THE NEED FOR A STANDARD OF PROFESSIONAL PRACTICE

IN CIVIL ENGINEERING

by

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A DISSERTATION

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ABSTRACT

The premise for this research is that a standard of professional practice for design management will aid in the reduction of engineering failures. The data for this research was obtained from diverse group of peer reviewed journal articles, civil and forensic engineering authored books, and Travelers Indemnity Company. The structure of the dissertation is composed of a broad introduction followed by three journal articles: Article One "Inadequate Design Management Compared to Unprecedented Technical Issues: As a Cause for Engineering Failure," Article Two "Standards of Professional Practice for Design Management," and Article Three "Measuring the Responses and Attitudes for a Proposed Standards of Professional Practice for Design Management," and a broad conclusion. Each individual article provides a methodology for proving a need exists in the form of a standard to help reduce engineering failures resulting from inadequate management practices.

DEDICATION

This dissertation manuscript is dedicated to my Grandmother Mary Johnson Williams who has given me emotional and spiritual guidance through the trials and tribulations of developing this manuscript. I would also like to thank my wife Alix Davis Williams and my two sons: Cameron Williams and Graham Williams, for their unwavering support the last four years developing this dissertation manuscript through its completion.

LIST OF ABBREVIATIONS AND SYMBOLS

ACI	American Concrete Institute
ANSI	American National Standards Institute
ASCE	American Society of Civil Engineers
ASNI	American National Standards Institute
c	Confidence Interval (expresses as decimal)
CQI	Continuous Quality Improvement
EPC	Engineering, Procurement, and Construction
MES	Mississippi Engineering Society
N	Population Size
p	Percentage picking a choice, expressed as (.5 used for sample size needed)
QC/QA	Quality Control and Quality Assurance
RAM	Recognize, Activate, and Monitor
RR	Response Rate
Rs	Rate of Significance
SS	Sample Size
TIC	Travelers Indemnity Company
Z	Z value (e.g. 1.9 for 95% confidence level)

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INTRODUCTION TO THE DISSERTATION

Research Problem

If most engineering failures occur due to errors and omissions resulting from inadequate design management rather than weaknesses in existing technical codes and standards, then the design management processes is flawed. If so, then a standard of professional practice may hold the key to engineering failure reduction. It is unquestionable that errors and omissions will occur during the design process (Petroski, 1994). But while we accept that errors and omissions will occur, what procedures or processes can be used to minimize their occurrence?

Research Solution

This research proposed a hypothesis that a standard of professional practice for design management will aid in the reduction of engineering failures. The research tested the hypothesis by evaluating the engineering methods and processes of 47 engineering failure case studies. The findings supported the hypothesis, and a prototypical standard of professional practice aimed at design management was developed. The process for developing a prototypical standard of professional practice is shown through a collection of three journal articles. Each article is independently written but cohesively defines, explains, and defends the need for a standard of professional practice.

Dissertation Research

This dissertation research was conducted at the University of Alabama's Department of Civil, Construction and Environmental Engineering, and it focused on design processes, inadequate design management, and engineering failures. The objective of this research was to prove that a need exists in the form of a standard of professional practice aimed at design management to reduce the occurrence of failures. The process for developing this research project came from studying and evaluating 47 modern and historical engineering failure case studies and their causes for failure. The results from the analysis showed two broad causes for failure: 1) Inadequate Design Management, and 2) Unprecedented Technical Issues. The authors further subdivided these two categories into six subcategories under. The Inadequate Design Management subcategories are Design QC/QA, Communication, and Post Design Inspection. The subcategories under Unprecedented Technical Issues are Structural Behavior, Material Properties, and Geotechnical.

The research provided a qualitative approach using summarized evaluations by experienced professionals in the field of forensic and civil engineering. Additionally, a rating methodology was developed to determine the contribution to failure for each independent failure case study. The rating scale used was subjective and based on the opinions and evaluations of other authors and the research authors as to the cause of failure. The rating scale for the case studies was scored from 0 to 2 with: with 0 = insignificant, 1 = some contribution and 2 = substantial contribution to failure. The scale was deemed simple and direct with adequate discrimination for a subjective measurement scale.

The research also evaluated data from Travelers Indemnity Company (TIC). Travelers Indemnity Company is a professional liability company that provides liability insurance policies to design professionals and firms against losses resulting from negligence, errors, and omissions in the performance of professional services. To better serve their policy holders TIC reviewed engineering claim files in an effort to better understand the professional liability issues facing design professionals. The investigation focused on 100 of their most severe filed claims as the data source. The investigation performed by TIC is similar to the engineering failure case study analysis, but TIC focused solely on claims filed for errors and omission within the design process. This research focused on inadequate management practices within the design process. In relation to both studies each agrees that when expected outcomes do not meet its intended purpose a failure has occurred.

After completing our assessment on the failure case studies and determining inadequate management practices contributes more often than unprecedented technical issues as a cause for failure, the research began the process for developing a prototypical standard of professional practice. The development process focused on solely on the design process, and not so much on other project delivery strategies such as EPC, design-build, and fast track methods associated with the project delivery. All are integral in discussing the design process, but are not the focus of this dissertation work.

This research has determined that there is no systematic process for improving the design process, and no systematic method for incorporating lessons learned to minimize the occurrence of failures. This research determined that improving management practices through developing a standard of professional practice will improve the design process, and reduce engineering failures, by offering a vehicle to incorporate lessons learned for continuous improvement. The standards presented in this dissertation work are prototypical, so that members of the engineering professional community may become informed about the benefits of adopting a standard of professional practice. Future successive versions of the standards will evolve through future research and maturation.

For instance communication is an issue in any professional and non-professional organization, and there is an abundance of literature on the benefits of improved communications. The standard for communication developed did not rely on numerous references to make our point on how ineffective communication contributes to engineering failures. The authors heavily relied on personal experiences to articulate how important effective communications are needed as a standard to help improve the design process while reducing the occurrence of engineering failures. The other standard introduced was an original idea based on risk assessment. Traditionally risk assessment is not applied within the design process, but more so within the construction process. The development of the RAM theory (Recognize, Activate, and Monitor) was based on applying the concepts of assessing risk within the design process. It was not our intention to focus on reliability or resiliency as it relates to risk, but on how design engineers in the role of managers can better identify failure modes to improve the design process.

It should be noted that design engineers play a vital role in management, and often the lead design engineer who seals the final drawing plays this role. It was not the intention of this research study to contrast the study of engineering management and the role of the design engineer as a manager overseeing the design process. This dissertation work will only focus on those design engineers who are lead engineers in the role of manager. Therefore the importance of recognizing potential failure modes, activating plans of action to mitigate those failure modes, and provide continuous monitoring of the design process is critical to project success. The other duty of the design engineer should be within the construction process, as an inspector. Post design inspection is an important function that allows for continuing involvement by the design engineer despite whether or not contractual obligations extend past the design. The design engineer should be involved in all aspects of the design process including procurement, but it should not end at this stage. The role of the design engineer who has sealed the final drawings offers the most information regarding his or her design, and should be involved throughout the construction process to maintain the integrity of the design if changes occur to the original drawings.

The validation process for the research was performed through a survey. The researchers used a Likert rating scale to extract subjective opinions from survey participants. The questions were designed to be short and concise in order to accurately reflect the attitudes and opinions of responding participants. The researchers developed three ten question surveys that were administered to three groups at different times and locations. The results from the survey show that a standard of professional practice would be accepted by a majority of civil engineering professionals.

Research Significance and Limitations

This dissertation research will provide to the professional engineering community a prototypical standard of professional practice for design management. The purpose of developing a standard of professional practice will help aid in the reduction of engineering failures resulting from inadequate design management. The research was limited to data collected from past and modern engineering failure case studies, and data supplied from Travelers Indemnity Company. We feel the dissertation research conducted has provided measurable data that has allowed us to prove our hypothesis. The results from this dissertation research were critical in our development of a prototypical standard of professional. We feel our work has laid the foundation for others to continue this research study in the future.

ARTICLE ONE

Inadequate Design Management Compared to Unprecedented Technical Issues: As a Cause for Engineering Failure

1.1 Abstract

Engineering design failures fall into two broad categories, those that occur due to a hitherto unknown or unprecedented technical cause, and those that occur due to a known cause that was overlooked during the design process. The latter can be considered a failure of design management, and the purpose of this paper is to compare and contrast inadequate design management to unprecedented technical issues as a cause for engineering failures. Failures that occur due to improper maintenance or abuse are not the scope of this paper. Two approaches were taken, namely: (1) evaluation of current and historical engineering failures for instances of inadequate design management and/or unprecedented technical issues, and (2) review of filed claims data for design errors and omissions to determine whether inadequate design management is a substantial issue. This research may provide useful information in understanding how both categories limit the success of the design process.

1.2 Introduction

The practice of engineering involves the principles of design, technical codes, and graduated experience. This research is focused on the design process. The principles of design will be explored by assessing factors that are commonly associated with control of the design process. These factors include communication, design redundancy, errors and omissions, and design quality control and quality assurance measures (Carper, 1987). However, if not properly managed, the integrity of the design process may be compromised. The researchers acknowledge that these factors represent routine design practices. To assess the impact of these factors on the design process as it relates to engineering failures, two studies were implemented.

In the first study, 47 modern and historical civil engineering failure case studies were examined and evaluated as to the cause of failure. Failures in civil engineering are attributed to "errors in basic design concepts, drafting and detailing, construction, and inspection - what forensic engineers call procedural errors or information transfer deficiencies" (Carper, 1989). Reviews of failure case studies assist engineers by exposing procedural and technical shortcomings within the design process (Sowers, 1991). Lessons learned from failure case studies allow engineers in practice to avoid similar mistakes, thus creating more dependable and efficient structures (Wu and Chou, 2012).

In the second study several professional liability insurance providers were contacted to gain data on filed claims due to errors and omissions within the design process. Travelers Indemnity Company, a professional liability company that provides liability insurance for professional engineers and architects was the only company to respond and provide data. Travelers reviewed 100 of their most extreme filed claims to gain insight into the design process from civil engineers in professional practice. The information provided from their company was used as a benchmark to identify factors relevant to the current research.

1.3 Failure & Design Management

Leonards (1982) defined an engineering failure as "an unacceptable difference between expected and observed performance." Although minimizing or eliminating potential problems solidifies the design confidence of the engineer, project failure seems an inevitable part of the process. Design confidence is an engineering progression that comes from experience, judgment, and the ability to incorporate procedures to ensure the project is done right (Burgess, 1988). During this progression most engineers experience some form of project failure through mistakes, omissions, errors, and occasionally from hitherto unknown causes. Even with the steady progress of technological advances within the engineering profession, projects continue to fail. Failures come from "technical problems, physical problems, human errors and procedural deficiencies" (Khachaturian, 1985: Feld and Carper, 1997). The importance of recognizing management issues is just as vital as exposing technical and physical problems as a sources of engineering failures (Carper, 2005). Failure investigations often focus on technical and physical problems, such as a failed structural member, a materials failure, inadequate geological investigations, or something similar. At one extreme such technical failures may expose a flaw in accepted technical standards or practices, while at the other extreme they happen because accepted standards weren't implemented.

In this research the first is termed a failure due to *unprecedented technical issues,* while the second is termed a failure due to *inadequate design management*. The discovery of unprecedented technical issues generally leads to revised technical standards and better designs, but there are no shared standards for engineering management that can be revised based on instances of inadequate design management. The Quebec Bridge, the Teton Dam, the Schoharie Creek Bridge, and the Mianus Bridge are all well-known engineering failures resulting from both unprecedented technical issues and inadequate design management. The challenge for the researchers will be to plausibly explain how inadequate design management compared to unprecedented technical issues in each of these engineering failures.

1.4 Research Approach

Appendix A, Table 1-2 displays a list of all the modern and historical civil engineering failure case studies reviewed for this research, a brief description of each failure, and a rating of significance based on the most probable cause for failure. The list separates the failure case studies into two broad categories and six subcategories for the purpose of rating their significance. The first category, inadequate design management, is subdivided into three-subcategories: design quality control and quality assurance, communication, and post design inspection. These subcategories represent steps within the process, which more carefully and thoroughly implemented, could have prevented the failures. The second category, titled unprecedented technical issues, is divided into three subcategories: structural behavior, material properties, and geotechnical. In this research these subcategories represent three problem areas that were beyond the technical knowledge of engineering practices at that time.

Appendix B displays the rating criteria used to assess the cause for failure for each case study. In the evaluation process each of cases were rated to the perceived contribution of each subcategory to the failure. Each of the 47 cases studies were evaluated for the significance of the contribution of each subcategory and the significance was scored on a scale from 0 to 2 with: 0 = insignificant; 1 = some contribution; and 2 = substantial contribution to failure. The calculation process for each individual failure case study was performed by adding all of the scored points by one single subcategory with a maximum rated score of 94. So a score of 94 in a subcategory would indicate that the subcategory made a substantial contribution to the failure in every case study. The total rated maximum score for each category was 282, which is the result of multiplying the individual maximum rated score for each subcategory (3 x 94 = 282).

1.5 Research Results

The researcher's used the rate of significance methodology as previously stated to rate the failure case studies independently. The rating of each individual failure case study resulted in a total rate of significance score, and percentage score. The results are tabulated in Table 1-1:

Table 1-1 Tabulated Rate of Significance Results

Inadequate Design Management	(Rs) Score	Total (Rs)/(Rs) Score	Avg. (Rs) Score	(Rs) = 1	(Rs) = 2	Unprecedented Technical Issues	Rs (Score)	Total (Rs)/(Rs) Score	Avg. (Rs) Score	(Rs) = 1	(Rs) = 2
Design Quality Control and Quality Assurance	86.00	0.54	1.82	8.00	39.00	Structural Behavior	47.00	0.49	1.21	31.00	8.00
Communication	28.00	0.18	1.12	22.00	3.00	Material Properties	22.00	0.23	1.22	14.00	4.00
Post Design Inspection	44.00	0.28	1.33	22.00	11.00	Geotechnical	27.00	0.28	1.93	1.00	13.00
Total (Rs) & Avg. Rate of Significance Score	158.00		1.42			Total (Rs) & Avg. Rate of Significance Score	96.00		1.45		
Total Rate of Significance Score/Total Rated Maximum Score (282)	56%					Total Rate of Significance Score/Total Rated Maximum Score	34%				

The percentage score calculation for inadequate design management is shown below:

$$\frac{Design\ Quality\ Control\ and\ Quality\ Assurane}{Total\ Rate\ of\ Significance\ Score} = \frac{86}{158} = \mathbf{54\%}$$

$$\frac{Total\ Rate\ of\ Significance\ Score}{Total\ Rated\ Maximum\ Score} = \frac{158}{282} = \mathbf{56\%}$$

The results for inadequate design management show 54% of the design process issues are due to a lack of Design Quality Control and Quality Assurance. Following in a distant second is Post Design Inspection at 28%, and coming in third is Communication 18%. The results for unprecedented technical issues show 49% of the technical issues significance is due to structural behavior. Geotechnical issues came in second with 28 %, while material properties were third at 23%. The results from the comparison between the two categories show 56% significance for Inadequate Design Management; and 34% significance for Unprecedented Technical Issues. The results support the hypothesis that management issues within the design process are a substantial source of engineering failures.

Traditionally quantitative methods are used to evaluate civil engineering research studies. This study used qualitative research methods to analyze the chosen failure case studies included in this research study. Forty-seven modern and historical civil engineering failure case studies were evaluated using the qualitative approach and utilizing the experience and judgment of the researchers to assign the cause for failure. Clearly, somewhat different outcomes would be expected had random or controlled participants been chosen to rate the case studies. However, finding a group of qualified individuals to carefully study 47 failure case studies was beyond the current capacity of the researchers, so outside participation was not considered a viable option. The methodology for rating the case studies was modified from the paper titled "Forensic Studies of Geosynthetic Reinforced Structure Failures" (Wu and Chou, 2012). The results are not scientifically exact, but do show that apparently management issues exist within the design process more often than unprecedented technical issues. Corroboration of the case studies analysis was sought through an independent source, professional liabilities companies.

1.6 The Travelers Indemnity Company

Research data from professional liability companies was integral when testing the research hypothesis about issues within the design process that contribute to engineering failures. Travelers Indemnity Company was the only company that responded to our inquiry among several professional liability companies contacted for the purpose of this research. Travelers Indemnity Company conducted a research study that focused on 100 of their most severe claims that were filed in connection with engineering design. Appendix C displays two charts labeled as Figure 1-1 (Civil Engineering Claims) and Figure 1- 2 (Design Phase Claims).Figure 1 results show over 60% of the filed claims was due to design phase issues. The second graph Figure 1-2, offers a more detailed look into the design phase issues, and indicates that more than 60% of the filed claims are due to errors and omissions.

The research performed by Travelers Indemnity Company is similar to the case study analysis, but it is focused solely on modern cases. Both studies focus on issues relating to the design process. Travelers Indemnity Company refers to these issues affecting the design phase as errors and omissions, while this research refers to issues affecting the design process as management issues. But both studies agree that lack of technical knowledge is not the main problem. Rather, the failure to use well-known technical knowledge lies behind more than half of engineering failures.

1.7 Lessons Learned

This research has shown that civil engineering failures are likely more often the result of design management issues than unprecedented technical issues. The case studies evaluated for this research and the research performed by Travelers Indemnity Company exposed a consistent problem in regards to flaws within the design process. New technical codes and regulations incorporate information concerning failures from unprecedented technical issues. Unfortunately, that is not the case with design management issues. Although, many of the failures happened years ago, the inadequate management practices that resulted in these failures continue. The research looked for trends within the failure case studies used for this study, but found no evidence of measurable increases or decreases in failure type with time. Both studies show management issues that exist within the design process to be as serious today as they were 100 years ago. Although, the engineering profession embraces standards to assure that technical mistakes are not repeated, no professional standard exist to prevent the repetition of errors in the engineering design management process.

1.8 Additional Research Acknowledgement

The research/information used in Appendix A for this paper came from notable civil and forensic engineers such as: Kenneth Carper, Gerald Leonards, George Sowers, Norbert Delatte, Matthys Levy, Mario Salvordori and others. Their evaluations of these failure case studies gave us a solid foundation from which to evaluate the failures from both a management and a technical perspective. Certainly not all evaluations agree and new findings are often made available, but through differing interpretations of failures may affect the details of the current study, they are unlikely to change the general conclusion that the best opportunity to reduce future failures may be through better management of the design process.

1.9 Conclusion

The admission of imperfection due to errors and omissions is often difficult. Although perfection is unachievable due to the human element regarding decisions and judgment, it is not an excuse for failing to implement sufficient procedures or practices to achieve a desired engineering purpose. Analyzing and evaluating engineering failure case studies is of the utmost importance. Engineering failure case study review allows for better understanding of past mistakes with the objective of reducing their future occurrence. It is in our best interest as practicing engineers to understand management issues in design management that contribute to failures. This research has provided a reasonable theory concerning the causes of engineering failures by evaluating civil engineering failure case studies focusing on the design process. Further, the research concludes that more often than not, the reason for engineering failure is inadequate design management rather than unprecedented technical issues. Thus, the research concurs with an assessment by Mr. Jack D. Gillum, engineer of record for the Kansas City Hyatt Hotel walkway when he said, "a nationwide standard of practice should be adopted" (Gillum, 2000). The adoption of a standard of professional practice may be the best method of reducing the occurrence of management issues affecting the design process, while simultaneously minimizing the occurrences of engineering failures.

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Appendix A

Table 1-2 Summaries of Civil Engineering Failure Case Studies

Civil Engineering Failure Case Studies				Probable Causes for Failure and Rating Significance					
				Inadequate Design Management			Unprecedented Technical Issues		
Case No.	Failure Case Studies	Brief Description of Failures	Date	Design QC/QA	Communication	Post Design Inspection	Structural Behavior	Material Properties	Geotechnical
1	Dee Bridge	Torsional buckling instability among the bridge girders	1847	2	0	0	2	0	0
2	Ashatabula Bridge	Failure likely due to fatigue and brittle fracture at a flaw in an	1876	2	0	0	2	0	0
3	Tay Bridge	Failure due to a faulty design	1879	2	0	1	1	0	0
4	The Bussey Railroad Bridge Collapse	Failure due to fractured short tension hangers in the top chord joint block.	1887	2	1	1	2	1	0
5	Johnstown Flood (Southfork Dam)	Inadequated design due to modifications.	1889	1	2	2	1	1	2
6	Quebec Bridge	Failure due to improper design of the latticing on the compression chords.	1907	1	1	1	1	0	0
7	Austin (Pennsylvania) Dam	Inadequate design	1911	2	0	1	1	1	2
8	The Transcona Grain Elevator	Failure mechanism due to a lack of redundancy in the soil-bearing capacity	1913	2	0	0	0	0	2
9	St. Francis Dam	Failure due to an inadequate foundation.	1928	1	1	1	1	1	2
10	Tacoma Narrows Bridge	Failure due to the wind causing extreme undulations.	1940	2	0	1	1	0	0

Table 1-2 Summary of Civil Engineering Failure Case Studies (Cont'd)

Civil Engineering Failure Case Studies				Probable Causes for Failure and Rating Significance					
				Inadequate Design Management			Unprecedented Technical Issues		
Case No.	Failure Case Studies	Brief Description of Failures	Date	Design QC/QA	Communication	Post Design Inspection	Structural Behavior	Material Properties	Geotechnical
11	The Fargo Grain Elevator	Failure mechanism due to a lack of redundancy in the soil-bearing capacity	1955	2	0	0	0	0	2
12	Malpasset Dam Failure	Dam shifted due to crack in the seam of the concrete dam structure.	1959	1	0	0	1	0	2
13	King Street Bridge Collapse	Inappropiate steel, poor design details, and low ambient temperature.	1962	2	0	1	1	1	0
14	Vaiont Dam Resevoir Slope Stability Failure	Slope stability failure (landslide)	1963	1	0	0	0	0	2
15	Silver Bridge	Failure due to a defective eyebar design.	1967	2	0	1	2	0	0
16	Ronan Point Apartment Tower Collapse	Failure due to flaws in the deisgn.	1968	2	1	1	1	1	0
17	Collapse of 2000 Commonwealth Avenue	Failure due to low punching shear.	1971	2	0	1	1	0	0
18	Skyline Plaza in Bailey's Crossroad	Failure due to punching shear failure.	1973	2	1	1	1	1	0
19	Teton Dam	Failure due seepage under the abutment wall, geological factors, and	1976	1	1	1	1	1	2
20	Hartford Civic Center Stadium Collapse	Failure due to exterior/interior compression members.	1978	2	1	2	2	1	0
21	Citicorp Tower	Inadequate design.	1978	2	1	1	2	0	0
22	Willow Island	Inadequate form system design.	1978	1	1	1	2	2	0

Table 1-2 Summary of Civil Engineering Failure Case Studies (Cont'd)

Civil Engineering Failure Case Studies				Probable Causes for Failure and Rating Significance					
				Inadequate Design Management			Unprecedented Technical Issues		
Case No.	Failure Case Studies	Brief Description of Failures	Date	Design QC/QA	Communication	Post Design Inspection	Structural Behavior	Material Properties	Geotechnical
23	Kemper Arena	Failure due to fatigue failure in the A490 bolds used in the connection.	1979	2	0	2	2	0	0
24	Harbour Cay Condominium	Failure due to punching shear failure.	1981	2	0	0	1	0	0
25	Cocoa Beach Collapse	Failure due to design error.	1981	2	1	1	1	0	0
26	Hyatt Regency Collapse	Failure due to flaws in the design process due to inadequate mangement.	1981	2	2	2	0	0	0
27	Roof Collapse, Magic Mart Store Bolivar, Tennessee	Failure due to a lack of bottom chord bracing.	1983	2	0	0	1	0	0
28	Mianus River Bridge	Lack of proper design & inspection.	1983	2	1	2	1	2	0
29	Carsington Dam	Limited design and geotechnical experience.	1984	2	1	1	0	1	2
30	Roof Collapse, Taxi Cab Company Garage, Champaign Illinois	Failure due to a leaky roof, and no redundancy on the truss.	1986	2	0	1	1	0	0
31	Retail-Grocery-Floor Failure	Failure of linoleum-floor tile due to moisture movement in concrete	1986	2	1	2	0	0	0
32	Schoharie Creek Bridge	The cause of failure was due to extensive scour under Pier 3.	1987	1	1	2	1	0	0
33	L' Ambiance Plaza Collapse	Failure due to several procedural deficiencies.	1987	2	1	1	1	0	0
34	Collapse Analysis of the La Tienda Amigo	Failure due to insufficient plans, permit review, lack of web stiffeners.	1988	2	0	0	1	0	0

Table 1-2 Summary of Civil Engineering Failure Case Studies (Cont'd)

Civil Engineering Failure Case Studies				Probable Causes for Failure and Rating Significance					
				Inadequate Design Management			Unprecedented Technical Issues		
Case No.	Failure Case Studies	Brief Description of Failures	Date	Design QC/QA	Communication	Post Design Inspection	Structural Behavior	Material Properties	Geotechnical
35	Supermarket Roof Collapse in Burnaby British Columbia, Canada	Failure due to an underdesigned beam.	1988	2	0	0	1	0	0
36	Cypress Viaduct	Inadequate design.	1989	2	1	1	1	1	0
37	Cold Formed Steel Beam Construction Failure	Improper design procedures of hot-rolled & cold-formed steel.	1990	2	0	0	1	0	0
38	Agricultural Product Warehouse Failures	Failure due to improper design .	1990	2	1	1	1	1	2
39	Failure of Cyanide Overflow Pond Dam	Failure due improper design and construction procedures.	1990	2	0	0	0	0	2
40	Failure of a Hydroelectric Power Project Dam	Embankment slope failure.	1993	2	0	2	0	2	2
41	Chicago Post Office Collapse	Temporary connection failed due to poor communication.	1993	2	2	2	1	0	0
42	Collapse of a Trunk Storm Sewer in Boston	Failure due improper improper design.	1997	2	1	2	1	0	2
43	Injaka Bridge Collapse	Failue due to an under-designed deck slab.	1998	2	0	1	1	0	0
44	John Hancock Center Scaffold Collapse	Failure due to forces of dead load and down-draft wind loads.	2002	2	1	0	1	0	0
45	New Orleans Hurricane Katrina Levee Failures	Failure due indequate engineering-related policies.	2005	2	1	0	1	0	1
46	Minneapolis I-35W Bridge Collapse	Undersized gusset plates.	2007	2	1	2	1	1	0
47	BP Macondo Well Blowout	Procedural & Technical Management Errors.	2010	2	1	1	1	1	0

Appendix B

Probable Causes for Failure

Inadequate Design Management

1. Design Quality Control and Quality Assurance:

    a. Lack of design management involvement
    b. Lack of implementing design procedures and practices
    c. Misunderstanding of the design scope and project objectives
    d. Lack of redundancy
    e. Changes to Design plans and specifications
    f. Mismanagement of design team
    g. Lack of a Failure Risk Analysis Plan

2. Communication:

    a. Ineffective communication transfer processes
    b. Poor organizational management structure
    c. Poor language and reading skills
    d. Cultural and ethnic differences of the design team participants

3. Post Design Inspection:

    a. Design drawings and specifications not accurately applied or supervised during construction (Fehr, 2012).

    b. Lack of specific authority on all design related changes performed in the construction process that may affect the original design integrity, function and purpose.

Unprecedented Technical Issues

1. Structural Behavior: Unexpected performance of structural components that failed under specifically designed loading conditions.

2. Material Properties: Lack of specific knowledge about applicable standards for concrete, steel, asphalt, composites, and admixtures based on accepted design standard specifications. This is also inclusive of manufactured defects, material deformities, and premature deterioration.

3. Geotechnical: Lack of specific knowledge about geological and geotechnical concepts based on existing site conditions.

Appendix C

Summary of Graphical Analysis

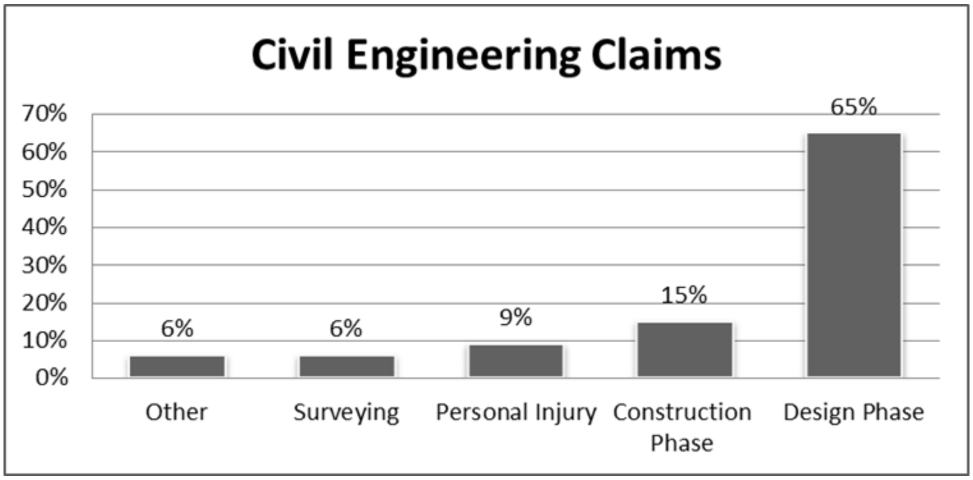

Figure 1-1 Civil Engineering Claims (Courtesy of the Travelers Indemnity Company)

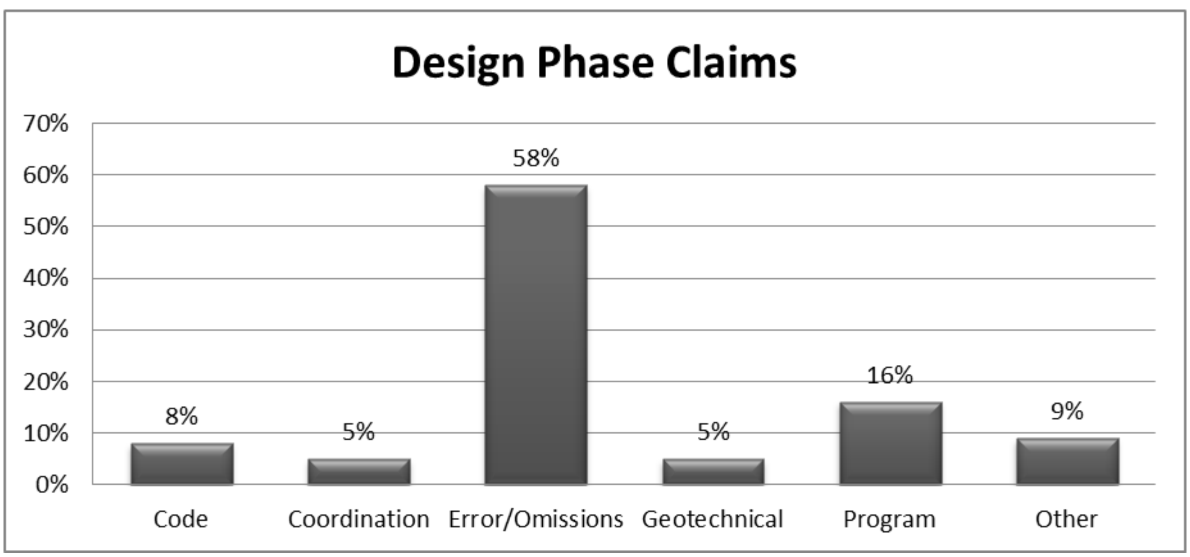

Figure 1-2 Design Phase Claims (Courtesy of the Travelers Indemnity Company)

ARTICLE TWO

Standards of Professional Practice for Design Management

2.1 Abstract

The research shows that many failures occur due to well-known technical issues overlooked by management during the design process. Such failures are often termed errors and omissions. This research further indicates that systematic design quality control and quality assurance, careful communication, and post design inspection are management techniques that could prevent a large number of engineering failures. In an effort to decease the incidence of management issues, the authors propose to structure a prototypical standard of professional practice for design management. In developing that structure, the authors: 1) explored the nature of standards and the similarities that exist in definitions by various professional organizations; and 2) reviewed the standard of care and considered why it may not be the engineering profession's best resource for evaluating duties and practices.

2.2 Introduction

The foundation for this research was based on showing causes for engineering failures that occur due to well-known technical issues often overlooked or ignored by design management. Further, this research wanted to indicate that systematic design quality control and quality assurance, careful communication, and post design inspection are management techniques that could prevent a large number of engineering failures. It has been investigated and proven that introducing design quality control and quality assurance procedures, engineering peer reviews, and effective communication programs are essential elements in reducing engineering failures (Carper, 2001).

Design projects involve various engineering principles that need strong cognitive managerial skills, thus the need exists for a standard of professional practice aimed at design management. This paper will focus on two approaches with the purpose of developing a prototypical standard of practice for design management: 1) explain the development process of a standard and the similarities that exist among definitions from various professional organizations; and 2) review the evolution of the standard of care and how it may not be the engineering profession's best resource for evaluating design practices.

2.3 Previous Research

The administration and oversight of the design process is the central concern of design management. This research focused on factors hindering the success of the design process that resulted from improper management practices. The evaluation of 47 historical and modern engineering failure case studies discovered that design management issues within the design process fell into three categories: design quality control and quality assurance, communication, and post design inspection. A previous paper written by the authors titled "Inadequate Design Management Compared to Unprecedented Technical Issues: As a Cause for Engineering Failure" discovered that a large portion of those 47 historical and modern engineering failures occur because existing technical codes and standards are not enforced, indicating flaws in the design management processes. The authors showed that of the issues identified within the design process that contribute to engineering failures, 56% were preventable by effective design management, and 34% stemmed from unprecedented technical issues. In addition to our study of engineer failures, the authors reviewed data from Travelers Indemnity Company in reference to filed claims for errors and omissions. The information from Travelers Indemnity Company supported the authors' findings that management issues are a significant contributing factor to engineering failures. The authors' final conclusion suggested that the development of a standard for professional practice aimed at design management may hold the key to reducing engineering failures resulting from management issues.

2.4 What is a Standard?

As a result of engineering failures, new technical standards are written and existing standards revised. Standards can differ among professions based on the level of quality and performance expected. Table 2-1 in Appendix A provides a diverse list of standards and their definitions gathered from various sources. Generally, engineering standards have the following characteristics:

1. Standards establish norms for processes, products or practices to assure safety and reliability.
2. Standards are promulgated by a recognized authority, usually a professional or trade organization such as ASCE, ACI or ANSI.
3. Standards are accepted and applied by consensus.
4. Standards are systematically updated by the users to incorporate new knowledge and prevent repetition of past mistakes.

5. Engineering standards are, in fact, an industry-wide continuous quality improvement process first implemented long before the term CQI was coined.

As a whole, the civil engineering profession lacks standards for managing the design process. Technical standards provide systematic technical guidance and instruction, not management guidance. Certainly individual firms have good in-house design management processes, but such processes lack three elements. First, they lack the authoritative backing of a standards organization. Second, they lack industry-wide consensus, and third they lack the systematic sharing of experiences across the profession that makes engineering standards so effective. The current research strongly suggests that an industry-wide standard of professional practice may be the most promising method for failure reduction. Once in place, the standard of practice could evolve through professional participation providing a reliable and continuously improving structure for managing the design process.

2.5 The Standard of Care

The Standard of Care is currently the only valid and recognized legal standard used to evaluate the performance of design professionals and evaluate whether professional duties were neglected. A design engineer in legal litigation charged with negligence must show that they exercised their professional duties consistent with the standard of care of their profession (Kardon, 2005). In the engineering profession, the standard of care is used as a tool to both question and measure design practices when a project fails. The defining measure of the standard of care is often complex. The standard of care is often used in litigation where an expected result failed to meet its intended purpose or use, and the design engineer is considered to be at fault.

The standard of care is a broadly defined measure of negligence used by the courts, not a standard in engineering operations and functions. It is not directly focused on safety, reliability or technical assistance, nor is it promulgated by a technical organization; it seems to be applied by consensus, but there is no systematic process through which it evolves to prevent repetitions of past mistakes. It is in no way designed to improve the engineering profession, only to assign blame. Further, since it can be so broadly interpreted, it does not even seem to be a particularly good legal doctrine, unless the goal is to increase the length and cost of a trial. Professional engineers in practice should not continue to "allow the legal profession to define the duties, obligations, and specific actions that constitute good engineering practice on a case-by-case basis after the fact" (Luth, 2000). The limitations of the standard of care, the continuing threat of legal litigation, and the ethical responsibility to reduce errors and omissions warrant a standard of professional practice. Given such a standard of practice, a design engineer in litigation could document that they met the standard of care by showing that they followed a true engineering standard.

2.6 Why a Standard of Professional Practice

The purpose of developing a standard of professional practice is primarily to reduce failures resulting from management issues within the design process. Our research has shown that many failures occur due to well-known issues that were overlooked by management during the design process. This research has determined that careful application of design quality control and quality assurance, communication, and post design inspection could prevent many failures. The purpose of developing a prototypical standard of practice is to provide: **A written set of standard engineering practices for the design management process; adopted and continuously upgraded by the engineering professional community for the purpose of**

reducing engineering failures as a result of management issues within the design process. A recognized set of written standards for design management may be the most promising method of reducing engineering failures as a result of management issues within the design process. These written standards of professional practice will comprise our expectations concerning good engineering design management, with the expectations of reducing engineering failures threatening the integrity of our profession.

2.7 Prototype Standards of Professional Practice for Design Management

2.7.1 Standard I: Design Quality Control and Quality Assurance

The decisions made within the design process are critical to the project outcome and performance as it meanders through the construction process. Adequate design quality control and quality assurance measures are vital components of the design process that must be managed continuously and efficiently. The authors proposed two elements for design quality control and quality assurance procedures: 1) Design Redundancy 2) Design Failure Risk Analysis.

2.7.1.1 Design Redundancy:

Previous research conducted on modern and historical engineering failure case studies showed that a high percentage of those case studies lacked redundancy. Redundancy is defined as "designing, incorporating, and including physical and human processes in to analysis, design, and construction in such a way that if one element, whether physical or human, fails to function in the way intended, other elements take over in such a way that the structure will function essentially as intended" (Osterberg, 1989). Redundancy in design comes in at least two forms, structural redundancy and procedural redundancy. Structural redundancy assures that if a member fails there are other members to take the load (Ortega, 2003). If there is a standard in place that requires structural redundancy to be checked "the use of improper methods, invalid assumptions, or incorrect modeling techniques" will be deterred (Burgess, 1988). Procedural Redundancy is when there are "provisions of additional, distinctive steps that include multiple design approaches in order to validate the design" (Ortega, 2003). When design management lacks a plan of action to implement redundancy measures within the design process, engineering failures can occur. In short, there needs to be a systematic method of design checking in place.

Design Redundancy Plan of Action:

a. Provide continuous oversight through the design process by checking all design assumptions, calculations and engineering theories concerning design methods and practices.

b. No design changes will be authorized without a paper trail and specific checks prior to approval by the design engineer.

c. Establish secondary peer reviews to check and assure all design requirements have been met prior to sealing the final design drawings.

2.7.1.2 Design Failure Risk Analysis

The cornerstone of this research has been the analysis of ways and means of preventing engineering failures that are the result of management issues. Authors such as Petroski, Kaminetzky, and Carper have promoted the need for failure avoidance in their respected publications. The need for design failure risk analysis prompted this question: how often do engineers examine the possibility of design failure? Failure analysis has often been used to evaluate technical weaknesses, not issues in management. Risk analysis has been used by many business organizations to assess risk for investments, stocks, and financial portfolios to aid their clients in making the best financial decisions. This research feels that the introduction of a failure risk analysis process would be a great tool for engineers who manage the design process.

The RAM theory is based on the concept that engineers in management need to perform three basic failure risk analyses to minimize potential failure threats within the design process: **1. Recognize** – identify potential modes of failure; **2. Activate** – develop plans of action to mitigate those modes of failure; and **3. Monitor** - continuously monitor and provide oversight to assure that the mitigation plans are implemented. The authors admit the introduction of this proposed standard is based on past design experiences that failed due to improper management practices and failure risk assessment of the proposed designed. The lack of raw data to support this standard may attract negative comments and references regarding its implementation; however, the authors strongly feel that consideration is warranted. The RAM theory is in its infant stage, and the authors hope that future researchers who feel that the standard is a promising tool for failure reduction will continue to stress its significance and implementation even to the point of pushing it to evolve as engineering and design practices change in the future.

2.7.2 Standard II: Communication

The process of communication can be defined as the "imparting or interchange of thoughts, opinions, or information through speech, writing, or signs" (Folland, 1983). Communication cannot exist in any form without the exchange of thoughts, ideas, and opinions between two participating parties (Folland, 1983). In order for the communication process to be completed there must be feedback from the individuals who received the communication (Folland, 1983). Design projects driven by cost and time may side-step the communication process leading to errors and mistakes. Ineffective communication within the design process is a management issue that plays a major part in the failure of many design projects. Unfortunately, there has been little effort to measure the results of ineffective communication in relation to engineering failures or the result thereof. Ineffective communication is not a new subject when discussing design project management. This research has shown through evaluation of past and modern engineering failures, that ineffective communication is an issue within the design process.

The importance of establishing effective communication procedures is vital and critical to project success. The lack of a systematic communication process in place for design management to govern the design process ultimately leads to errors and omissions. Establishing effective informational methods will be complex and difficult to maintain during the design process. In order to achieve adequate effective communication within the design process, systematic communication processes must exist. Below are suggested methods to help maintain an effective communication process:

a. Establish routine project status meetings that require feedback in the form of exchanges of thoughts, opinions, and suggestions from the design staff.

b. Establish methods of communication through memo, email or other electronic devices that provide notification of delivery and receipt.

c. Maintain records of all design decisions, changes, and written correspondence relating to design duties and responsibilities. This information should be shared with all new design team members and discussed at scheduled progress meetings

d. Develop an organizational chart placing a design team member who is respected by the design staff to promote effective communication without intimidation or fear (Hensey, 1987).

e. Effective communication will not exist without oversight and input from design management continuously throughout the design process.

2.7.3 Standard III: Post Design Inspection

As a practicing professional engineer who has offered design services as a private consultant, and as a government employee overseeing numerous projects, the author is aware that post-design involvement is critical to project success. The design engineer's role during the construction process has been debated by many engineering professionals. There are three issues of concern regarding this debate: 1) Authority 2) Liability and 3) Ethical obligations. In many cases the contractual obligation of the design engineer is to produce plans and specifications based on an agreed upon scope of work. Once the design engineer signs and seals the drawing, they are released to the owner. The contractual obligation ends with the release, but has the authority and liability of the engineer ended regarding his or her design? And if it has, should it end? In addition, ethical obligations may arise when the engineer needs to speak out about an error or omission discovered in the design. Many questions arise within the construction process that can only be answered or interpreted by the design engineer. The role of the design engineer should be a point of reference if questions arise concerning potential design changes, shop drawing changes, or testing procedures that could impact the integrity of the design's intent and purpose. It is our opinion that the design engineer should stay engaged past the design process, and his or her role should be agreed when developing the scope of services to be performed. The following are suggested roles and duties for the design engineer, which are recommendations and guides to help facilitate involvement and engagement by the design engineer into the construction process.

1. Construction Field Representative:

a. Establish routine project site visits to engage in discussion with the contractor, owner, and other construction representatives concerning any project changes or site issues pertaining to the design plans or specifications of the project (Avvakumovits, 1996).

2. Shop Drawings Approval:

a. Establish protocol with the contractor to review all shop drawings pertaining to the design intent and purpose as it relates to the plans and specifications.

b. Establish an understanding with the contractor that the design engineering professional will only serve in an advisory role concerning design related issues regarding compliance and standards set within the written specifications and design drawing plans (Avvakumovits, 1996).

3. Site Testing Representative:

a. Serve in an advisory role concerning site testing procedures as needed for quality control and quality assurance purposes regarding required project materials requested within the written specifications or noted on the plan drawings.

b. Provide interpretations of required procedures regarding material testing as required by written specifications; provide guidance and recommendations concerning changes requested that deviate from the original specified requirements (Avvakumovits, 1996).

2.8 Conclusion

Because of the human element, engineering failures will by no means cease. Even though errors and omissions will continue to occur, it does not negate our duty to instill standards to minimize their occurrence. What this research has tried to articulate is that though engineers by nature focus on technical issues, the most promising method for failure reduction may be the development of a standard of professional practice for design. The research focused on design management issues that affected the design process. Those management processes fall into the categories of design quality control and quality assurance, communication and post-design inspection. The research objective was to gain an audience of professional engineering organizations to discuss our findings and outline the benefits of establishing a standard of professional practice. We recognize that our research will not be an easy topic of discussion for many engineering professionals to accept or embrace. This research supports the adoption by consensus of a standard of professional practice for design management that will define responsible engineering practice in-lieu of the standard of care. Jack Gillum (2000), engineer of record for the Kansas City Hyatt Hotel walkway collapse states that, “a nationwide standard of practice should be adopted” in order to ensure that a level of integrity exists regarding design quality and process. The authors agree.

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Appendix A

Table 2-1 Typical Standard Definitions

Typical Standard Definitions	Sources
According to 15 USCS § 205c (2) [Title 15. Commerce and Trade; Chapter 6. Weights and Measures and Standard Time; Metric Conversion], the term "engineering standard" means "a standard which prescribes (A) a concise set of conditions and requirements that must be satisfied by a material, product, process, procedure, convention, or test method; and (B) the physical, functional, performance and/or conformance characteristics thereof."	http://definitions.uslegal.com/e/engineering-standard/
"A document established by consensus and approved by a recognized body that provides for common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context"	http://www.etsi.org/Website/Standards/WhatIsAStandard.aspx
"A prescribed set of rules, conditions, or requirements concerning definition of terms; classifications of components; specifications of materials, performance, or operations; delineations of procedures; or measurement of quantity and quality in describing materials, products, systems, services, or practices"	http://www.techstreet.com/whystandards.tmpl
" A standard can be defined as a set technical definitions and guidelines, "how to" instructions for designers, manufacturers, and users. Standards promote safety, reliability, productivity, and efficiency in almost every industry that relies on engineering components or equipment."	http://asme.org/kb/standards/about-codes
"Something established by authority, custom, or general consent as a model or example"	http://www.merriam-webster.comm/dictionary/standard
"Something set up and established by authority as a rule for measure of quantity, weight, extent, value, or quality"	http://www.merriam-webster.comm/dictionary/standard
"Codified guidelines that define how processes are to be performed or measured, or how products are to be designed. Usually written by businesses, industrial organizations, and government bodies. Serve to increase product quality and safety, and allow for interchangeability of parts"	http://library.umaine.edu/science/standardsdefinition.htm

ARTICLE THREE

Measuring the Responses and Attitudes for a Proposed Standards of Professional Practice for Design Management

3.1 Abstract

Our research has determined that major contributors to engineering failures are the lack design quality control and quality assurance, communication, post design inspection measures often attributed to being overlooked or ignored by management. Thus, the authors have looked at different methods to aid in the reduction of engineering failures resulting from these identified management issues. The purpose of this paper is to measure the responses and attitudes about developing a prototypical standard of professional practice for design management to aid in the reduction of engineering failures.

3.2 Introduction

This research is based on the hypothesis that a standard of professional practice for design management will aid in the reduction of engineering failures. The research looked at the engineering methods and processes of past and modern engineering failures using case studies as a data source. The findings support the need for a standard of professional practice covering design quality control and quality assurance, communications, and post-design inspection. Consequently the authors developed a prototypical standard of professional practice for design management. The purpose of this paper is to measure responses and attitudes about the idea of a standard of professional practice for design management. A survey was designed to measure these attitudes.

3.3 Research Approach

3.3.1 Survey Design

The objective and goals of the survey design were to extract subjective opinions about a proposed standard of professional practice for design management. The questions were designed to be short and concise in order to accurately reflect the attitudes and opinions of responding participants. The researchers developed three ten question surveys that were administered to three groups at different times and locations. Some of the questions on each survey were identical and some similar to gather specific responses among the groups for comparison. The questions used for the survey are shown in Table 3-1. The delivery process for administering the surveys was through PowerPoint presentations and email. The survey asked identical, similar and different questions as it relates to the research turned out e beneficial in gaining additional insight about how the respondents viewed our research work. The researchers decided the Likert rating scale was the best tool to extract subjective opinions from survey participants, and the responses were measured in the form of: 1) Strongly Disagree, 2) Disagree, 3) Undecided, 4) Agree, and 5) Strongly Agree (Bertram, 2009).

Table 3-1 Survey Questions

Questions No.	Survey A	Survey B	Survey C
	Forensic Class	Mississippi Engineering Society	American Society of Civil Engineers MS Section
1	Based on your knowledge of failure case studies do you agree a standard of professional practice is warranted?	Based on your professional experience and knowledge of engineering failures due to design issues do you agree a standard of professional practice is warranted?	Based on your professional experience and knowledge of engineering failures due to design issues do you agree a standard of professional practice is warranted?
2	Do you agree that adopting standards would help engineering management decrease design process issues?	Do you agree that adopting a standard of professional practice will help decrease design process issues?	Do you agree that adopting a standard of professional practice will help decrease design process issues?
3	Do you think a proposed standard of professional practice will help engineers mitigate project risk?	Do you think a proposed standard of professional practice will help engineers mitigate project risk?	Do you think a proposed standard of professional practice will help engineers mitigate project risk?
4	Do you think the proposed standards presented portray design issues identified in the failure case studies reviewed?	Do you think proposed standards presented portray issues identified in most design processes?	Do you think proposed standards presented portray issues identified in most design processes?
5	If the future of engineering is headed to globalization, will a standard of professional practice help maintain professional integrity?	If the future of engineering is headed toward globalization, will a standard of professional practice help maintain professional integrity?	If the future of engineering is headed toward globalization, will a standard of professional practice help maintain professional integrity?
6	Do you agree that if a standard of professional practice was in place it would have lessen the chance of failure for the Hyatt Regency Collapse and others structural disasters?	Do you agree that if a standard of professional practice was in place it would have lessen the chance of failure for the Hyatt Regency Collapse and others structural disasters?	Do you feel that knowledge of engineering failure case studies will help you become a better engineer or engineering manager?
7	Do you agree to many errors and mistakes occur within the design process due to poor engineering management?	Do you agree too many errors and mistakes occur within the design process?	Do you agree too many errors and mistakes occur within the design process?
8	Do you agree that engineering management is the key to project success?	Do you agree that civil litigation has increased due to engineers not using good or proper engineering judgement?	Do you agree a Design Management Class should be offered in undergraduate or graduate engineering curriculums?
9	Should academia put more emphasis on engineering management practice, and how to manage design project issues?	Do you feel academia and professional societies need to put more emphasis on engineering management practices?	Do you agree a Design Management Class should be offered in undergraduate or graduate engineering curriculums?
10	Have you benefited from taking this Forensic class?	Do you agree that the current "Standard of Care" could benefit from a Standard of Professional Practice?	Do you agree that the practice of engineering is changing due to technological advances?

3.3.2 Survey Participants

It should be noted that the cornerstone of a research project is the validation process that's begins with sampling a target population. Unfortunately, this research was limited in fielding a wider target population due to limited financial resources and time. In an effort to achieve reasonable accuracy, the target population was selected from both academia and professional engineers in practice. The students who participated in the survey were taking a class in Forensic Engineering at the University of Alabama within the Civil, Construction and Environmental Department. Because the students had current knowledge of the failures reviewed for the research; and knows of the researcher's affiliation as a graduate student, a certain level of bias may exist in the survey results. The total class size of 50 was targeted including a mix of undergraduate and graduate students. A brief PowerPoint presentation about the research study was given to the 27 students in attendance. The survey was given to all of the 27 students in attendance. All 27 students participated in filling out the survey and turned in their responses. The response rate was calculated using the targeted audience of 50, which gave us a 54% response rate.

A second survey was given to members of the Mississippi Engineering Society in attendance at the annual Regional Winter Conference in Jackson, Mississippi. A brief PowerPoint presentation was given to fifty members of the Mississippi Engineering Society on management issues within the design process and the relationship to engineering failures. The outline for a proposed standard of professional practice was also discussed including the benefits of how it could possibly reduce engineering failures resulting from inadequate management practices. The survey was administered to the attendees after the presentation was over. A total of forty-one participants out of fifty completed the survey, which provided a response rate of 82%. The survey participants were a mix of all levels of engineering experience, and a majority of the participants were from the Mississippi Department of Transportation a state government agency.

A third survey was administered to members of the Mississippi Section of the American Society of Civil Engineers. A PowerPoint presentation was not given to this group, just a brief description of the research study that was attached to a survey that was emailed. The research sampled 100 of the 928 registered members of the Mississippi Section of the American Society of Civil Engineers. The sampled population of 100 was considered adequate for reasonable level of accuracy. The researchers received 25 completed surveys out of the 100, giving a 25% response rate. The response rate (RR) for survey C is calculated (SurveyMonkey, 2009), by

$$\frac{\#\ of\ Completed\ Survey\ \ Recieved}{\#\ of\ Survey\ \ Delivered} = RR$$

$$\frac{25}{100} = \ 25\%$$

3.3.3 Sampling Results

A survey was chosen as the best instrument available to extract indiscriminately subjective opinions. The development of a survey can be a complex process. The ability to secure reliable, valid, unbiased, and complete data is critical to the success of the research study. Statistical approaches were used to validate and test the survey results. The survey was given to two controlled audiences through a PowerPoint presentation, and one non-controlled audience that received a copy of the survey through email. Appendix A shows the outline for a proposed prototypical standard of professional practice for design management that was presented to all survey participants.

Table 3-2 shows results from determining the sample size needed from participants to achieve an acceptable level of accuracy based on a target population size. The researchers understood that with a limited number of participants it can be difficult to achieve a high level of accuracy. A broader audience with more participants would field a better level of accuracy with minimum variations within the survey results. The Z value, 95% confidence level, estimated level of accuracy, and confidence interval were values used based on the worst case scenario to determine the sample size required to accurately represent the targeted population. The results shown in Table 2, demonstrate that the sampled groups used for the survey did meet the sample size requirements based on an acceptable targeted population size. The sample size required was calculated (Creative Research Systems, 2012), by

$$\frac{Z^2 * (p) * (1-p)}{c^2} = \text{Sample Size Required}$$

$$\frac{1.96^2 * (.50) * (1-.50)}{.25^2} = 15$$

Z = 1.96 for a 95% Confidence Level
p = estimated level of accuracy (.50)
c = confidence interval (.25)

Table 3-2 Sample Size Requirements Results

Survey	Confidence Interval	Confidence Level	Target Population Size	# Surveys Received	Sample Size Required	Z
A	0.25	95%	50	27	15	1.96
B	0.25	95%	50	41	15	1.96
C	0.25	95%	100	25	15	1.96

3.4 Survey Results

The structure of the questions was designed to test the survey respondents' attitudes toward adopting a standard of professional practice to minimize the occurrence of engineering failures due to inadequate management practices within the design process. Each group surveyed was given six questions either identical or similar regarding their individual opinions concerning a proposed standard of practice presented to them by PowerPoint presentation or email. The questions used for each survey group are shown in Table 1 for reference. The first group surveyed was a forensic class studying at the University of Alabama within the Civil, Environmental and Construction Department. The class had been reviewing and evaluating failure case studies over the semester. The survey was conducted toward the end of the semester, so the students, a mix of undergraduates and graduates, were exposed to various discussions about causes of engineering failures. The results in Table 3-3 show the first five questions asked in relation to a standard of professional practice were favorable in agreement. The class did agree that errors and mistakes resulting from inadequate management do affect the design process as shown in the results for Q7.

Table 3-3 Survey A/Forensic Class Results

Survey A/Forensic Class					
Questions	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
Q1	0%	7%	4%	33%	56%
Q2	0%	0%	4%	52%	44%
Q3	0%	4%	4%	37%	56%
Q4	0%	4%	4%	37%	56%
Q5	0%	0%	4%	41%	56%
Q6	0%	0%	7%	52%	41%
Q7	0%	0%	11%	52%	37%
Q8	0%	5%	7%	63%	30%
Q9	0%	0%	7%	56%	37%
Q10	0%	4%	4%	37%	56%

Members of the Mississippi Engineering Society were the second group surveyed. The Mississippi Engineering Society is an affiliate of the National Society of Professional Engineers who has local, regional and state chapters throughout the US. A majority of the survey participants were from the Mississippi Department of Transportation, a state highway agency. The other participants were self-employed or professional engineers in private practice as design consultants working for private engineering firms. The results shown in Table 3-4 from the first five questions in relation to a standard of practice were not high in agreement, but had higher percentages of undecided when compared to the other groups surveyed. For instance, look at Q4 where 54% of the participants surveyed responded undecided about this question as it relates to issues identified within the design process. The research concluded that those survey participants who responded high percentages for undecided were from District Construction offices that have limited involvement with the functional mechanics of the design process. This logical reason can also be applied to questions Q1 through Q4 and Q7. The results do indicate an overall agreement with the exception of Q4 for warranting a standard of professional practice. The results show an overall agreement for Q7 that describes that too many errors and mistakes occur within the design process.

Table 3-4 Survey B/Mississippi Engineering Society Results

Survey B/Mississippi Engineering Society					
Questions	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
Q1	0%	7%	24%	27%	41%
Q2	0%	12%	29%	34%	24%
Q3	0%	5%	24%	46%	24%
Q4	5%	5%	54%	20%	17%
Q5	0%	5%	41%	34%	20%
Q6	0%	5%	29%	46%	20%
Q7	0%	17%	22%	44%	17%
Q8	0%	32%	41%	24%	2%
Q9	0%	5%	41%	34%	20%
Q10	0%	2%	46%	41%	10%

The final group surveyed was members of the American Society of Civil Engineers, Mississippi section. The American Society of Civil Engineers is a national civil engineering professional society that has local, regional, and state chapters throughout the US. The research used email to send out surveys to 100 out of 1000 ASCE registered members in Mississippi. The results from the first five questions shown in Table 3-5 demonstrate a favorable response to the adoption of a standard of professional practice. It should be noted that some uncertainty still exists especially in regards to Q2, which had 20% undecided, and Q4, which had 24% undecided. The participants who responded to the survey were a mix of professional civil engineers who represented themselves as either self-employed or consultants in private practice. The results for Q7 show a high percentage of agreement that errors and mistakes do occur within the design process.

Table 3-5 Survey C/ASCE Mississippi Section Results

Survey C/ASCE Mississippi Section					
Questions	Strongly Disagree	Disagree	Undecided	Agree	Strongly Agree
Q1	0%	4%	8%	56%	32%
Q2	0%	8%	20%	40%	32%
Q3	4%	0%	12%	52%	32%
Q4	4%	4%	12%	36%	44%
Q5	4%	0%	24%	40%	32%
Q6	4%	0%	0%	36%	60%
Q7	4%	4%	8%	36%	48%
Q8	0%	12%	8%	52%	28%
Q9	0%	0%	40%	44%	16%
Q10	0%	0%	8%	68%	24%

3.5 Further Evaluation

Table 3-6 shows a tabulated comparison of Q1, Q2, Q3, Q4, Q5, and Q7, all of which directly address the need for standard of professional practice. In looking at the weighted average score column of Table 6 groups A and C were in agreement to accepting a standard of professional practice, but survey group B was less enthusiastic. Survey group B was comprised of members from the Mississippi Engineering Society. A majority of the members were from construction divisions at MDOT, a statewide government highway agency. In effect these engineers represent an owner agency, not a design agency, bear little or no liability for errors in design. The higher number of undecided choices by those members demonstrates that many engineers who are not associated with the working mechanics of the design process will not likely see the need for a standard of professional practice. In many government agencies there are standards in place, so it can be understood why some governmental engineers may not be receptive to additional standards or see the benefit of adding additional standards even if warranted. Engineers who are self-employed or work for private consulting firms may see the need for implementing a standard of professional practice, especially if the benefit will result in improving the efficiency of the design process by reducing errors and omissions.

The combined weighted average column in Table 3-6 shows a strong support overall for a standard of professional practice. This highlights the success of the surveys used by the research. We also were able to identify potential groups who may be less enthusiastic about a standard of professional practice. Those groups who are local, county, state and federal agencies that hire civil engineers who will be less likely to accept or adopt a standard of professional practice due to their agency provides liability coverage for design errors and mistakes.

After further evaluation the questions could have been worded or structured for better clarification. This is evidently apparent for Survey B, question Q7 “Do you agree that Civil Litigation has increased due to engineers not using good or proper engineering judgment?” The authors might have disagreed with that question also. But if we asked “can a standard of professional practice reduce the incidence of civil litigation,” would a different response have been recorded by the survey participants? We cannot accurately predict what the survey participants would check, but restructuring the question would help reduce indiscriminate answers leading to results that are more accurate.

Table 3- 6 Comparison of Survey Groups A, B & C

Comparison of Survey Groups A, B & C							
Questions	**Strongly Disagree**	**Disagree**	**Undecided**	**Agree**	**Strongly Agree**	**Weighted Score Average**	**Combined Weighted Score Average**
Q1A Forensic Class	**0%**	**7%**	**4%**	**33%**	**56%**	**4.4**	**4.2**
Q1B MES	**0%**	**7%**	**24%**	**27%**	**41%**	**4.0**	
Q1C ASCE	**0%**	**4%**	**8%**	**56%**	**32%**	**4.2**	
Q2A Forensic Class	**0%**	**0%**	**4%**	**52%**	**44%**	**4.4**	**4.0**
Q2B MES	**0%**	**12%**	**29%**	**34%**	**24%**	**3.7**	
Q2C ASCE	**0%**	**8%**	**20%**	**40%**	**32%**	**4.0**	
Q3A Forensic Class	**0%**	**4%**	**4%**	**37%**	**56%**	**4.5**	**4.1**
Q3B MES	**0%**	**5%**	**24%**	**46%**	**24%**	**3.8**	
Q3C ASCE	**4%**	**0%**	**12%**	**52%**	**32%**	**4.1**	
Q4A Forensic Class	**0%**	**4%**	**4%**	**37%**	**56%**	**4.5**	**4.0**
Q4B MES	**5%**	**5%**	**54%**	**20%**	**17%**	**3.4**	
Q4C ASCE	**4%**	**4%**	**12%**	**36%**	**44%**	**4.1**	
Q5A Forensic Class	**0%**	**0%**	**4%**	**41%**	**56%**	**4.6**	**4.1**
Q5B MES	**0%**	**5%**	**41%**	**34%**	**20%**	**3.7**	
Q5C ASCE	**4%**	**0%**	**24%**	**40%**	**32%**	**4.0**	
Q7A Forensic Class	**0%**	**0%**	**11%**	**52%**	**37%**	**4.3**	**4.0**
Q7B MES	**0%**	**17%**	**22%**	**44%**	**17%**	**3.6**	
Q7C ASCE	**4%**	**4%**	**8%**	**36%**	**48%**	**4.2**	

3.6 Conclusion

The premise of our research was to provide applicable standards of practice that would reduce civil engineering failures resulting from inadequate management practices. This paper focused on measuring the responses and attitudes of three groups surveyed to extract their subjective opinions with minimum indiscriminate responses concerning a standard of professional practice. The results from the surveys validate the need for a standard of professional practice.   This research is unique and original, and our hope that it will lead to broader audiences on a national stage discussing the importance of standards as it relates to governing the design process and reducing the occurrences of engineering failures. The results showed a standard of professional practice would be accepted by a majority surveyed, but additional work is needed to convince those who saw no need for it or lacked the understanding for its purpose.

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Appendix A

Prototype Standards of Professional Practice for Design Management

Standard I: Design Quality Control and Quality Assurance

The decisions made within the design process are critical to the project outcome and performance as it meanders through the construction process. Adequate design quality control and quality assurance measures are vital components of the design process that must be managed continuously and efficiently. The authors proposed two elements for design quality control and quality assurance procedures: 1) Design Redundancy 2) Design Failure Risk Analysis.

Design Redundancy:

Previous research conducted on modern and historical engineering failure case studies showed that a high percentage of those case studies lacked redundancy. Redundancy is defined as "designing, incorporating, and including physical and human processes in to analysis, design, and construction in such a way that if one element, whether physical or human, fails to function in the way intended, other elements take over in such a way that the structure will function essentially as intended" (Osterberg, 1989). Redundancy in design comes in at least two forms, structural redundancy and procedural redundancy. Structural redundancy assures that if a member fails there are other members to take the load (Ortega, 2003). If there is a standard in place that requires structural redundancy to be checked "the use of improper methods, invalid assumptions, or incorrect modeling techniques" will be deterred (Burgess, 1988). Procedural Redundancy is when there are "provisions of additional, distinctive steps that include multiple design approaches in order to validate the design" (Ortega, 2003). When design management lacks a plan of action to implement redundancy measures within the design process, engineering failures can occur. In short, there needs to be a systematic method of design checking in place.

Design Redundancy Plan of Action:

a. Provide continuous oversight through the design process by checking all design assumptions, calculations and engineering theories concerning design methods and practices.

b. No design changes will be authorized without a paper trail and specific checks prior to approval by the design engineer.

c. Establish secondary peer reviews to check and assure all design requirements have been met prior to sealing the final design drawings.

Design Failure Risk Analysis

The cornerstone of this research has been the analysis of ways and means of preventing engineering failures that are the result of management issues. Authors such as Petroski, Kaminetzky, and Carper have promoted the need for failure avoidance in their respected publications. The need for design failure risk analysis prompted this question: how often do engineers examine the possibility of design failure? Failure analysis has often been used to evaluate technical weaknesses, not issues in management. Risk analysis has been used by many business organizations to assess risk for investments, stocks, and financial portfolios to aid their clients in making the best financial decisions. This research feels that the introduction of a failure risk analysis process would be a great tool for engineers who manage the design process.

The RAM theory is based on the concept that engineers in management need to perform three basic failure risk analyses to minimize potential failure threats within the design process: **1. Recognize** – identify potential modes of failure; **2. Activate** – develop plans of action to mitigate those modes of failure; and **3. Monitor** - continuously monitor and provide oversight to assure that the mitigation plans are implemented. The authors admit the introduction of this proposed standard is based on past design experiences that failed due to improper management practices and failure risk assessment of the proposed designed. The lack of raw data to support this standard may attract negative comments and references regarding its implementation; however, the authors strongly feel that consideration is warranted. The RAM theory is in its infant stage, and the authors hope that future researchers who feel that the standard is a promising tool for failure reduction will continue to stress its significance and implementation even to the point of pushing it to evolve as engineering and design practices change in the future.

Standard II: Communication

The process of communication can be defined as the "imparting or interchange of thoughts, opinions, or information through speech, writing, or signs" (Folland, 1983). Communication cannot exist in any form without the exchange of thoughts, ideas, and opinions between two participating parties (Folland, 1983). In order for the communication process to be completed there must be feedback from the individuals who received the communication (Folland, 1983). Design projects driven by cost and time may side-step the communication process leading to errors and mistakes. Ineffective communication within the design process is a management issue that plays a major part in the failure of many design projects. Unfortunately, there has been little effort to measure the results of ineffective communication in relation to engineering failures or the result thereof. Ineffective communication is not a new subject when discussing design project management. This research has shown through evaluation of past and modern engineering failures, that ineffective communication is an issue within the design process.

The importance of establishing effective communication procedures is vital and critical to project success. The lack of a systematic communication process in place for design management to govern the design process ultimately leads to errors and omissions. Establishing effective informational methods will be complex and difficult to maintain during the design process. In order to achieve adequate effective communication within the design process, systematic communication processes must exist. Below are suggested methods to help maintain an effective communication process:

a. Establish routine project status meetings that require feedback in the form of exchanges of thoughts, opinions, and suggestions from the design staff.

b. Establish methods of communication through memo, email or other electronic devices that provide notification of delivery and receipt.

c. Maintain records of all design decisions, changes, and written correspondence relating to design duties and responsibilities. This information should be shared with all new design team members and discussed at scheduled progress meetings.

d. Develop an organizational chart placing a design team member who is respected by the design staff to promote effective communication without intimidation or fear (Hensey, 1987).

e. Effective communication will not exist without oversight and input from design management continuously throughout the design process.

Standard III: Post Design Inspection

As a practicing professional engineer who has offered design services as a private consultant, and as a government employee overseeing numerous projects, the author is aware that post-design involvement is critical to project success. The design engineer's role during the construction process has been debated by many engineering professionals. There are three issues of concern regarding this debate: 1) Authority 2) Liability and 3) Ethical obligations. In many cases the contractual obligation of the design engineer is to produce plans and specifications based on an agreed upon scope of work. Once the design engineer signs and seals the drawing, they are released to the owner. The contractual obligation ends with the release, but has the authority and liability of the engineer ended regarding his or her design? And if it has, should it end? In addition, ethical obligations may arise when the engineer needs to speak out about an error or omission discovered in the design. Many questions arise within the construction process that can only be answered or interpreted by the design engineer. The role of the design engineer should be a point of reference if questions arise concerning potential design changes, shop drawing changes, or testing procedures that could impact the integrity of the design's intent and purpose. It is our opinion that the design engineer should stay engaged past the design process, and his or her role should be agreed when developing the scope of services to be performed. The following are suggested roles and duties for the design engineer, which are recommendations and guides to help facilitate involvement and engagement by the design engineer into the construction process.

1. Construction Field Representative:

a. Establish routine project site visits to engage in discussion with the contractor, owner, and other construction representatives concerning any project changes or site issues pertaining to the design plans or specifications of the project (Avvakumovits, 1996).

2. Shop Drawings Approval:

a. Establish protocol with the contractor to review all shop drawings pertaining to the design intent and purpose as it relates to the plans and specifications.

b. Establish an understanding with the contractor that the design engineering professional will only serve in an advisory role concerning design related issues regarding compliance and standards set within the written specifications and design drawing plans (Avvakumovits, 1996).

3. Site Testing Representative:

a. Serve in an advisory role concerning site testing procedures as needed for quality control and quality assurance purposes regarding required project materials requested within the written specifications or noted on the plan drawings.

b. Provide interpretations of required procedures regarding material testing as required by written specifications; provide guidance and recommendations concerning changes requested that deviate from the original specified requirements (Avvakumovits, 1996).

c. Provide interpretations of required procedures regarding material testing as required by written specifications, and provide guidance and recommendations to changes requested that deviate from the original specified requirements (Avvakumovits, 1996).

CONCLUSIONS AND RECOMMENDATIONS

Introduction

This dissertation study provides three individual articles written in journal style format. The journal articles independently discuss a broad range of management issues within the design process. The journal papers as a whole cohesively formulate an intelligent argument for justifying the need for a standard of professional practice aimed at design management. The evaluation of modern and past engineering failures and claims data from Travelers Indemnity Company provided mechanisms supporting our hypothesis, and to support the process for developing standards to govern the design process through better management skills and practices.

The Journal Articles

Inadequate Design Management Compared to Unprecedented Technical Issues: As a Cause for Engineering Failure

This article introduces a methodology that engineering design failures fall into two broad categories, those that occur due to a hitherto unknown or unprecedented technical cause and those that occur due to a known cause that was overlooked during the design process. The latter can be considered a failure of design management, and the purpose of this paper is to compare and contrast inadequate design management to unprecedented technical issues as a cause for engineering failures. Failures that occur to improper maintenance or abuse are not the scope of this paper. Two approaches were taken, namely: (1) evaluation of current and historical engineering failures for instances of where inadequate design management and/or unprecedented technical issues, and (2) review of filed claims data for design errors and omissions to determine whether inadequate design management is a substantial issue. This research may provide useful information in understanding how both categories limit the success of the design process.

The researchers evaluated engineering failure case studies from peer reviewed journals and filed claims for errors and omissions from Travelers Indemnity Company. The results from the researcher's evaluation showed that more than often engineering failures occur due to design management issues when compared to technical issues.

Standards of Professional Practice for Design Management

Article Two focused on management issues within the design process, and how those management issues translate into engineering failures. The research shows that many failures occur due to well-known technical issues overlooked by management during the design process. Such failures are often termed "errors and omissions." This research further indicates that systematic design quality control and quality assurance, careful communication, and post design inspection are management techniques that could prevent a large number of engineering failures. In an effort to reduce the incidence of management issues, the authors introduced a prototypical standard of professional practice for design management.

Measuring the Responses and Attitudes for a Proposed Standard of Professional Practice for Design Management

The purpose of article three was to measure the responses and attitudes about a proposed standard of professional practice aimed at design management. The authors developed three surveys to gather subjective opinions from participants concerning their position about a standard of practice. The results from the surveys show a standard of professional practice would be accepted by a majority of those surveyed. It also important to point out that more likely engineers who are classified as self-employed or in private engineering practice would be more receptive to a standard of professional practice when compared to engineers who work for owner agencies. Engineers who work for owner agencies typically are not design oriented and bear little or no liability for errors in design.

Final Research Recommendation

Jack Gillum, the engineer of record for the Hyatt Regency Collapse in 1984, advised that a standard of practice should strongly be considered by the civil engineering profession. The purpose of this dissertation was to provide three journal articles each independently justifying the need for a standard of practice aimed at design management. Although, limited in resources the study was able to develop a prototypical standard of professional practice. The authors measured responses and attitudes among professional peers through administered surveys. The results showed a standard of professional practice would be received by a majority surveyed, but additional work is needed to convince those who saw no need for it or lacked the understanding for its purpose. Additional research is needed beyond the scope of this study to expand the suggested standards presented in this dissertation. The authors of this dissertation have proven that there is a need for a standard of professional practice as it relates to managing the design process and may be the most promising method for reducing the occurrences of engineering failures.

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