A Study of Risk Communication in Engineering and Management Curricula

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Abstract

An examination of problems in risk assessment and communication among management and engineering disciplines is undertaken in an attempt to recognize inadequacies in engineering students' skills in properly communicating risk. This paper presents a study devised to test a set of hypotheses concerning opportunities for improvement in engineering curricula. A better understanding of these shortcomings can lead to the development of methods to improve the learning process for students of engineering in this area. Additionally, within an educational framework, enhanced interaction between engineers and managers would provide for a more effective relationship in industry. This paper describes this protocol study in detail along with observations of students' communication. Data is presented, conclusions drawn and recommendations given. It is believed that certain areas that contribute to the development of the skill of communication across fields are lacking in engineering curricula. This study attempts to identify these areas to provide insight into the nature of risk communication problems in industry.

1 Introduction

In the pursuit of providing a full complement of technical skills to engineering students, developing management and traditionally "soft" skills is often overlooked. As a result, the graduating engineering student may not possess sufficient skills or at least an awareness of the primary management aims of business. Perhaps one of the most crucial areas that is affected due in part to this perceived gap in engineering education is the students' abilities to assess and communicate risk within a company.

On January 28, 1986, Space Shuttle *Challenger* flight 51-L of the National Aeronautics and Space Administration (NASA) exploded in flight at 73 seconds after liftoff, killing all seven passengers aboard. It was a disaster – *not* an accident – witnessed by millions of Americans, making it one of the most tragic moments in the nation's history. This infamous event has been analyzed from all angles, from physical design[1,2] to ethics[3] to communication[4,5] in attempt to understand how and why such a disaster could happen. This study rests on the belief that there were interdisciplinary risk communication problems that can be addressed with an emphasis of "knowledge across fields" in undergraduate education.

The communication of risk within and between organizations is the responsibility of all involved, regardless of position and cannot be overlooked. A tragedy such as that of *Challenger* was felt throughout the nation due to its public nature, but similar instances of poor risk communication are most likely present in many organizations, especially those outside the public spotlight. This case study was developed and implemented with undergraduate engineering and management students to understand whether such occurrences are in part a result from shortcomings in college-level curricula in both management and engineering programs. The engineering students were seniors, while the management students were comprised of sophomores and juniors. It is important to note that the engineering students did not have any formal training in risk analysis and assessment in their curriculum.

2 Challenger Disaster Background

The Physical Cause

The physical cause of the disaster originated in the aft field joint of the right solid rocket booster (SRB). These solid fuel boosters were the largest of their kind ever used for manned space flight. The O-ring seals were used in the joints between fuel segments to maintain internal pressure and prevent hot gas or flame from escaping during the ascent of the flight. Once an SRB is fired it cannot be shut down until its fuel is exhausted. In the *Challenger* launch, both primary and secondary seals failed due to the cold temperature and resulted in the eventual explosion of the shuttle. Due to a constrained budget, many design trade-offs were made; the final design for the SRB was far from NASA’s original conceptualization.

The Communication/Managerial Cause: The Eve of Launch

There were various pressures to get the mission off the ground in time to avoid delays for other flights downstream. Political pressure included the accepted notion that success was crucial to the continued funding support from Congress. “Production pressure” comes from using adherence to the launch schedule as the means to secure funds essential to the program.[7] NASA only managed to secure half of what it requested from Congress for the shuttle program. Economical efforts made by NASA included cutting spending on safety testing, design trade-offs, and other development work for the shuttle components.[7]

According to Vaughan,[7] the escalating level of risk of the O-ring seals was normalized by MTI and NASA engineers over the course of shuttle development. On the eve of the launch, engineers with NASA's Marshall Space Flight Center in Huntsville, Alabama, and with Morton Thiokol Inc. (MTI), contracted builder of the shuttle's solid rocket booster (SRB) rockets, held an unscheduled teleconference to discuss the effects of cold weather on the sensitive rubber O-ring seals in *Challenger*'s booster rockets. MTI engineers unanimously recommended a launch postponement because they feared the O-rings might not seat properly because of the cold weather. Based on the data they had from previous flights, MTI engineers hypothesized that the O-ring design was not reliable, particularly when temperatures dropped below 53º. NASA objected to the MTI recommendation, claiming the engineers did not have enough data to support their concerns. Then the MTI program manager for SRBs called for an off-line caucus between Marshall and MTI management, excluding MTI engineers. After a half hour, Morton Thiokol managers, who originally voted with the engineers to delay launch, reversed the decision and approved blastoff. The matter was never passed on to higher-level NASA managers because the issue had been resolved. The next day, the worst failure occurred: *Challenger* exploded in mid-flight, and all seven astronauts were killed.[8]

The flawed decision-making in NASA can in part be linked to the influence of those pressures discussed. The decision to launch flight 51-L was made in the face of risk that pointed to the ultimate failure: the loss of human life. Communication breakdown was a factor in the decision. Vaughan[7] states that MTI and NASA engineers created a culture in which they accepted an inferior seal design and their accepted deviations from performance expectations in order to keep the vehicles flying. Winsor[4] suggests that 1) managers and engineers view the same facts from different perspectives and 2) there is a general difficulty to send or receive bad news, particularly when it must be passed to superiors. It is possible that the level of risk was not effectively communicated to higher levels of management. Lighthall[6] argues that there was a lack in basic skills in statistics with the engineers, and that the data and analyses were not valid but deficient. In fact, NASA safety organizations were not staffed with professional statisticians or risk analysts, and project engineers were not trained in modern statistical analysis techniques.[3]

The following hypothesis and supporting hypotheses are thus presented for this study:

Engineering curricula need to address appropriate analysis and communication of risk. Shortcomings in these areas can lead to inappropriate management decisions with varying detrimental effects, with the ultimate failure being loss of life.

<u>Supporting hypothesis:</u>

Although current engineering curricula stresses the importance to collect, analyze, and interpret data, there is a need for more emphasis on how to communicate it.

The nature of these shortcomings is such that they can be minimized or at least reduced by adding and/or modifying material taught in current engineering courses for scholastic improvement. The nature of these course material changes should support focus on communication skills by including 1) risk assessment and communication aspects associated with industry applications in the area of study and 2) the business management perspective of these aspects.

3 Masking the Challenger Scenario to Develop an Effective Case Study

<u>Intentions for an Effective Study</u>

It is difficult to create a case study that imitates both the physical conditions of the *Challenger* and the emotions of the engineers and managers the night of the fatal decision. Imitating the physical conditions of the *Challenger* involves developing a product that has inherent design flaws that result in the product's susceptibility to catastrophic failure in cold temperatures. Given the long-term involvement of both the engineers and managers at Morton Thiokol, simulating the psychological component completely is essentially impossible. The best method of simulating the psychological conditions is to provide a product that the subjects can relate to in the context of a university setting and provide pressure from various avenues. This case study worked with a mixed undergraduate (sophomore to senior) managerial statistics course and a senior-level mechanical engineering design course. It is important to note that the students involved were approximately between the ages of four and six at the time of the *Challenger* disaster; most probably do not remember the *Challenger* tragedy firsthand and regard it as only history.

The Case Scenario: The Redi-Grill Company, Its Product, and Its Problem

A brainstorming session was held to attempt to find a subject to which the students could relate, and that could be perceived to be real. The solution to this need is the formulation of the "Redi-Grill outdoor grilling system." The Redi-Grill product is a system of small outdoor grilling units all connected to a common propane source. This provides a convenient means of outdoor gatherings on large campuses. The source of danger would be a poorly designed valve connection that could fail in cold temperatures. Failure of the valve and the existence of a nearby spark would result in a catastrophic explosion.

The valve design exhibited the desired characteristics in terms of danger associated with a realistic product. However, the design itself did not have the familiarity and personal involvement needed to effectively simulate the mindset of the engineers and managers. This need led to the creation of the company, Redi-Grill Inc., and a fictitious setting in which the company needed to expand their market out of the southeast for survival. Redi-Grill, Inc. is an Atlanta-based company that manufactures and installs the large-scale outdoor grilling systems for university and corporate campuses. Since the company's current market resides in relatively warmer year-round weather, the effects of faulty seal design have not clearly surfaced and thus the design is perceived to be safe.

Redi-Grill has chosen to expand its market to the northeastern U.S., and its first customer is Bucknell University. The use of Bucknell University allows for the introduction of the temperature-dependent risks associated with this faulty design and the personalization of the situation. The colder climate of Pennsylvania amplifies the possibility of failure in the system.

In addition to accurately simulating the physical and psychological conditions for the *Challenger* launch decision, it was important to provide the engineers with similar data that was available to Morton Thiokol engineers the night of the launch. The final set of data used to present to the engineers was modeled after the original data from the twenty-four previous flights. This includes data that shows effects of erosion and/or blow-by (if any), measured joint temperature, number of incidents found, and quantitative measurements of O-ring erosion. These data were taken directly from the Rogers Commission Report.[8] As was the case with all supplied documentation (described in the next section), these data were masked in the form of a memo from the service department that has observed behavior from twenty-four previously installed units, all located in the southeastern U.S. The memo cites sporadic seal wear and minor gas leakage over a period of abnormally lower winter temperatures and suggests that attention be paid to the apparent problem.

4 The Case Study

Engineering Session

The first portion of the case study involved presenting the situation to thirty-three senior mechanical engineering students, divided into nine groups of three to four people. Each group was to assess the information presented and create a document that would serve as a recommendation to cancel the contract with the University due to the perceived temperature-related problems with the product. This segment of the case study was scripted for precision in the manner in which the information and data were presented.

The engineering subjects were introduced to the situation by a short presentation and an accompanying packet, called 'Packet 1.' Packet 1 gave general information regarding the company and product. This includes a company brochure, product specifications, and a notable customer list. The intent of this portion of the case study was to sufficiently familiarize the engineers with their company and its product prior to being presented with the actual problem.

The basis of the case study was distributed to the engineers in a second packet, 'Packet 2'. This packet included a memorandum from the marketing department of Redi-Grill, which informs the engineers of the recent order by the University and the memorandum from the service department that cites recent problems with the valve seals. Five of the groups were also given a Failure Modes and Effects Analysis (FMEA) document for the product. The FMEA is not information that was available to Morton Thiokol engineers. This document was entered into the study to determine whether the subjects were able to understand and appropriately communicate its meaning. The memorandum from the marketing department details the specifics of the University order, including costs, schedule, and installation locations. This was for the express purpose of introducing the factor of recognition to the situation. This memorandum also put pressure on engineers to show the urgency with which the company needed to accept this order. A memorandum from the technician was the essence of the case study, which presented the problem at hand, gave a possible cause, and provided all the data that was available to the engineers.

After a 20-minute introduction, the engineering groups were given the task of creating a presentation aimed at convincing their managers to discontinue sales of their product in its current form. The contract with the University is the imminent sale in question. Due to time limitations, this period was split into 30- and 50-minutes segments. Each group was provided with a computer that facilitated access to the Internet and told that the presentation could not last more than 20 minutes and must be communicated through the Microsoft Office program suite. This offered the freedom to collect information from outside sources, but also gave time and presentation format restrictions as in the eve of the launch, when Morton Thiokol engineers were told they had a short amount of time to compile all of their information onto projection sheets for faxing. The resulting presentations were to be given to the management groups via a third party. Due to scheduling conflicts, the presentations were not given to management by the engineering groups themselves. Instead, each groups was to create the presentation and provide slide notes that would be visible upon presentation inspection by management. Answers to any questions during this session were limited to the content of the documentation provided.

Management Session

Forty-three management subjects were divided into eleven groups of three to four individuals. As with engineering, each group received Packet 1 and a brief presentation as an introduction to the company and its product. Following a 20-minute introduction, the management subjects were given a second packet of information, which was comprised of all documents in Packet 2 *except* the memo from the service department. Thus, the managers were never given any information regarding the actual data or design. In addition, management received a memo from the CEO informing them of an emerging competitor and the heightened importance of market growth for the company's welfare. The intent of this memo was to increase pressure to continue production and sales for assured company success. Each management group was then given access to a desktop computer and a floppy disk that contained a presentation from one of the nine engineering groups. To make up for the two-group differential between the disciplines, two engineering presentations were duplicated. At this time the management groups were given up to 50 minutes to assess the information from the documents and the presentation and to arrive at a decision regarding the contract with University. A form with several questions was provided for the groups to use for stating their decision. Answers to any questions during the session were limited to the content of the information provided. No questions were answered pertaining to the content of the engineering presentations. At the conclusion of the experiment, all participants involved (both engineering and management received a debriefing document.

5 Results

Engineering Presentations: Defining Failure, Content, Communication Performance

The nine engineering groups, hereafter referred to as Teams 1 through 9, created PowerPoint presentation files. Seven of nine groups provided supplementary notes that describe and/or discuss each slide, as was suggested in the instructions. It was decided that each presentation be analyzed with regard to how failure was defined as well as the general content of the presentation, and then assessed on overall communication performance. Table 1 details these three areas of interest in assessing the engineering presentations. Areas that make up defining failure include the temperature-gasket failure relationship, a description of the physical system design, and a description of the possible consequences if failure were to occur. General content is information *in addition to* that which helps to define failure and includes factors dealing with safety, testing and redesign, cost, time, and marketing. Overall communication performance was assessed based on the organization of the presentation, physical readability, and clarity of the recommendations.

Table 1. Engineering Presentation Assessment Structure

DEFINING FAILURE		
Failure-temperature relationship	Explanation of physical nature of system design	Identifying/ describing consequences

GENERAL CONTENT				
Safety	Testing/ Redesign	Cost/ Financial/ Liability	Time/ Scheduling/ Installation	Marketing (reputation, customer satisfaction, sale competition, etc.)

COMMUNICATION PERFORMANCE		
Organization	Easy to read? (colors/fonts/size/ neatness)	Overall Clarity of the delivered message/ recommendations

Table 2 depicts the assessment of defining failure among the 9 engineering presentations. Note that Teams 5 through 9 received the FMEA as part of the supplied information in the study.

Table 2. ***Defining Failure*** **Results**

Team Number FMEA shaded	Failure-temperature relationship	Explanation of physical nature of system design	Identifying/ describing consequences	Graphical means used?
1	■	-	-	X
2	■	◘	◘	
3	■	■	■	X
4	■	◘	■	X
5	■	■	-	
6	■	■	■	
7	■	■	-	
8	■	■	■	X
9	■	◘	■	

" ■ " = detailed attention; "◘" = mentioned; implied; brief comment;" –" = not present

As can be seen in Table 2, all groups cited the temperature-gasket failure relationship to some degree; four of these groups (Teams 1, 3, 4, and 8) used graphical means to communicate this relationship. Eight presentations described (3, 5, 6, 7, 8) or at least mentioned (2, 4, 9) the physical nature of the problem and the physical system. Four groups (4, 6, 8, 9) described possible consequences due to failure in detail, while two groups (2, 3) only mentioned or implied possible consequences. The remaining three groups (1, 5, 7) did not allude to consequences at all.

In terms of general content, testing and redesign arguments were strongly discussed in eight of the nine engineering presentations. As can be seen in Table 3, other content areas were referenced in detail by two or three groups, while many groups only mentioned or just did not include them. For example, two groups (4 and 8) referenced marketing factors in detail, three groups only alluded to these factors, and the remaining four groups (1, 5, 6, 7) did not reference factors dealing with marketing at all.

Table 3. *General Content* Results

Team Number FMEA shaded	Safety	Testing/ Redesign	Cost/ Financial/ Liability	Time/ Scheduling/ Installation	Marketing (reputation, customer satisfaction, competition, etc.)
1	-	■	-	-	-
2	■	■	■	■	◘
3	◘	■	◘	-	◘
4	◘	-	◘	■	■
5	■	■	■	■	-
6	◘	■	◘	-	-
7	◘	■	-	-	-
8	■	■	◘	-	■
9	◘	◘	-	-	◘

" ■ " = detailed attention; "◘" = mentioned; implied; brief comment;" –" = not present

Again, overall communication performance was assessed with regard to organization, readability, and clarity. Table 4 presents these results. Organization was of excellent quality with five groups (2, 3, 5, 6, 7) while three groups (1, 4, 8) displayed a moderate quality in organization. Four groups (2, 4, 6, 7) provided presentations that were very easy to read and four other groups' (1, 3, 5, 8) presentations were lacking in readability and neatness. Overall clarity was relatively strong among all groups; seven groups (1, 2, 4, 5, 6, 7, 9) outlined clear recommendations while two groups (3 and 8) were somewhat vague in communicating their overall message to management.

Table 5. *Overall Communication Performance* Results

Team Number FMEA shaded	Organization	Easy to read? (colors/fonts/ font size/neat)	Overall Clarity of Message
1	◘	◘	■
2	■	■	■
3	■	◘	◘
4	◘	■	■
5	■	◘	■
6	■	■	■
7	■	■	■
8	◘	◘	◘
9	-	-	■

" ■ " = excellent; "◘" = fair-good; " –" = poor

Management Decisions

Table 6 lists the engineering groups and the corresponding management decisions, which were written down with their reasoning in a supplied questionnaire. Observation by inspection indicates that nine of the eleven management groups canceled the University contract due to the presented risk. Of the two remaining teams, one (Team 3) accepted the contract, conditioned upon making immediate seal improvements. The other (Team 5) accepted the contract under a renegotiation that would notify the University about needed product modifications. The detail of this renegotiation is not entirely clear, but it is evident that the decision was made to pursue sales of the current product in the western United States while amending the University contract. Presentations from Teams 4 and 8 were duplicated to match the two-group differential between engineering and management. Hence, two separate decisions are listed for those teams.

Table 6. Management Decisions

Team Number FMEA shaded	Management Decision on Univ. Contract *Yes = Proceed* *No = Terminate*
1	**No**
2	**No**
3	**Yes**
4a	**No**
4b	**No**
5	**(Yes)**
6	**No**
7	**No**
8a	**No**
8b	**No**
9	**No**

6 Analysis

Defining Failure

Based on the decision/reasoning questionnaires filled out by the management groups, the extent of the influence of each engineering presentation was inferred. Beginning with “defining failure,” it can be seen in Table 7 how the managers relied upon combinations of all three “defining failure” factors in making their decisions.

Table 7. *Defining Failure* Factors Considered in Management Decision

Team Number FMEA shaded	Failure-temperature relationship	Explanation of physical nature of system design	Identifying/ describing consequences	Graphical means used?	MGMT Decision (Y/N)
1	■	-	-	X	N
2	■	◘	◘		N
3	■	■	■	X	Y
4a	■	◘	■	X	N
4b	■	◘	■	X	N
5	■	■	-		(Y)
6	■	■	■		N
7	■	■	-		N
8a	■	■	■	X	N
8b	■	■	■	X	N
9	■	◘	■		N

” ■” = detailed attention; “◘” = mentioned; implied; brief comment;” –“ = not present

[yellow] = considered in MGMT decision

Nine of eleven management groups (1, 4a, 4b, 5, 6, 7, 8a, 8b, 9) used the failure-temperature relationship for decision reasoning, about which all engineering groups provided in detail. Five of eleven groups (1, 5, 6, 8a, 9) used the explanation of the physical nature of the system design to support their decisions, despite the fact that engineering Team 1 did not provide such information and Team 9 only alluded to the information. All management groups except Team 3 considered the possible consequences of failure in their decision-making, although engineering Teams 1, 5, and 7 did not include such information in their presentations and Team 2 only indirectly referenced this information. Four of the six groups who received graphical information considered it in support of their decisions. It is interesting to note that although engineering Team 3 provided detailed information on all three areas of defining failure, the corresponding management team did not use any of the information in its decision-making process, which yielded an acceptance of the University contract. Conversely, the other management group that did not explicitly accept or reject the contract (Team 5) used all three factors for defining failure, despite the fact that the corresponding engineering presentation did not present any possible consequences due to failure of the system.

Other inferences can also be drawn concerning the degree of influence of the engineers’ analyses upon the managers’ decisions: if the factor in question was presented in detail by engineering AND used by management, it can be inferred that the engineering information influenced the decision. If the factor in question was not present or merely mentioned by engineering AND management considered implications associated with the factor, then the management decision was made independent of engineering with respect to that factor, as was the case with Team 5. The corresponding management team even stated in their decision response form, "… consequences in the systems malfunctions were neglected [by engineering]."

General Content

As can be seen in Table 8, the management decision relied on many different factors, with marketing and financial liability arguments being the most significant. All but one management group (Team 1) relied on marketing arguments, including company reputation, customer satisfaction, and competition threats, despite the fact that three of the corresponding engineering groups merely alluded to such arguments and three other groups did not mention any marketing arguments at all. Safety and testing/redesign factors were also significant in the management decision; the majority of groups used them in the process. Only three management groups used time and scheduling factors in support of their decision.

Table 8. *General Content* Factors Considered in Management Decision

Team Number FMEA shaded	Safety	Testing/ Redesign	Cost/ Financial/ Liability	Time/ Scheduling/ Installation	Marketing (reputation, customer satisfaction, competition, etc.)	MGMT Decision (Y/N)
1	-	■	-	-	-	N
2	■	■	■	■	◘	N
3	◘	■	◘	-	◘	Y
4a	◘	-	◘	■	■	N
4b	◘	-	◘	■	■	N
5	■	■	■	■	-	(Y)
6	◘	■	◘	-	-	N
7	◘	■	-	-	-	N
8a	■	■	◘	-	■	N
8b	■	■	◘	-	■	N
9	◘	◘	-	-	◘	N

" ■ " = detailed attention; "◘" = mentioned; implied; brief comment; " –" = not present

[yellow] = considered in MGMT decision

Overall Engineering Communication Performance, Management Assessment

As previously shown in Table 5, Table 9 presents an assessment of the engineering presentations themselves in terms of organization, readability, and overall clarity. Table 9 also shows comments made by the management groups that serve as peer assessments of the engineering presentation that each of the groups received. All management teams said that the information provided by engineering was useful in the decision-making process, although a few also cited some of the information as being "too technical" and not in "laymen's terms." Management Teams 1, 5, and 7 all identified the lack of discussion or description of consequences from system failure in the engineering presentation.

Table 9. Communication Performance by Engineering; Management Assessment

Team Number FMEA shaded	Organization	Easy to read?	Overall Clarity	MGMT Decision (Y/N)	*Comments made by MGMT on engineering presentations/communicated information*
1	◘	◘	■	**N**	*Good, but info could be biased b/c we were not told about the dangers of a broken gasket & how much it would cost to fix it.*
2	■	■	■	**N**	*Helped in decision-making; good presentation.*
3	■	◘	◘	**Y**	*Provided good facts and options to improve; laid out well and explained clearly. The chart was useful.*
4a	◘	■	■	**N**	*Would have liked more info on ... other options; not enough information communicated, but was easy to understand.*
4b	◘	■	■	**N**	*Graph was helpful to show risk; short, concise.*
5	■	◘	■	**(Y)**	*Evaluation was very thorough, but consequences w/ the system malfunctions were neglected; it was simplified enough so management "dummies" could understand.*
6	■	■	■	**N**	*Information very helpful in decision; provided enough info for us to make a clear and fairly quick decision.*
7	■	■	■	**N**	*General principles of the grill were understood; some info was too technical & was not clear; not enough background info; it was fairly clear that grill would blow up when too cold.*
8a	◘	◘	◘	**N**	*Information was not too technical.*
8b	◘	◘	◘	**N**	*Helpful info on weather pattern & liabilities; it was straightforward; only presented the problems, w/o mentioning advantages.*
9	-	-	■	**N**	*Made us aware of problem & safety issues; did not express how to amend the problem in order to make it possible to expand our market; made us aware of the problem, but did not give detailed info.*

" ■ " = detailed attention; "◘" = mentioned; implied; brief comment; " - " = not present

Identification of opportunities for educational improvement

The previous analysis leads to recognition of certain inadequacies in the engineers' efforts to communicate the definition of failure for the product in question. This identification of a lack in describing consequences in failure leads to certain inadequacies in communicating the definition of failure for the product in question. Of particular concern is the variance in the type of *language* used by engineers in their communications with management, as evidenced by breakdowns in communication effectiveness. Some managers viewed the engineers' information to be “too technical,” while others cited the information to be intelligible. The majority of the management teams (six of eleven) cited the need for more information, claiming that engineering did not provide enough information in some areas. Yet the management team (Team 3) that decided to accept the University contract received information from engineering that adequately described the nature of the physical system and possible failures as well as their consequences. Analysis indicates that this management group did not rely on this information at all and instead centered its decision on the company and its need for business. Perhaps there is a cultural component; a few management teams alluded to stereotypes of the two disciplines. For instance, one group said that the information was simplified enough “so that management ‘dummies’ could understand.” Not enough data has been collected to make certain conclusions as to why or how the managers made their decision in the face engineering analysis of the given system.

However, it seems that general trends have been discovered with regard to the content of information communicated to management by engineering and its influence (or lack thereof) on the management decision-making process:

1. When engineering provides risk assessments and management considers that information in making their decision as part of support in the decision, it is fair to say that engineering had an influence on the management decision.

2. When engineering provides risk assessments and management does *not* consider it in its decision-making process, then either engineering did not communicate it well enough or management did not assess the information correctly.

3. When engineering does *not* provide risk assessments and management considers factors associated with that information in making its decision, then engineering did not adequately provide content.

4. When engineering does *not* provide risk assessments and management does *not* consider factors associated with that information, then either the information is either irrelevant or both disciplines have shortcomings appropriately identifying the information as important.

7 Conclusions and Recommendations for Further Study

This study attempts to uncover opportunities for educational improvement in engineering curricula in risk communication using a case study. Preliminary findings indicate the need to further identify and understand the role of defining failure in risk communication. With regard to the hypotheses presented, it has been determined that additional similar studies must be conducted to more fully understand trends of what, how, and how well engineering communicates risk to management. Communication faults have been detected, but the exact nature and origin of which have yet to be identified. Only one of the eleven management groups tested in this study decided to accept a contract in a failure-prone scenario despite adequate representation of risks from engineering. Post-study feedback indicated that in general the engineers felt that they presented sufficient data that “spoke for itself.” Conversely, management wanted to know about possible specific consequences resulting from failure. To resolve this, engineers must be able to better communicate risk from a standpoint of both likelihood of failure *and* consequences in the event of failure. A more explicit risk-vs.-benefit discussion may have provided the necessary knowledge for management to make an informed decision.

Several limitations of this case study may have an effect on the data collected. The topic of the case was probably not important enough to the student subjects, as it dealt with a luxury product rather than with a more critical need for the University community. Therefore, psychological pressures may not have been as influential as intended. Moreover, the students already possessed an inherent bias toward the University's welfare and thus the decision-making process may have been affected. Perhaps a more controversial topic that would minimize initial student bias would yield more valid outcomes.

Another area for project enhancement is restructuring the time allotment in the engineering and management sessions. Several engineering students complained that the allotted time was insufficient to produce a quality presentation. Within the limits of course time and schedules, it is difficult to simulate a scenario that requires the subjects to absorb and retain knowledge, especially tacit knowledge that can only be acquired over time through repeated interactions among team members. A mere 20-minute introduction to the case does not sufficiently meet this requirement. Perhaps a longer-term scenario can be constructed that culminates in a hurried attempt on the part of engineering to present data to management would better simulate the time constraints experienced on the eve of the *Challenger* launch. Nevertheless, this work has uncovered certain interesting behaviors in students' abilities to assess and communicate risk across disciplines.

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Biographical Information

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