however, the data contain indirect identifiers that make distinctive cases visible. It is the goal of the researcher to protect theme park owner/operators, ride designer/manufacturers, and accident victims. The researcher of this project has considered the analytic importance of the qualitative-secondary data collection for this project and has concluded that removing direct or indirect identifiers impose limitations on future research that hope to replicate and augment content. Therefore, the datasets will be divided into two categories; public-use and restricted-use data files in order to maintain the integrity of the analysis.

Public-use data collections: Where feasible, direct and indirect data has been removed to reduce the risk of disclosure whether directly obtained from data or inferred due to deductive reasoning. In other cases special treatment of the data has been used to conceal disclosure information. In these cases, the files may be access directly from the University institutional repository website.

Restricted-use data collections: When alternate treatment or removal of indirect or direct identifiers isn't viable due to the loss in data integrity, certain files associated with this project will be restricted-use data files and researchers will be required to apply for access to these files. They will also be required to submit a security data plan and provide written acceptance of the restricted data use agreement as required by the university to maintain confidentiality.

The datasets shall be deposited to the University's Institutional Repository at the end of the project. Intellectual property and data generated under this project will be administered in accordance with both University and NSF policies, including the NSF Data Sharing Policy and *ODU policy numbers 5350 and 3504:*

Ownership of sole or joint inventions developed under the project will be owned by the institution(s) employing the inventor(s). Inventors shall be determined by U.S. Patent law, Title 35 USC. University and Participating investigators/institutions will disclose any inventions developed under the project and such inventions will be reported and managed as provided by NSF policies. Sole inventions will be administered by the institution employing the inventor. Joint inventions shall be administered based on mutual consultation between the parties. Similar procedures will be followed for copyrights.

4. Provisions for re-use, re-distribution, and the production of derivatives

Access to databases and associated software tools generated under the project will be available for educational, research and non-profit purposes. Such access will be provided using web-based applications, as appropriate.

Digital materials generated under the project will be disseminated in accordance with University/Participating institutional and NSF policies. Depending on such policies, materials may be transferred to others under the terms of a material transfer agreement.

Publication of data shall occur during the project, if appropriate, or at the end of the project, consistent with normal scientific practices. Digital research data which documents, supports and validates research findings will be made available after the main findings from the final research data set have been accepted for publication. Such research data will be redacted to prevent the disclosure of personal identifiers.

5. Plans for archiving and preserving access to data and materials

Short Term:

The data product will be updated as records are collected and revision control is maintained with each update. Revision control will be reflected by a sequential letter designation and date. The working data are stored and backed up weekly onto two external hard drives or whenever large data collection, data processing or data analyses occur.

Long Term:

The long-term object of this project is to produce high quality datasets which will be made available to academic community, private sector, and individuals with an interest in these data and will be available for use perpetuity. The secondary raw data will also be available in perpetuity for future researcher to corroborate results.

Old Dominion University Institutional Repository, Norfolk, Virginia shall be responsible for the long-term stewardship, curation, protection and availability of data in accordance with University policy 3504- Data Classification policy.

APPENDIX D

OLD DOMINION UNIVERSITY
University Policy

Policy # 5350
RESEARCH AND SCHOLARLY DIGITAL DATA MANAGEMENT POLICY

Responsible Oversight Executive:	Provost and Vice President for Academic Affairs
Date of Current Revision or Creation:	January 24, 2014

A. PURPOSE

The purpose of this policy is to establish digital data management standards and set the shared responsibilities for ensuring that digital research and scholarly data serve the needs of the University and the funding agencies.

B. AUTHORITY

Virginia Code Section 23-9.2:3, as amended, grants authority to the Board of Visitors to establish rules and regulations for the institution. Section 6.01(a)(6) of the Board of Visitors Bylaws grants authority to the President to implement the policies and procedures of the Board relating to University operations.

Virginia Code § 23-49.11 et seq., as amended

Bylaws of the Old Dominion University Board of Visitors, Article VI, §6.01 (c) (7)

C. DEFINITIONS

Access **-** The ability to read, enter, copy, query, download, or update data.

Consumer/User **-** An individual, organization, or software tool that accesses Research and Scholarly Data.

Digital Data **-** The representation of discrete facts; any information in electronic or audio-visual format.

Institutional Data **-** Recorded information that documents a transaction or activity by or with any appointed board member, officer, or employee of the University. Regardless of physical form or

characteristic, the recorded information is a University record if it is produced, collected, received or retained in pursuance of law or in connection with the transaction of University business. The medium upon which such information is recorded has no bearing on the determination of whether the recording is a University record. University records include but are not limited to: personnel records, student records, academic records, financial records, patient records and administrative records. Record formats/media include but are not limited to: email, electronic databases, electronic files, paper, audio, video and images (photographs). See University Policy 3700 – Records Management Policy.

Research and Scholarly Data ("Research Data") **-** Digitally recorded information (necessary to support or validate a research project's observations, findings, or outputs. Specifically, data that are:

1. Acquired and /or maintained by University employees and/or students in performance of research and/or in pursuit of a scholarly activity;
2. Created or updated in pursuit of a research or scholarly function;
3. Necessary to support research or scholarly findings, establish validity of inventions, and prove ownership of Intellectual Property Rights.

Research and Scholarly Data Governance Committee (RSDGC) - The University-level committee that establishes overall policy and guidelines for the management of and access to the University's Research Data in accordance with existing University policies and applicable law and regulation.

Research Data Management Plan **-** Plan for collecting, organizing, maintaining, and sharing or providing access to Research Data.

Researchers **-** Members of the University including employees, students, volunteers, employees of affiliated organizations, and visitors to the institution and those who are not members of the University but who are conducting research on University premises or using University facilities.

D. SCOPE

This policy applies to all employees, students, volunteers, employees of affiliated organizations, and visitors to the institution who create, preserve, retain, or use Research Data and covers all externally funded research conducted by the University or affiliated organizations. Employees include all staff, administrators, faculty, full- or part-time, and classified or non-classified persons who are paid by the University. Students include all persons attending classes whether enrolled or not enrolled. Affiliated organizations are separate entities that exist for the benefit of the University and include the Foundations, the Community Development Corporation, and the Alumni Association. Visitors include vendors and their employees, parents of students, volunteers, guests, uninvited guests and all other persons located on property owned, leased, or otherwise controlled by the University.

Personal medical, psychiatric, or psychological data for employees, students, and clinic patients; sole possession notes and records that are the personal property of individuals in the University community; Institutional Data; and instructional notes and materials are excluded from the scope of this policy, except as approved by the Institutional Review Board or individual college Human Subjects Review Committees for use in research.

E. POLICY STATEMENT

Old Dominion University seeks to promote the highest standards in the management of Research Data as fundamental to both high quality research and academic integrity.

The University recognizes that accurate and retrievable Research Data are an essential component of any research project and necessary to verify and defend, when required, the process and outcomes of research. Research Data are valuable to researchers for the duration of their research and may well have long-term value for research, teaching and for wider exploitation for the public good, by individuals, government, business and other organizations, as a project develops and after research results have been published.

The University acknowledges its obligations under research sponsors' data-related policy statements and codes of practice to ensure that sound systems are in place to promote best practices, including through clear policy, guidance, supervision, training and support.

Researchers, departments/faculties, divisions, central administrative units and service providers and, where appropriate, research sponsors and external collaborators, need to work in partnership to implement good practices and meet relevant legislative, research sponsor and regulatory requirements.

Research Data should be:

- Accurate, complete, authentic and reliable;
- Identifiable, retrievable, and available when needed;
- Secure and safe;
- Kept in a manner that is compliant with legal obligations and, where applicable, the requirements of funding bodies and project-specific protocols approved through Office of Research;
- Able to be made available to others in line with appropriate ethical, data sharing, continuing research, intellectual property, proprietary, and open access principles.

Research Data should be retained for as long as they are of continuing value to the researcher and as long as specified by research sponsor, patent law, legislative, and other regulatory requirements.

When research is supported by a contract or a grant that includes specific provisions regarding ownership, retention and access to data, the provisions of that agreement will take precedence in the event of a conflict with this policy.

If Research Data are to be deleted or destroyed, either because the agreed period of retention has expired or for legal or ethical reasons, this should be done so in accordance with all legal, ethical, and research-sponsor and collaborator requirements and with particular concern for confidentiality and security.

F. PROCEDURES

1. Researchers

   Researchers have primary responsibility for:

   a. Managing Research Data in accordance with the principles and requirements in the policy section, including the preservation of data integrity.

b. Authorizing or identifying access to Research Data, to include reading, entering, downloading, copying, querying, or updating data or information, as appropriate.

c. Developing and documenting clear procedures for the collection, storage, use, re-use, access and retention or destruction of the Research Data associated with their research. This shall include policies and procedures established by the Research and Scholarly

Data Governance Committee and, where appropriate, defining protocols and responsibilities in a joint or multi-institution collaborative research project. This information should be incorporated, where appropriate, in a Research Data Management Plan, for example, by using the DMPTool https://dmp.cdlib.org/.

d. Planning for the ongoing custodianship (at the University or using third-party services) of their data after the completion of the research or, in the event of their departure or retirement from the University, reaching a written agreement with the head of the department/faculty (or designee) as to where such data will be located and how it will be stored. A copy of the written agreement shall be provided to the chair of the Research and Scholarly Data Governance Committee.

e. Ensuring that any requirements in relation to Research Data management placed on their research by funding bodies or regulatory agencies or under the terms of a research contract with the University or Affiliated Organizations are also met.

2. Research and Scholarly Data Governance Committee (RSDGC)

The RSDGC reports to the Provost and Vice President for Academic Affairs on the development and enforcement of the University's Research and Scholarly Digital Data Management Policy. The Provost appoints Committee members, to include representatives from the faculty, University Libraries, Office of Research, Old Dominion University Research Foundation, Information Technology Services (ITS) and senior University management. The Provost will solicit recommendations from the Faculty Senate for the faculty representatives, who will comprise the majority of the committee. The Office of University Counsel will advise the RSDGC. The RSDGC may create subcommittees and task forces as needed to carry out its responsibilities.

Other Committee responsibilities include:

a. Guiding updates to this policy.

b. Coordinating the data management efforts of the operating units involved with Research Data management. The operating units include, but are not limited to, the University Libraries, Office of Research, Old Dominion University Research Foundation, Information Technology Services (ITS), Colleges, Departments, Centers, and the Office of University Counsel.

c. Defining and applying formal guidelines, procedures, and tools to manage the University's data resources, to include providing access for outside researchers. Overseeing the administration and management of all externally funded Research Data.

d. Defining a data stewardship model for protection and availability of research and scholarly data, based on University Policy 3504 – Data Classification Policy.

e. Resolving conflicts in the definition of centrally-used Research Data attributes, data policy, and levels of access. Resolving issues with regard to standard definitions for data elements that cross stewardship boundaries.

f. Establishing policies and procedures that manage Research Data as a University resource and communicating these policies and procedures to the University community.

g. Establishing specific goals, objectives, and action plans to implement the policy and monitor progress in its implementation.

h. Prioritizing the management of Research Data including identifying which data is most critical and assigning management priorities to all data entities and sources.

i. Considering delivery modes for transmitting Research Data.

j. Defining attributes and assigning maintenance responsibilities for data retention, disposition, and preservation. The retention and disposition of Research Data should conform to the policies of the Virginia State Library as interpreted through University Policy 3700 – Records Management Policy.

k. Coordinating with the Institutional Review Board on providing access to ODU's Research Data. Access to Research Data that is a public record should be managed in accordance with the Virginia Public Records Act.

l. Implementing and executing a training program available to scholars and researchers who create, preserve, retain, or use Research Data.

3. Vice Presidents (or Designees)

   Vice Presidents (or their designees) are responsible for:

   a. Providing access to services and facilities for the storage, backup, deposit, security, and retention of Research Data that allow researchers to meet their requirements under this policy and those sponsors funding their research.

   b. Providing researchers with training, support and guidance in Research Data management.

   c. Providing the necessary resources to those operational units charged with the provision of these services, facilities and training.

4. Consumers/Users

   Responsibilities of consumers/users include:

   a. Confidentiality: Respecting the confidentiality and privacy rights of individuals whose records they may access.

   b. Ethics: Observing the ethical restrictions that apply to data to which they have access.

c. Policy Adherence: Abiding by applicable laws and University policies with respect to access, use, protection, proper disposal, and disclosure of data.

d. Responsible Access: Accessing and using Research and Scholarly Data only as required in their conduct of University business. Reporting any breaches of University information in a timely manner according to procedures defined in ITS Standard 05.2.0 Data Breach Notification.

e. Quality Control: Reviewing reports created from data to ensure that the analysis results are accurate and the data has been interpreted correctly.

G. RESPONSIBLE OFFICER

University Librarian

H. RELATED INFORMATION

Health Insurance Portability and Accountability Act of 1996 (HIPAA)

Family Educational Rights and Privacy Act (FERPA)

Virginia Data Collection and Dissemination Practices Act § 2.2-3800 et seq

Board of Visitors Policy 1424 – Policy on Intellectual Property

Board of Visitors Policy 1426 - Policy, Procedures and Timeline for Responding to Allegations of Misconduct in Scientific Research and Scholarly Activity

University Policy 3501 – Information Technology Access Control Policy

Data Transfer Agreement (Office of Research)

APPENDIX E

OLD DOMINION UNIVERSITY
University Policy

Policy #3504
DATA CLASSIFICATION POLICY

Responsible Oversight Executive:	Vice President for Administration and Finance
Date of Current Revision or Creation:	April 26, 2011

A. PURPOSE

The purpose of this policy is to establish a uniform data classification framework to assist data owners in determining the level of data security that must be implemented to secure the information for which they are responsible.

B. AUTHORITY

Virginia Code Section 23-9.2:3, as amended, grants authority to the Board of Visitors to establish rules and regulations for the institution. Section 6.01(a) (6) of the Board of Visitors Bylaws grants authority to the President to implement the policies and procedures of the Board relating to University operations.

Restructured Higher Education Financial and Administrative Operations Act, Virginia Code Section § 23-38.88, as amended

C. DEFINITIONS

Data Classification - In the context of information security, it is the classification of data based on its level of sensitivity and the impact to the University should that data be disclosed, altered or destroyed without authorization**.**

Data Owners **- I**ndividuals responsible for decisions about the usage of University data.

Data Users - Individuals who access University data in order to perform their assigned duties or to fulfill their role in the University community.

Information Security Officer (ISO) – The Old Dominion University employee, appointed by the President or designee, who is responsible for developing and managing Old Dominion University's information technology (IT) security program.

Information Technology Resources – Include, but are not limited to, computers, telecommunication equipment, networks, automated data processing, databases, the Internet, printing, management information systems, and related information, equipment, goods, and services.

Security Administrators - Individuals who ensure that appropriate controls, mechanisms, and processes are in place to meet the security requirements necessary to protect an information technology resource.

University Data - All data or information owned, used, created or maintained by the University whether individually controlled or shared, stand-alone or networked.

D SCOPE

This policy applies to all users of Old Dominion University information technology resources and governs all information technology resources either owned by or operated for University business through contractual arrangements. Users may include employees, students, volunteers, employees of affiliated organizations, and visitors to the institution. Employees include all staff, administrators, faculty, full- or part-time, and classified or non-classified persons who are

paid by the University. Students include all persons attending classes whether enrolled or not enrolled. Affiliated organizations are separate entities that exist for the benefit of the University and include the Foundations, the Community Development Corporation, and the Alumni Association. Visitors include vendors and their employees, parents of students, volunteers, guests, uninvited guests and all other persons located on property owned, leased, or otherwise controlled by the University.

This policy refers to all data owned, used, created or maintained by the University whether individually controlled or shared, stand-alone or networked. It applies to all data sources found on equipment owned, leased, operated or contracted.

E POLICY STATEMENT

The security of University information and the infrastructure upon which it is processed, transmitted or stored is patterned after accepted standards for management of information security, such as ISO/IEC 17799, Information Technology - Code of Practice for Information Security Management, and industry best practices.

Classifications and associated protective controls for information take into account academic and business needs for sharing or restricting information and the impacts associated with such needs. Data classification impacts other security decisions on system security plans, risk assessments, locations regarding data storage, authorization and access requirements, and continuity of operations and disaster recovery planning.

The Office of Computing and Communications Services (OCCS) provides guidance to enable users to understand their particular custodial roles and responsibilities with respect to information. OCCS implements the technical infrastructure that allows University employees to effectively exercise these custodial roles.

Every user has a responsibility toward the protection of University data; some offices and individuals have very specific responsibilities. Data owners, in particular, determine the level of data security and classification that must be implemented. As described below, data owners, data users and security administrators have distinct roles and associated responsibilities under this policy.

1. Data Custodial Roles and Responsibilities

a. Data owners are responsible for:

- knowing and understanding the data for which they are responsible;
- evaluating and ensuring the data have been appropriately classified based on State and Federal law, regulatory agency requirements and/or any contractual obligations, and University policies;
- establishing access and utilization criteria;
- exercising due care in setting standards for protection of data;
- monitoring compliance and enforcing policy; and
- implementing practices to assure data accuracy.

b. Data users are responsible for:

- protecting their access privileges;
- proper use of the University data they access;
- following policy and information access procedures established by data owners;
- accessing only the information for which they are authorized;
- reporting suspected or actual violations of policies; and
- exercising due care in the use of data.

c. Security administrators are responsible for:

- executing access authorizations or data transfers authorized by the data owner;
- using best practices to maintain the confidentiality, integrity, and availability of information;
- providing a mechanism for monitoring compliance and enforcing policy; and
- exercising due care in the administration of systems hosting the data.

The examples provided in this policy are illustrative only. Nothing in this policy is intended to identify a restriction on the right of data owners to require policies and/or procedures in addition to the ones identified in this document.

2. Data Classification Levels

The data classification levels are listed in order from the most secure to the least secure:

a. Highly Confidential

Highly confidential information requires special precautions to ensure the integrity and confidentiality of the information in its storage, usage, and transmittal. This information must be protected from unauthorized modification or retrieval and is not generally disclosed. Highly confidential information may be used with third parties when safeguards and countermeasures are in place to protect that information. Unauthorized disclosure of highly confidential information can adversely and/or seriously affect the University as a whole or in part.

Examples of highly confidential data include, but are not limited to,

i. Student records
ii. Legally protected data
iii. President's working papers or correspondence
iv. Privileged attorney-client data
v. Access control data

b. Protected

Protected data includes both confidential information for use only by select individuals or systems within the University and private data used by the University that is specific to an individual. Confidential data are distributed on a need-to-know basis between members of the University staff, its systems, and specific third parties where appropriate, and unauthorized disclosure can adversely affect the University as a whole or in part. Private data may only be disclosed to a third party with the permission of affected individuals. Unauthorized disclosure of private information can adversely affect individuals associated with the University, but may not necessarily affect the University as an entity.

Examples of confidential data may include, but are not limited to,

- Non-public contracts
- Donor information
- Information exempt from disclosure under the Virginia Freedom of Information Act

Examples of private data include, but are not limited to:

- Appointment schedules
- Performance reviews

c. Public

Public information is, by its very nature, designed to be used by anonymous persons or systems that may have an interest with the University. Public information is routinely disclosed and made freely available. Further, the University also depends on data exchange with certain outside third party organizations, and the University must make sure that information is exchanged according to this policy based on the information classification level.

Examples of public data include, but are not limited to,

- Press releases
- Directory information classified as such by the University under FERPA
- Schedule of classes

Violations of this policy should be reported to the University's Information Security Officer (ISO). The ISO role is assigned to the Assistant Director for Information Security and Operations in the Office of Computing and Communications Services. Any faculty, staff or student found to have violated this policy may be subject to the appropriate disciplinary action.

F. PROCEDURES

For security purposes, some procedures related to data classification are maintained internally. Procedures are available upon request to relevant parties, notably data owners responsible for major systems, such as the Registrar, the Controller, and Institutional Research and Assessment, as authorized by the Office of Computing and Communications Services.

Other data owners are directed to the Data Classification Procedure for further assistance.

Data owners and users are provided additional guidance in Best Practices in Protecting University Data.

G. RESPONSIBLE OFFICER

Assistant Vice President for Computing and Communications Services

H. RELATED INFORMATION

Board of Visitors Policy 1424, Policy on Intellectual Property
University Policy 3500 - Use of Computing Resources
University Policy 3501 - IT Access Control Policy
University Policy 3505 - Information Technology Security Policy
University Policy 4100 – Student Record Policy
OCCS Standard 02.2.2 - IT Security Roles and Responsibilities
OCCS Standard 08.2.2 - Access Determination and Control
OCCS Standard 09.2.2 - Threat Detection
OCCS Standard 09.3.2 - Security Monitoring and Logging
OCCS Standard 09.4.2 - IT Security Incident Handling
OCCS Standard 09.5.2 - Data Breach Notification
OCCS Standard 10.2.1 - IT Asset Control
Data Classification Procedure
Guideline: Best Practices in Protecting University Data
OCCS System Inventory Index
Office of Research Volunteer or Visiting Scholar Agreement

APPENDIX F

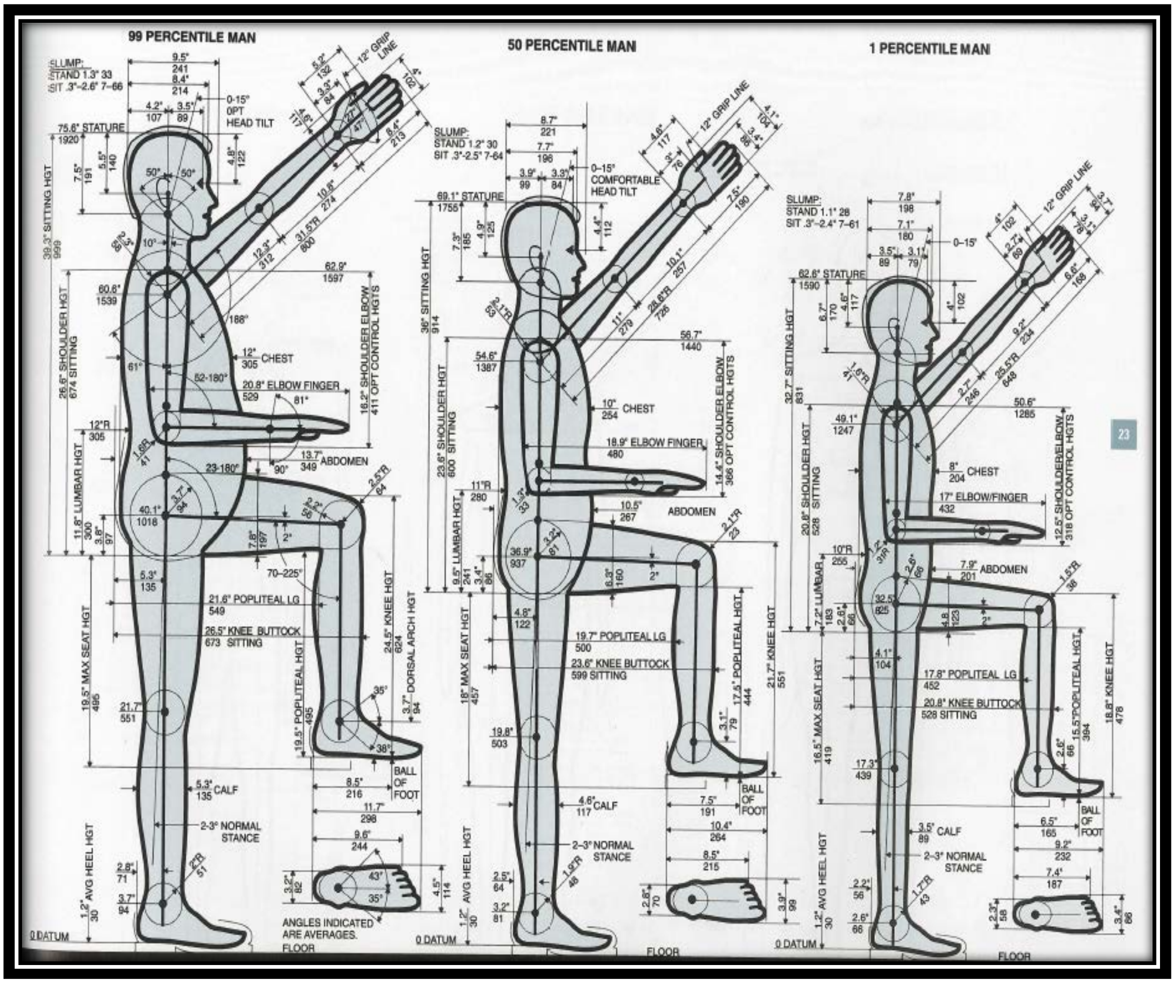


Figure 13. Man Form: Anthropometric Data: Dryfuss Human Scale (2002)

APPENDIX G

Table 19. Ride Type: R²CS Failure Frequencies by Year

	coaster	kiddie trai	carousal	pendulum	flume	rotate up-	rotate in p	free fall/t	rotating/ s	ferris whe	ski/chair l	swing cha	rotate/sp	boat	simulator	unknown
1995	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1996	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
1997	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
1998	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0
1999	3	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0
2000	2	2	0	0	0	0	0	0	2	0	0	0	0	1	0	0
2001	0	1	0	0	1	0	0	0	3	1	0	0	0	0	0	0
2002	1	0	0	0	0	0	3	0	1	2	0	0	0	0	0	0
2003	1	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0
2004	0	2	0	0	1	0	2	1	0	2	0	0	0	0	0	0
2005	2	0	0	0	0	0	1	1	0	1	0	0	1	1	1	0
2006	3	0	0	0	2	0	2	0	0	1	0	0	1	0	0	1
2007	1	0	0	0	0	0	2	0	1	2	0	0	0	0	1	2
2008	0	1	0	0	0	1	0	0	1	0	0	0	0	0	0	0
2009	2	1	0	0	1	0	0	0	2	0	0	1	1	0	0	0
2010	0	2	0	0	0	1	1	0	1	0	0	2	0	0	0	1
2011	3	1	0	0	0	0	1	0	2	1	0	1	0	0	0	0
2012	1	1	0	0	0	1	2	0	1	0	0	0	0	0	0	0
2013	1	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0
2014	0	0	0	0	0	0	1	0	1	1	0	0	0	0	0	0

APPENDIX G continued

Table 20. Failure Mode: R²CS Failure Frequencies by Year.

FAILURE MODE N=112	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
1-ejection/fall	0	1	1	3	5	5	6	6	2	7	8	9	9	2	6	6	8	6	3	4
secured/extraction					1	2		1	1	1	1	1	1	1	2	2	1			

Table 21. Gender: R²CS Failure Frequencies by Year.

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Total
1-male	0	0	0	3	6	4	2	2	1	4	4	6	4	2	2	4	5	2	2	1	54
2-female	0	1	1	0	0	3	4	5	2	4	5	4	6	1	5	4	4	4	1	3	57
0-unknown	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1
total	0	1	1	3	6	7	6	7	3	8	9	10	10	3	8	8	9	6	3	4	112

Table 22. Cognitive Level: R²CS Failure Frequencies by Year.

Year	2014	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000	1999	1998	1997	1996	1995	total
# of injuries	4	3	6	9	8	8	3	10	10	9	8	3	7	6	7	6	3	1	1	0	112
0-unkn	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	2
1-pre-operational	0	3	2	1	1	0	1	3	3	1	4	0	2	0	1	1	1	1	0	0	25
2-concrete operational	2	0	1	4	3	4	1	0	1	3	0	0	2	0	2	2	0	0	0	0	25
3-formal operational	2	1	3	4	2	2	1	7	6	4	3	2	1	4	4	2	1	0	0	0	49
4-mentally disabled	0	0	0	0	0	0	0	0	0	1	0	0	2	0	0	1	0	0	1	0	5
5-sensor-motor	0	0	0	0	1	1	0	0	0	0	0	0	0	1	0	0	1	0	0	0	4
6-distraught	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2

APPENDIX G continued

Table 23. Site Type: R^2CS Failure Frequencies by Year.

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
1-fixed	0	0	0	2	5	4	2	3	1	4	2	5	2	0	2	2	4	3	2	0
2-mobile	0	1	0	1	1	2	3	4	1	1	3	3	7	2	6	5	5	3	1	3

Table 24. Behavior Style: R^2CS Frequencies by Year

NON-COMPLIANT BEHAVIOR N=*48*															
	injury	1-norm	2-subst	4-wav	5-stand	6-MP	7-uncon	8-unruly	9-kneel	10- F_BK	12- unl re	13- rock c	14- cr leg	15 exit RV	0-unkn
1995	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1996	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0
1997	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0
1998	3	1	0	0	0	0	0	0	0	0	0	0	0	1	1
1999	6	3	0	0	0	1	0	0	0	0	0	0	0	1	1
2000	7	3	0	0	0	0	0	0	1	1	0	0	0	2	0
2001	6	2	0	0	1	1	0	0	0	0	0	0	0	1	1
2002	7	1	0	0	2	1	0	0	0	0	1	0	0	0	2
2003	3	1	0	0	0	0	0	0	0	0	1	0	0	0	1
2004	8	3	0	0	0	1	0	0	1	0	0	2	0	0	1
sub tot	42	14	0	0	4	4	0	0	2	1	3	2	0	5	7
2005	9	4	0	0	0	1	0	0	0	0	0	1	0	0	3
2006	10	3	0	0	0	1	0	0	0	0	1	0	0	4	1
2007	10	2	0	0	3	0	0	0	1	0	0	0	0	2	2
2008	3	1	0	0	0	0	0	0	0	0	1	0	0	1	0
2009	8	6	0	0	0	0	0	0	0	0	0	0	0	1	1
2010	8	5	1	0	1	1	0	0	0	0	0	0	0	0	0
2011	9	5	0	0	0	1	0	0	0	0	2	0	0	0	1
2012	6	3	0	0	0	1	0	0	0	0	0	0	0	1	1
2013	3	0	0	0	0	1	0	0	0	0	0	0	0	0	2
2014	4	3	0	0	0	0	1	0	0	0	0	0	0	0	0
sub tot	70	32	1	0	4	6	1	0	1	0	4	1	0	9	11
total	112	46	1	0	8	10	1	0	3	1	7	3	0	14	18

.

APPENDIX G continued

Table 25. Physical Limitation: R²CS Failures by Year

Year	cognitive/	too large	petite	4-Normal	total
1995	0	0	0	0	0
1996	0	0	0	1	1
1997	0	0	0	1	1
1998	0	0	0	3	3
1999	0	1	0	5	6
2000	0	0	0	7	7
2001	0	1	0	5	6
2002	1	0	0	6	7
2003	0	0	0	3	3
2004	0	2	0	6	8
2005	0	1	0	8	9
2006	0	1	0	9	10
2007	0	0	0	10	10
2008	0	0	0	3	3
2009	0	0	3	5	8
2010	0	0	0	8	8
2011	1	1	0	7	9
2012	0	0	0	6	6
2013	0	1	0	2	3
2014	0	0	0	4	4
total					112

Table 26. Injury Severity: R²CS Failures by Year

Injury	1-minor	2-major	3-death	0-unkn	# injuries
1995	0	0	0	0	0
1996	0	0	1	0	1
1997	0	0	1	0	1
1998	1	0	2	0	3
1999	2	0	3	1	6
2000	1	2	4	0	7
2001	1	1	3	1	6
2002	1	0	1	5	7
2003	0	1	1	1	3
2004	2	3	2	1	8
2005	0	4	4	1	9
2006	0	3	3	4	10
2007	3	5	2	0	10
2008	0	1	0	2	3
2009	1	3	2	2	8
2010	5	3	0	0	8
2011	1	3	5	0	9
2012	0	6	0	0	6
2013	1	1	1	0	3
2014	0	3	1	0	4

Table 27. Age: R²CS Frequency Failures by Year

Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	20	sub total
# of events	8	3	2	5	6	3	5	5	6	7	1	4	7	9	2	3	2	1	1	3	83

Age	21	22	23	24	25	28	30	31	32	34	35	37	38	40	45	46	48	52	55	60	sub total
# of events	1	2	1	1	1	1	5	2	1	1	1	3	1	1	2	1	1	1	1	1	29
																				grand total	112

APPENDIX G continued

Table 28. Restraint Type: R^2CS Frequency Failures by Year

Restraint type	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Total
1-collective lap bar			1		1	2	1	3		3	1	4	3	1		3	2	3	2	3	33
2-over shoulder		1			4	2			2		3				3		1			1	17
3-none				2		1		3		1	2	5	1			1	2				18
4-strap betw legs																					0
5-seatbelt							1	1	1	1	1			1				2			8
6-indiv lap bar					1										4	2	2		1		10
7-T-bar																					0
0-unknown				1		2	4			3	2	1	6	1	1	2	2	1			26
tot	0	1	1	3	6	7	6	7	3	8	9	10	10	3	8	8	9	6	3	4	112

Table 29. Previous Restraint Issue: R^2CS Frequency Failures by Year

Previous Issue	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
yes					5	2	1	4		2	1	1				1	1	2		
similar			1	2	1		2	1		4	3	6	4	2	2	1	3			
unknown		1		1		5	3	2	3	2	5	3	6	1	6	6	5	4	3	4

APPENDIX H

Table 30. Legend: R²CS Coding of Raw Failure Data

Event item	Source		Date	Injury Severity		Failure Mode	F1	F2	Gender		Age		Cognitive Stage		Behavior	B-1	B-2	B-3	Physical Limitation		Site type		Ride Type		Seating Config		Restraint Type	R-1	R-2	Restraint Class	Prev Issue		Region		Region	
				unkn	0	unknown	0		unk	0	unk	0	unknown	0	unknown	0			unknown	0	unkn	0	unknown	0	unknown	0	unknown	0		0	unknown	0	unknown	0	NH	26
1	RAs.com	1		minor	1	ejection/fall	1		male	1	<2	1	pre-operational (2-7 yrs)	1	normal	1			special needs	1	fixed	1	coaster	1	single rider	1	multi lap bar	1		1	yes	1	AK	1	NJ	27
2	ASO	2		major	2		2		female	2	2	2	concrete operational (8-12 yrs)	2	drugs/alcohol	2			too large	2	mobile	2	kiddie train	2	dual rider	2	over shoulder	2		2	similar	2	Asia	2	NM	28
3	NEISS	3		death	3	misposition /extraction	3				3		formal operational (13 yrs - adult)	3	thrill seeking	3			too small	3			carousal	3	multi riders	3	none	3		3	no	3	Australia	3	NV	29
4	NSC	4				dragged	4				4		mentally disabled	4	waving hands	4			none	4			360 loop coaster	4			strap betw legs	4		4			Az	4	NY	30
5	SaferParks	5				struck equip	5				5		sensor-motor (0<2 yrs)	5	standing up	5							flume	5			seatbelt	5		5			CA	5	OH	31
6	HSE	6				oper error	6				6		distraught	6	extraction mispositioning	6							kiddie coaster	6			indiv lap bar	6					Canada	6	PA	32
7	OBAB	7				pinned/crushed	7				7				unconsciousness	7							rotate in plane	7			T-bar	7					CO	7	Philippines	33
8	Other	8									8				climbing	8							free fall/tower	8									CT	8	SC	34
											9				kneeling	9							rotating/ spinning	9									Eng/UK	9	Singapore	35
											10				facing bwkd	10							ferris wheel	10									FL	10	southern_HEM	36
											11				fear	11							ski lift style	11									GA	11	Spain	37
											.				unlatched restraint	12							swing chair	12									IA	12	TN	38
											.				rocking car/gondola	13							bungee/sling shot	13									IL	13	TX	39
											.				crossed legs	14							inv coaster	14									IN	14	UAE	40
											60				existing RV	15							kiddie ride	15									Japan	15	Hawaii	41
															Unruly	16							boat/water	16									KN	16		42
																							simulator	17									LA	17		43
																							stand up coaster	18									MA	18		44
																							cage	19									MD	19		45
																							pendulum	20									MI	20		46
																																	MN	21	UT	47
																																	MO	22	VA	48
																																	MS	23	WA	49
																																	NC	24	WI	50
																																	NE	25	Europe	51

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Table 31. 2014 R²CS Failure Data

2014																					
RIDE RESTRAINT AND CONTAINMENT SYSTEM FAILURES																					
					failure mode						behavior							restraint type				
events	injuries	data source	accident date	injury severity	FM1	FM2	gender	age	cognitive ability	B1	Motive	Compl	patron limitation	site type	ride type	seating config	R1	R2	restraint class	prev issues	region
1	1	1,2	2014-Sep-12	3	1		2	8	2	1	0	1	4	2	9	1	2		5	0	3
2	2	1,2	2014-Aug-21	2	1		1	8	2	1	0	1	4	2	10	2	1		0	0	20
	3	1,2	2014-Aug-21	2	1		2	16	3	1	0	1	4	2	10	2	1		0	0	20
3	4	1,2	2014-Apr-17	2	1		2	18	3	7	1	1	4	2	7	3	4		6	0	9

Table 32. 2013 R²CS Failure Data

2013																					
RIDE RESTRAINT AND CONTAINMENT SYSTEM FAILURES																					
					failure mode						behavior							restraint type				
events	injuries	data source	accident date	injury severity	FM1	FM2	gender	age	cognitive ability	B1	Motive	Compl	patron limitation	site type	ride type	seating config	R1	R2	restraint class	prev issues	region
1	1	1	2013-Dec-24	2	1		1	7	1	0	0	2	4	2	11	2	1		0	0	23
2	2	2	2013-Aug-14	1	1		1	5	1	1	0	1	4	1	2	2	1		2	0	30
3	3	1	2013-Jul-19	3	3	1	2	52	3	1	0	2	2	1	1	0	1		2	0	39

Table 33 2012 R²CS Failure Data

2012																					
RIDE RESTRAINT AND CONTAINMENT SYSTEM FAILURES																					
					failure mode						behavior							restraint type				
events	injuries	data source	accident date	injury severity	FM1	FM2	gender	age	cognitive ability	B1	Motive	Compli	patron limitation	site type	ride type	seating config	R1	R2	restraint class	prev issues	region
1	1	2	2012-Apr-4	2	1		2	20	3	1		1	4	1	9	3	3		1	0	2
2	2	1	2012-June-17	2	1		0	0	0	0		0	0	1	2	1	5		2	3	15
3	3	1,2	2012-Mar-14	2	3	1	2	3	1	1		2	4	2	6	3	5	0	0	3	39
4	4	1,2	2012-Nov-3	2	1		2	9	2	1		1	4	2	7	3	1		2	1	9
5	5	1,2	2012-Nov-10	2	1		2	20	3	1		1	4	2	7	3	1		2	1	17
6	6	2	2012-Jun-17	2	1		1	13	3	15		2	4	1	1	0	0		0	0	6

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Table 34. 2011 R^2CS Failure Data

2011 RIDE RESTRAINT AND CONTAINMENT SYSTEM FAILURES																					
					failure mode					behavior							restraint type				
events	injuries	data source	accident date	injury severity	FM1	FM2	gender	age	cognitive ability	B1	Motive	Compl	patron limitation	site type	ride type	seating config	R1	R2	restraint class	prev issues	region
1	1	1,2	2011-Oct-24	3	1		2	31	3	1	0	1	4	2	9	3	1		0	2	9
2	2	2	2011-Sep-3	1	1		1	9	2	12	0	2	4	2	12	0	0		0	2	19
3	3	1,2	2011-Aug-23	0	1		1	12	2	1		1	4	1	9	3	2	1	5	0	9
4	4	2	2011-Jun-20	2	1		1	15	3	1		1	4	2	7	3	3		1	1	9
5	5	2	2011-Jul-2	2	1		2	12	2	1		1	4	2	1	3	0		0	2	9
6	6	1,2	2011-Jun-11	3	1		2	11	2	0		2	4	1	10	3	3		1	0	27
7	7	1,2	2011- Apr-11	3	1		1	3	1	12		2	4	1	2	2	0		0	0	13
8	8	1,2	2011-Mar-20	3	1		1	46	3	1		1	4	2	1	3	1	5	0	0	39
9	9	1,2	2011-Jan-30	3	3	1	1	34	3	1		2	2	2	1	0	6		0	0	15

Table 35. 2010 R^2CS Failure Data

2010 RIDE RESTRAINT AND CONTAINMENT SYSTEM FAILURES																					
					failure mode					behavior							restraint type				
events	injuries	data source	accident date	injury severity	FM1	FM2	gender	age	cognitive ability	B1	Motive	Compli	patron limitation	site type	ride type	seating config	R1	R2	restraint class	prev issues	region
1	1	2	2010-Oct-10	1	1		2	30	3	1		1	4	2	7	3	3		1	1	2
2	2	2	2010-Oct-2	2	1		1	22	3	1		1	4	2	6	3	1		0	2	41
3	3	1,2	2010-Sep-24	2	1		0	8	2	1		1	4	2	2	2	1		0	0	39
4	4	8	2010-Aug	1	1		1	20		2		2	4	1	0	0	0		0	0	5
5	5	1	2010-Sept-5	1	1		2	2	5	5		2	4	2	2	2	0		0	0	18
6	6	1,2	2010-Jul-27	1	3	1	2	9	2	6	0	2	4	2	6	3	1		0	0	5
7	7	2	2010-Jul-18	2	1		0	3	1	1		1	4	2	12	3	0		0	0	9
8	8	1	2010-Jul-18	2	1		2	10	2	1		1	4	1	12	1	1		0	0	39

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Table 36. 2009 R²CS Failure Data

2009 RIDE RESTRAINT AND CONTAINMENT SYSTEM FAILURES																					
					failure mode					behavior							restraint type				
events	injuries	data source	accident date	injury severity	FM1	FM2	gender	age	cognitive ability	B1	Motive	Compli	patron limitation	site type	ride type	seating config	R1	R2	restraint class	prev issues	region
1	1	2	2009-Oct-30	0	1		2	12	2	1	0	1	3	2	13	0	0	0	0	0	9
2	2	1,2	2009-Sep-19	2	1		2	15	3	1	0	1	3	2	9	2	2			2	31
3	3	1,2	2009-Sep-07	3	1		2	11	2	1	0	1	4	2	5		6		0	0	51
4	4	2	2009-Aug-23	0	1		2	35	3	1	0	1	3	1	1	1	6	4	0	0	51
5	5	1,2	2009-May-2	1	1		0	8	2	1	0	1	4	2	12	1	6		2	2	34
6	6	2	2009-Apr-10	0	1		2	8	2	1	0	0	4	2	1	1	2		0	0	9
7	7	1	2009-Mar-10	2	1		1	1	5	1	0	2	4	2	2	0	0		0	0	0
8	8	1	2009-Feb-14	3	1		1	37	6	15	3		4	1	1	1	2		0	0	0

Table 37. 2008 R²CS Failure Data

2008 RIDE RESTRAINT AND CONTAINMENT SYSTEM FAILURES																					
					failure mode					behavior							restraint type				
events	injuries	data source	accident date	injury severity	FM1	FM2	gender	age	cognitive ability	B1	Motivr	Compl	patron limitation	site type	ride type	seating config	R1	R2	restraint class	prev issues	region
1	1	1	2008-Jul-17	0	1		1	4	1	15	2	2	4	2	14	0	0		0	0	0
2	2	2	2008-Jun 19	0	1		2	7	2	1	0	1	4	2	7	3	1		0	2	6
3	3	1,2	2008-Mar-21	2	1		1	23	3	15	0	2	4	2	9	3	5	2	0	2	24

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Table 38 2007 R²CS Failure Data

2007 RIDE RESTRAINT AND CONTAINMENT SYSTEM FAILURES																					
					failure mode					behavior							restraint type				
events	injuries	data source	accident date	injury severity	FM1	FM2	gender	age	cognitive ability	B1	Motive	Compli	patron limitation	site type	ride type	seating config	R1	R2	restraint class	prev issues	region
1	1	1,2	2007-Sep-28	2	1		2	60	3	5		2	4	2	10	0	0		0	2	38
2	2	1,2	2007-Sep-17	1	1		2	13	3	1		1	4	2	0	3	1		0	0	9
3	3	1,2	2007-Sep-17	2	1		2	28	3	1		1	4	2	0		1		0		9
3	4	1,2	2007-Sep-08	2	3		1	0	0	15		2	4	2	15	1	3		1	0	49
4	5	1	2007-Aug-12	2	1		2	17	3	15		2	4	2	0	0	0		0	0	9
5	6	1	2007-Aug-04	2	1		1	3	1	0		2	4	2	10	3	0			0	31
6	7	1,2	2007-Aug-03	1	1		2	6	1	5		2	4	1	9	3	1		0	2	19
7	8	1	2007-Jun-29	3	1		2	21	3	9	1	2	4	1	7	3	1		0	2	30
8	9	1	2007-Apr-09	3	1		1	7	1	1		1	4	2	7	3	1		0	2	1
9	10	1	2007-Mar-24	1	1		1	13	3	1		1	4	2	1	0	0		0	0	9

Table 39. 2006 R²CS Failure Data

2006 RIDE RESTRAINT AND CONTAINMENT SYSTEM FAILURES																					
					failure mode					behavior							restraint type				
events	injuries	data source	accident date	injury severity	FM1	FM2	gender	age	cognitive ability	B1	Motive	Compli	patron limitation	site type	ride type	seating config	R1	R2	restraint class	prev issues	region
1	1	1,2	2006-OCT-26	2	1		2	13	3	15	2	2	4	2	13	2	1		0	1	11
2	2	1,2	2006-OCT-08	2	1		1	0	3	1	0	1	4	2	1	3	1		0	2	39
3	3	1,2	2006-OCT-08	2	1		2	30	3	15	2	2	4	1	5	1	3		1	2	51
4	4	1,2	2006-Sep-10	3	1		2	12	2	15	2	2	4	1	5	1	3		1	2	33
5	5	1	2006-Aug-26	3	1		1	22	3	1	0	1	4	1	7	0	0		0	2	9
6	6	1,2	2006-Jul-29	3	3		2	45	3	1	0	2	2	1	1	3	1		0	2	1
7	7	1,2	2006-Jun-18	3	1		1	6	1	15	2	2	4	2	10	3	3		5	2	0
8	8	1,2	2006-Jun-09	2	1		1	4	1	1	0	1	4	1	7	3	3		5	0	17
9	9	1,2	2006-Apr-30	2	1	5	1	2	1	0	0	0	4	2	0	0	3		0	0	0
10	10	1	2006-Feb-25	2	1		1	13	3	12	1	2	4	1	1	2	1	5	0	0	0

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Table 40. 2005 R²CS Failure Data

2005

RIDE RESTRAINT AND CONTAINMENT SYSTEM FAILURES

					failure mode					behavior							restraint type				
events	injuries	data source	accident date	injury severity	FM1	FM2	gender	age	cognitive ability	B1	Motive	Compli	patron limitation	site type	ride type	seating config	R1	R2	restraint class	prev issues	region
1	1	1	2005-Dec-18	3	1		2	9	2	1	0	1	4	2	7	3	1		0	2	39
2	2	1	2005-Dec-02	2	1		2	9	2	1	0	1	4	1	1		0		0	0	35
	3	1	2005-Dec-02	2	1		2	11	2	1			4								35
3	4	1	2005-Sep-01	3	1		2	45	4	1	0	1	4	1	13	1	2	5	0	0	30
4	5	1	2005-Aug-03	3	1	4	1	7	1	0	2	2	4	2	14	3	3		1	1	30
5	6	1	2005-Jul-09	0	1		1	48	3	13	1	2	4	2	10	3	3		0	2	13
6	7	1	2005-May-19	2	1		1	14	3	1		1	4	2	8	3	2		0	2	39
7	8	1	2005-Apr-09	3	3	1	1	30	3	1	0	2	2	1	15	1	2	5	0	0	15
8	9	1	2005-Jan-10	2	1		2	0	3	1		1	4	0	1	0	5	0	0	0	6

Table 41. 2004 R²CS Failure Data

2004

RIDE RESTRAINT AND CONTAINMENT SYSTEM FAILURES

					failure mode					behavior							restraint type				
events	injuries	data source	accident date	injury severity	FM1	FM2	gender	age	cognitive ability	B1	Motive	Compli	patron limitation	site type	ride type	seating config	R1	R2	restraint class	prev issues	region
1	1	1	2004-Aug-28	1	1		1	0	0	1	0	1	4	0	2	2	1		0	0	0
2	2	1	2004-May-22	3	1		2	7	1	9	1	2	4	0	7	3	1			2	30
3	3	1	2004-May-01	0	3	1	1	55	3	1	0	2	2	1	8	1	5	7	0	1	18
4	4	1	2004-Apr-17	1	1		2	13	3	13	1	2	4	1	10	3	0	0	0	2	16
5	5	1	2004-Apr-15	3	3	1	2	16	3	1		2	2	1	5	3	0		0	1	9
6	6	1	2004-Mar-20	2	1		1	6	1	0		2	4	2	10	3	3		0	2	3
7	7	1	2004-Jan-08	2	3	1	2	6	1	6		2	4	1	7	3	1		0	2	3
8	8	1	2004-Jan-04	2	1		1	5	1	1		1	4	1	2	0	0		0	0	31

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Table 42. 2003 R²CS Failure Data

2003 RIDE RESTRAINT AND CONTAINMENT SYSTEM FAILURES																					
					failure mode					behavior							restraint type				
events	injuries	data source	accident date	injury severity	FM1	FM2	gender	age	cognitive ability	B1	Motive	Compli	patron limitation	site type	ride type	seating config	R1	R2	restraint class	prev issues	region
1	1	1	2003-Nov-30	0	1		1	0	0	1	0	1	4	2	7	1	2		0	0	10
2	2	1	2003-May-31	3	1		2	32	3	12	0	2	4	1	1	0	5	6	0	0	14
3	3	1	2003-Jun-29	2	1		2	31	3	1	0	1	4	0	12	0	2	4	0	0	0

Table 43. 2002 R²CS Failure Data

2002 RIDE RESTRAINT AND CONTAINMENT SYSTEM FAILURES																					
					failure mode					behavior							restraint type				
events	injuries	data source	accident date	injury severity	FM1	FM2	gender	age	cognitive ability	B1	Motive	Compli	patron limitation	site type	ride type	seating config	R1	R2	restraint class	prev issues	region
1	1	1	2002-Oct-02	0	1		1	8	2	5	1	2	4	2	1	2	3		0	1	18
2	2	1	2002-Jun-08	0	3	1	2	4	1	1	0	2	4	1	7	2	1		0	0	5
3	3	1	2002-Jul-26	0	1		2	9	2	5	0	2	4	2	7	3	1		0	0	30
4	4	1	2002-Jul-15	0	1		2	15	4	0	0	0	1	2	10	3	3		0	5	9
5	5	1	2002-May-27	0	1		2	5	1	0	0	2	4	1	10	3	3		0	1	47
6	6	1	2002-May-27	3	1		1	24	4	12	0	2	4	1	7	3	5	6	0	1	0
7	7	1	2002-Apr-15	1	1		2	0	3	1	0	1	0	2	9	2	1		0	1	20

Table 44. 2001 R²CS Failure Data

2001 RIDE RESTRAINT AND CONTAINMENT SYSTEM FAILURES																					
					failure mode					behavior							restraint type				
events	injuries	data source	accident date	injury severity	FM1	FM2	gender	age	cognitive ability	B1	Motive	Compli	patron limitation	site type	ride type	seating config	R1	R2	restraint class	prev issues	region
1	1	1	2001-Nov-03	2	1		1	1	5	15		2	4	2	2	0	0		0	5	23
2	2	1	2001-Sep-21	3	1		2	40	3	6		1	2	1	8	0	5	6	0	0	5
3	3	1	2001-Aug-04	1	1		2	13	3	1		1	4	2	9	0	0		0	5	9
4	4	1	2001-May-12	1	1		2	0	3	0		0	4	1	9	2	1		0	1	5
5	5	1	2001-May-06	3	1		2	45	3	5	3	2	4	1	10	3	0		0	0	13
6	6	1	2001-Apr-18	3	1		1	30	3	0		1	4	2	9	0	0		0	0	40

APPENDIX I continued

Table 45. 2000 R²CS Failure Data

2000																					
RIDE RESTRAINT AND CONTAINMENT SYSTEM FAILURES																					
					failure mode					behavior							restraint type				
events	injuries	data source	accident date	injury severity	FM1	FM2	gender	age	cognitive ability	B1	Motive	Compli	patron limitation	site type	ride type	seating config	R1	R2	restraint class	prev issues	region
1	1	1	2000-Nov-05	3	4		1	37	3	15	0	2	4	1	14	2	3		1	0	10
2	2	1	2000-Sep-22	2	1	4	1	4	1	1	0	1	4	1	9	2	1		0	1	5
3	3	1	2000-Jul-23	3	1		1	30	3	9	1	2	4	2	1	1	0		0	0	51
4	4	1	2000-Jul-22	3	1		1	11	2	1	0	1	4	1	1	3	0			0	9
5	5	1	2000-Jun-30	2	1		2	38	3	10	0		4	1	1	1	2	1	0	0	20
6	6	1	2000-May-27	3	1		2	12	2	1	0	0	4	2	9	1	2	7	5	0	9
7	7	1	2000-Apr-18	1	3		2	13	3	15	15	0	4	1	0	2	1		0	1	5

Table 46. 1999 R²CS Failure Data

1999																					
RIDE RESTRAINT AND CONTAINMENT SYSTEM FAILURES																					
					failure mode					behavior							restraint type				
events	injuries	data source	accident date	injury severity	FM1	FM2	gender	age	cognitive ability	B1	Motive	Compli	patron limitation	site type	ride type	seating config	R1	R2	restraint class	prev issues	region
1	1	1	1999-Sep-05	3	1		1	4	1	1	0	1	4	2	9	1	2		0	1	51
2	2	1	1999-Sep-04	0	1		1	9	2	1	0	1	4	1	7	3	1		0	5	5
3	3	1	1999-Sep-02	1	3		1	13	2	15	2	2	4	1	1	1	2	6	5	1	48
4	4	1	1999-Aug-23	3	1		1	20	3	0	0	2	4	1	1	1	2	6	5	1	48
5	5	1	1999-Aug-22	3	1		1	12	4	1	0	1	4	1	8	1	2	4	5	1	5
6	6	1	1999-May-16	1	3	1	1	37	3	1	0	2	2	1	1	2	6		0	1	30

APPENDIX I continued

Table 47. 1998 R^2CS Failure Data

1998																					
RIDE RESTRAINT AND CONTAINMENT SYSTEM FAILURES																					
					failure mode					behavior							restraint type				
events	injuries	data source	accident date	injury severity	FM1	FM2	gender	age	cognitive ability	B1	Motive	Compli	patron limitation	site type	ride type	seating config	R1	R2	restraint class	prev issues	region
1	1	1	1998-Aug-01	3	1		1	12	3	15	2	2	4	1	5	3	3		0	2	21
2	2	1	1998-Aug-30	3	1	4	1	1	5	0		0	4	2	2	0	0		0	2	5
3	3	1	1998-Dec-24	1	1		1	4	1	1		1	4	1	3	1	3		0	0	5

Table 48. 1997 R^2CS Failure Data

1997																					
RIDE RESTRAINT AND CONTAINMENT SYSTEM FAILURES																					
					failure mode					behavior							restraint type				
events	injuries	data source	accident date	injury severity	FM1	FM2	gender	age	cognitive ability	B1	Motive	Compli	patron limitation	site type	ride type	seating config	R1	R2	restraint class	prev issues	region
1	1	1	1997-Feb-22	3	1	4	2	3	1	5	1	2	4	0	7	3	1		0	2	29

Table 49. 1996 R^2CS Failure Data

1996																					
RIDE RESTRAINT AND CONTAINMENT SYSTEM FAILURES																					
					failure mode					behavior							restraint type				
events	injuries	data source	accident date	injury severity	FM1	FM2	gender	age	cognitive ability	B1	Motive	Compli	patron limitation	site type	ride type	seating config	R1	R2	restraint class	prev issues	region
1	1	1	1996-Aug-16	3	1	4	2	14	4	12	2	2	4	2	4	3	2	18	5	0	13

APPENDIX J

Rotate-Spin Ride   Source: flickr.com

Coaster   Source: wolframalpha.com/

Ferris Wheel Source: atlanticfunpark.com

Kiddie Ride Source: jenkinsons.com

Free Fall Source:.ultimaterollercoaster.com E. Gieszel (2000)

APPENDIX J continued

Kiddie Coaster Source: Coaster Gallery J.Rogers (2012**)**

Rotate-Spin Source: bestonamusementequipment .com

Rotate-Spinning Source: readthesmiths.com

Kiddie Ride Source: milwaukeebystorm.com

APPENDIX J continued

Rotate-spinning Source: Carter Shows (2014) ……………………………………………………

Rotate-Spinning Source: Amusement Ride Extravaganza. D. Burton (2014)

Sky Chair Source: Ceder Point (2016)

Swing Source: funlight.cz

APPENDIX K

From: Hooper, Kathe [mailto:khooper@astm.org]
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APPENDIX L

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APPENDIX M

NCHS: Anthropometric Reference Data for Children and Adults: United States, 2007–2010

SERIES 11, Number 252, October 2012

Suggested citation

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- Systems of Systems Engineering
- Leadership for Engineering Management
- Social Political Engineering
- Agile Project Management
- Methods for Advanced Engineering Projects
- Systems Analysis
- Engineering Ethics and Engineering Management
- Crisis Project Management
- Cost Estimation and Financial Analysis

PUBLICATIONS

Stenzler, P., Handley, H., & Woodcock, K. (2016, July). Identifying human factors mismatches in amusement ride containment failure. *Proceedings of the 2nd International Conference on Human Factors in Sports and Outdoor Recreation*, Orlando, FL.

Stenzler, P. & Handley, H. (2016, February). A Retrospective Study of Amusement Ride Restraint and Containment Systems. *Presented at ASTM F24 Safety Committee Conference*, New Orleans, LA.

MAJOR WORK BACKGROUND AREAS

Universal Creative-Parks and Resort -Engineering & Safety: Oversight of engineering, safety and *Ride Systems* development; Ride and Show systems integration management; and technical performance requirements for domestic and international parks. Establish overall goals, initiatives, and accountabilities for the Ride and Show engineering teams based on company mission and vision.

Universal Orlando Resort-Technical Services - Sustaining Engineering/Quality Control: responsible for sustaining engineering activities for a 48 multi-disciplined team of engineering and QC professionals. These teams are associated with *Ride* safety compliance, reliability enhancements and Capital projects for the Orlando theme parks including the State Affidavit regulatory compliance with Authority Having Jurisdiction (AHJ).

TRANSPORTATION GROUP -Redesign/adaptation of existing underground light rail passenger system for service between Capitol Hill, House and Senate Buildings.

PATENTS

Guest Positioning Assembly	US7694640B2 (4/13/2010)
Actuatable Motion Base System	Pending 311081-1 (10/7/2014)
Amusement Park Rider Tracking System	Pending311065-8 (3/30/2015)
Tracking System: Initiating Amusement Park Environment Elements	Pending311065-2 (5/20/2015)
Tracking System and Method: Surveying Amusement Park Equipment	Pending 311065-6 (5/20/2015)