

## **DETC2005/DTM-85405**

### **AN ANALYSIS OF RISK AND FUNCTION INFORMATION IN EARLY STAGE DESIGN**

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#### **ABSTRACT**

The concept of function offers a high potential for thinking and reasoning about designs as well as providing a common thread for relating together other design information. This paper focuses specifically on risk data by examining how this information is addressed for a design team conducting early stage design for space missions. Sample risk information is decomposed into a set of key attributes which are then used to scrutinize the risk information using three approaches from the pragmatics sub-field of linguistics: i) Gricean, ii) Relevance Theory, and iii) Functional Analysis. Based on the deficiencies identified in this analysis, the concepts of functional templates and a risk worksheet are used to suggest corrective actions for improving treatment of risk data by explicitly accounting for five risk attributes developed in this work.

#### **1.0 INTRODUCTION**

Risk information is an important component throughout all stages of the design process and allows engineers to make informed decisions. Identifying, communicating with, and acting on risk information are difficult tasks given the uncertainty and incompleteness inherent in design. Various processes such as Failure Modes and Effects Analysis and Process Hazard Analysis are used in industry to elicit risks and provide a standard framework in which discussion of risk can take place. In general, the goal is to ultimately describe a risk in terms of likelihood and consequence regarding a particular failure event. Reaching this goal is challenging especially in early design stages when physical solutions have not yet been fully selected and the design is described mainly in functional terms.

Functional descriptions are form independent specifications of design solutions that offer convenience for early stage design when generally many physical solutions have neither been chosen nor ruled out. While many function based

approaches have been proposed including IDEF models (NIST, 1993) and the functional basis (Hirtz et al., 2002), usage and adoption of functional modeling tools in engineering practice is mixed with little consensus as to an industry wide functional modeling standard for mechanical systems. By comparison, the Unified Modeling Language (UML) for software systems is a well-refined standard and widely used. Instead, early stage design may simply utilize terminology evolved in industry and references to physical solutions to support discourse and initial system modeling. Understanding the relation between this type of terminology and more formal functional languages, such as the functional basis, is important because this relation allows associations to be drawn between actual design language and many types of design information, including risk. This sets the stage to explore new design methods that associate risk and failure information with function-like descriptions that occur during natural discourse in engineering design settings.

For this paper, we address risk and function information with regard to an early stage design team at the Jet Propulsion Laboratory known as Team X. We examine how this team treats risks through analysis of excerpt samples and related data from past Team X design reports. This team performs conceptual design for space missions and is a good model for studying design activity given the multi disciplinary team makeup and the variety of missions involved.

The purpose of this work is to better understand risk and function information as communicated in the Team X setting. A brief outline of the paper that the approach section will detail, begins with decomposing risk information into meaningful categories. This provides risk composition and a means for analyzing, according to these categories, risk data from a linguistic perspective that directly accounts for communication effects. Finally, we present a set of high level functional templates that serve as initial points for developing functional models of space systems. These templates provide a

link between the natural language in a design setting to more formal terminology that can then be used in function based methods such as the Function Failure Design Method (Tumer et al., 2002).

## 2.0 BACKGROUND

The primary articles of interest for this work are *risk elements*, defined broadly here as phrases describing a failure, a failure scenario, failure cause, failure effect, an issue to consider related to a failure, or a concern related to a failure. Risk elements are isolated pieces of data from Team X sessions that are the focus of this paper.

Risk elements are elicited, discussed, and documented during Team X design sessions. Team X consists of about 19 members, in a single shared workspace setting to produce conceptual designs of space missions (Mark, 2002). One team member is tasked with compilation of all risk elements for a given design. This involves proactive participation with other team members to adequately identify risks. Each risk is recorded in a 2-D fever chart with axes of likelihood and consequence of failure. Certain failures warrant the generation of mitigations to reduce risk. Risk elements and any mitigations are listed in design session results in addition to being used in certain risk support tools undergoing continual development such as the Risk Analysis Prototype (RAP) tool (Meshkat et al., 2003).

The focus of Team X is on the conceptual design phase of space missions. During this design phase, their product exists first in the form of the functions it must fulfill before it assumes a physical form. Therefore, tools which help assess the product in this phase are valuable to Team X. One such aid is the functional basis, a standard language to describe the function of a product (Hirtz et al., 2002). This tool helps guide design activities such as problem decomposition, physical modeling, product architecture, concept generation, and team organization. It also helps to capture and exchange function information (Szykman et al., 1999), as well as provide consistency in functional descriptions (Ahmed and Wallace, 2003). The development of function representations is ongoing work where some recent effort includes the use of description logic (Kopena and Regli, 2003).

Part of the interest in investigating risk and function information during Team X designs stems from recent work in formalizing functions (Hirtz et al., 2002) and failure modes (Tumer et al., 2003). At present there is also an established relationship between product function and failure modes. This relationship is dependent on the languages used to describe both function and failure (Stone et al., 2005; Tumer and Stone, 2002; Uder et al., 2004). It is desirable to extend this mapping to risk assessment and this work uses concepts from linguistics to study risk and function information. Recent work has reported on an investigation of how archived failure and risk data can be used by Team X (Van Wie et al., 2005).

In the area of linguistics, the sub-field of *pragmatics* deals specifically with the issues of how statements are used in communicative acts and how those statements are related to the context of the discussion (Barsalou, 1992; Wilson and Keil, 1999). Understanding how people produce and comprehend statement *as they relate to a given context* encapsulates much

of the knowledge we seek toward explaining how designers communicate with risk and how they perhaps should communicate with risk information during conceptual design. Further, the *context* of a problem or failure event is closely related to the basic meaning of a risk (Gluch, 1994) which implies that an analysis of risk should benefit from using a theoretical approach that directly addresses this issue of context. Specifically, context here refers to the circumstances surrounding a failure event such as the presence of moisture in a system which may lead to corrosion and subsequent failure. Such context is an integral part of discussions concerning risks where these discussions may exhibit great variability in how accurately this context is communicated among engineers. The field of pragmatics is an appropriate perspective to take in analyzing risks given our interest in describing how risks are discussed and how these discussions can be improved.

The following sections outline somewhat competing theories of pragmatics used in our analysis. Three theories are presented but the premise in each is that communication is most effective when certain conditions are met. These theories each define a small set of conditions that characterize a given theory.

### 2.1 Gricean Cooperation Principle

The Gricean approach is perhaps the most often cited approach and rests on the Gricean Cooperation Principle. This principle consists of four maxims that describe cooperative interaction (Barsalou, 1992). The maxims are as follows:

*Quantity: Statements should be as informative as possible but not more informative than required.*

*Relevance: Statements should be relevant to the goals of the current conversation.*

*Quality: Statements should be true and based on sound evidence.*

*Manner: Statements should be clear, unambiguous, and orderly.*

According to this principle, unless the goal of communicators is a form of deceit, the four maxims should be followed for communication to be effective. Therefore, statements of risk element should follow all maxims.

### 2.2 Functional Approach

The so-called *functional* approach of pragmatics suggests that there are seven different functions that can be performed with communication. These functions are instrumental, regulatory, interaction, personal, imaginative, heuristic, and informative (Green, 1996). The latter seems to be the most relevant to this work since risks should primarily be descriptive and informative.

### 2.3 Relevance Theory

The relevance theory of pragmatics is composed of two parts, positive cognitive effect, and processing effort (Wilson and Keil, 1999).

*1. Other things being equal, the greater the positive cognitive effects achieved by processing an input, the greater the relevance of the input to the individual at that time.*

2. Other things being equal, the greater the processing effort expanded, the lower the relevance of the input to the individual at that time.

## 2.4 Background Summary and Motivation

The above concepts from linguistics provides a theoretical basis for analyzing risk data from Team X design sessions and prescribing corrective actions to improve communication regarding risk and function information. One premise for this research is that communication among designers can be improved regarding notions of both function and risk by addressing the established concepts of pragmatics. In particular, we isolate the language of designers, albeit through written reports, as the article under examination where we apply basic concepts of linguistic analysis to scrutinize current design communication practices. The expectation is that our conclusions i) will have a positive influence on how Team X and similar teams perform their work ii) will help design researchers understand certain characteristics of design language in general and iii) will expose how a linguistic perspective can offer insight into research on engineering design communication.

## 3.0 OBJECTIVES

The overall goal of this work is to analyze risk and function content of designer communication in order to understand the current deficiencies of risk statements and propose a systematic, function based approach to risk assessment. Toward this goal, our objectives are to:

- establish a set of attributes for risk elements,
- evaluate the risk elements in light of these attributes and the three approaches from pragmatics,
- develop functional templates to help initiate functional modeling of space systems, and
- propose corrective steps to better address risk.

## 4.0 APPROACH

### 4.1 Identifying Risk Element Attributes

Here we develop a set of attributes for risk elements where specific examples are given.

#### 4.1.1 Risk Element Examples

The following risk elements illustrate the heterogeneous nature of data within risk elements. These examples are from a sample of 117 risks identified from previous Team X designs. Three risk elements are highlighted to show the nature of risk element language and information content. Given the lack of specificity for some risk elements, it is difficult in these cases to associate a narrow set of functionality with the risk element.

Example risk element #1: “Instruments not able to view sample”

In this case it is clear that the performance parameter is “view sample accurately,” but there is no hint of exactly what is causing the failure.

Example risk element #2: “Insufficient performance”

This risk element is not very informative.

Example risk element #3: “Insufficient power for drilling operations”

This risk element is somewhat ambiguous because it is not clear if the power source is the problem or if a downstream system, for whatever reason, requires more than the specified nominal or peak power than such a downstream system should.

Example risk element #4: “Grounding faults during pyros”

This risk element is clear in description of an event, but does not clearly indicate much regarding the context of the event.

#### 4.1.2 Risk Element Attributes

Prior work by Gluch (1994) indicates that the meaning of risk is closely related to the context of the failure event. Here we develop a small set of risk attributes that essentially help to define this context in a succinct manner. There are many components to risks such as various risk properties described by Gluch (1994). An example includes a quantitative definition of risk that consists of a set of triplets  $\langle s_i, p_i, x_i \rangle$ , where  $s_i$  is the scenario,  $p_i$  is the probability, and  $x_i$  is the consequence (Kaplan and Garrick, 1981). While likelihood and consequence are two core aspects of risk, terminology for other risk attributes differs among various sources. Toward the development of risk attributes, we consider these variations and propose five risk attributes that include three holistic system parameters (P, D, and N) defined below, and two central concepts of risk (failure mode and failure scenario).

Variations in terminology associated with risks are apparent when considering different government organizations and industry groups including DOD, NASA and ISO based standards. The few examples of risks above suggest that significant variations exist within documented risks of Team X in terms of the information content. In order to analyze these risks, we first consider terminology associated with risks from multiple standards and practices as listed in Table 1.

**Table 1. Sample Sources for Risk Terminology**

Department of Defense
NASA - JPL Risk Management
NASA NPG 7120.5B (Program and Project Management Processes and Requirements)
Risk Assessment Prototype (RAP risk tool used at JPL)
Space Systems Risk Assessment (ISO 17666)
Det Norske Veritas (DNV) Risk Consultants
Probabilistic Risk Analysis

A brief review of information from literature in Table 1 indicates that there are many types or categories of risk. Some examples from ISO 17666 include “risk index, risk trend, residual risk, risk scenario,” etc. Much of these terms seem to be geared toward distinguishing various types of risk such as minor risks (“anomaly / problem”) and areas of blended interest (“concern”). However, these references also reveal a reasonable consensus on the basic notion of risk in which a likelihood and consequence of failure is accounted. Rather than utilize terminology emphasizing the classification of different risk types, we propose parameters that capture the basic attributes of risk and of the system associated with risk. As noted at the beginning of section 4.1, we take a somewhat

broad view of risk elements knowing that ultimately much of risk information is distilled into basic quantities such as likelihood and consequence.

Given this rather inclusive perspective for risk elements, we define five attributes to describe risk element attributes. Additional attributes can be defined such as likelihood of failure although these five attributes are suitable for studying the information found in risk element titles and descriptions, which are the primary documented source of how Team X designers communicate with risk information.

For a portion of the risk elements provided (17 earth orbit elements and 100 of the moon mission risk elements), each of the risk element attributes shown in Table 2 are identified. Note that P, D, and N are from the P-diagram concept in the quality literature. Due to the vagueness of some risk elements, values are not assigned to all attributes for the 117 risk elements inspected.

The attributes are defined in Table 2 and an example of these attributes is given in Table 3 for the risk element titled “Vibration Damage to Telescope” with a description of “Not obvious that telescope assemblies will survive launch profile” and reference to the “Science” and “Instrument” subsystems. The values for each attribute are inferred from the risk element title, description and the referenced subsystems. Note that in our analysis, we only associate functionality with design parameters although one may reasonably also consider other system specifications such as geometric or material choices. This restriction allows a direct account of function information present in risk elements.

**Table 2. Risk Element Attribute Definitions**

Attribute	Definition
Performance Parameter ( <i>P</i> )	Measurable indicator of system performance with respect to design objectives
Design Parameter ( <i>D</i> )	Parameters of a system which can be specified within the scope of the design
Noise Parameter ( <i>N</i> )	Parameters of the system or system operation that are beyond the control of the designer
Failure Mode ( <i>FM</i> )	A specific event that prevents proper functioning of a system
Failure Scenario ( <i>FS</i> )	A sequence of events and their context that results in one or more Failure Modes

**Table 3. Risk Element Attribute Examples**

Attribute	Examples
( <i>P</i> )	Optical performance parameters for telescope
( <i>D</i> )	Primary function – “channel, signal, control magnitude” Secondary function – “import, export, sense, process, actuate, regulate, change, stop”
( <i>N</i> )	Vibration loading due to launch
( <i>FM</i> )	Fatigue, structural failure
( <i>FS</i> )	Vibration during launch leading to fatigue, structural failure of the telescope assembly

Justification for these attributes is based on the following reasons: 1) these parameters are easily articulated and understood, 2) they capture two (FM, and FS) key aspects of risk and three (P, D, and N) key aspects of the system under study, and 3) these parameters are not terms that *classify* risks as in the case of many terms from the sources shown in Table 1, but rather these parameters describe the main *attributes* of risks. A distinction between the proposed attributes here and

past work is we claim that three system parameters (P, D, and N) are risk attributes. This rationale is based on the premise that discussions of risk should include at least a basic description of the system of interest in order to promote systematic consideration of risk in the context of system performance and the parameters governing that performance. In this sense, these parameters are included to improve the descriptiveness of how the context of risk is communicated.

## 4.2 Pragmatics Analysis

The approach is to use a basic set of concepts from pragmatics, a sub-field of linguistics, to analyze a sample of 117 risk elements. We examine this data from three perspectives found in pragmatic literature as described in the section 2: Gricean, Relevance Theory, and a Functional approach. Using all three approaches is an attempt to reduce experimental bias toward a particular pragmatic theory. The approach to analyze the risk elements consists of four steps.

*Step 1: Relate each linguistic theory to the risk elements.* Each linguistic theory is written relating to conversation in general and this step transforms the generality of the theory to one that pertains to risk elements.

*Step 2: Derive specific questions to relate the linguistic theories to risk element attributes.* These questions transition the general statements about risk achieved from Step 1 into specific questions about risk element properties. Answering these specific risk element property questions aims at validating (or invalidating) the general risk statement from Step 1 and thus the linguistic theory.

*Step 3: Derive logical relationships for the risk element attributes to determine if the linguistic theory criteria are satisfied.* The relationships between the risk element attributes and the linguistic theories determined in Step 2 are translated into logical relations in this step. A true result from the logical statement implies that the linguistic theory has been satisfied.

*Step 4: Evaluate each risk element.* The set of risk elements under evaluation are first examined with respect to their risk attribute makeup. The risk element attribute makeup is then entered into the logical relationships from Step 3 and analyzed.

The data used to analyze the risk elements is identified for the Gricean Cooperation Principle, Functional Approach and the Relevance Theory in Tables 5, 6, and 7 respectively. The various linguistic theories and theory-specific risk element relations are described in the following sections.

### 4.2.1 Gricean Cooperation Principle

The Gricean Cooperation Principle is used in this section to analyze the risk elements with respect to pragmatics. Recalling the four maxims, the first maxim involves *quantity*. We propose that a risk element that contains information about a design parameter and a failure mode presents the minimum *quantity* of information about the risk element. These two attributes are singled out because they identify the problem (failure mode) and the design aspect that is affected (design

parameter). Also, to prevent providing too many risk elements, i.e. too much quantity, the two parameters coupled together should only appear once per risk analysis.

The next maxim is relevance. A risk element is deemed *relevant* if it contains any of the 5 risk element attributes since the goal of risk conversation is to gather information about potential risks.

The *quality* maxim is first concerned with the truth about the risk element and then the justification for the risk element. Therefore, the first part of the quality analysis involved checking to make sure the risk element is feasible. The second part of the quality analysis involves evidence that a particular failure mode could occur through past failures or supporting calculations.

The final Gricean maxim is *manner*. For the purposes of this analysis all the risk elements are assumed to be orderly. This leaves their clarity and unambiguousness to analyze. A risk element is deemed unambiguous if it contains information on the source of the problem (failure scenario, noise parameter) and the function it affects (design parameter). Furthermore, a risk element is deemed clear if it contains information on the affected performance (performance parameter), and what is causing the problem (failure mode).

#### 4.2.2 Functional Approach

Since the risk elements themselves are shared with others and the risk element attributes are possibly implicit; yet desirable, information, the risk elements are deemed informative if they contain information regarding at least one of the risk element attributes.

#### 4.2.3 Relevance Theory

The proposition dealing with positive cognitive effect is related to the risk elements by counting the attributes of a risk element. Greater numbers of attributes in a risk element are positively correlated with greater positive cognitive effect because each attribute effectively results in some positive cognitive effect. The second proposition, which relates to processing effort, is divided into two categories, nominal processing and excessive processing. The risk elements require nominal processing if they contain between 3 and 5 risk element attributes. If less than 3 attributes exist, then the risk element requires too much processing, which, in turn, lowers the relevance of the risk item. This is essentially a binary test.

### 4.3 Functional Template Development

In addition to analyzing how functionality is currently addressed in risk elements, we seek to develop the process for how functionality can be more effectively addressed during Team X design sessions. Based on preliminary inspections of the risk element samples as well as on-site observations of Team X members during their design sessions, it is clear that Team X members utilize a somewhat specialized set of

terminology to refer to what would otherwise be known as functionality.

References to physical artifacts are prominent when discussing system function. This can be interpreted as a very form-centric (noun based) perspective, which poses a challenge if the goal is to explicitly account for system function. For example, references to an antenna and related physical systems may dominate a discussion that from a more function-centric view might be focused on functions (verb based) such as transmit signal. Thus, an avenue for improving the treatment of function within the context of risk in design, is the development of relations between the terminology found in the Team X environment with a more formal set of function terms such as those in the functional basis (Hirtz et al., 2002). This gives rise to *functional templates* that represents a broad set of systems associated with space missions.

Here we develop a set of functional templates that is intended to represent the breakdown of space mission systems in general and show their relation with functions in the functional basis language. This breakdown is at a very high level as shown in the appendix. This decomposition is intended to capture a basic set of physical elements that comprise the generality of space missions. Many partitioning schemes are possible for making this decomposition and we identify three high level systems: ground systems, launch vehicle, and spacecraft or payload. Note that these are not intended to replace existing work breakdown structures or the basic structure of Team X. Instead these four systems are established as a very high level to serve as a starting point for more specific functional models. Thus, these templates are intended to help initiate the process of functional modeling. The templates are presented in the appendix with a few levels of hierarchy beginning at the top level in Table 4. Here a platform\* is identified as four common subsystems among the three systems. Note that several function chains are identified as modules which facilitates their reuse in higher level modules or systems. A brief assessment of these templates is discussed in the results section of 5.4.

**Table 4. Top Level Functional Template Contents**

System	Subsystem
Platform*	Electrical Power Communication Debris Control Structure
Ground System	Platform
Launch Vehicle	Platform Propulsion Thermal Control
Payload / Spacecraft	Platform Propulsion Thermal Control Science Instruments Nuclear Power Solar Power

**Table 5. Risk Element Categories of Gricean Cooperation**

Maxim	Description	Risk Questions	Risk Attributes Concerned	Property Specific Questions		Logical Relationships
Quantity	Utterances should be as informative as possible but not more informative than required.	Is the risk element informative?  Is the risk element efficiently informative?	D FM	Qn.1  Qn.2	Does the risk element contain D & FM?  Does the specific D & FM appear only in this particular risk elements?	IF (D & FM) Then Qn.1=True  If (D & FM are specific to the risk) then Qn.2 =True
Relation	Utterances should be relevant to the goals of the current conversation.	Is the risk element specific to the particular mission or spacecraft?	P D N FM FS	R	Does the risk element contain P,D,N,FM, or FS?	IF (P or D or N or FM or FS) then R=True
Quality	Utterances should be true and based on sound evidence.	Is the risk element true?	P D N FM FS	Q.1.1 Q.1.2 Q.1.3	Can the FM affect the P? Is the D related to the P? Can the FM be caused by the FS or N?	
		Is the risk element based on sound evidence?	FM	Q.2.1  Q.2.2	Has the FM occurred previously? Are there supporting calculations for the FM?	
Manner	Utterances should be clear, unambiguous, and orderly.	Is the risk element clear?	P FM	M.1	Does the risk contain a P and FM?	IF (P & FM) Then M.1=True
		Is the risk element unambiguous?	D N FS	M.2	Does the risk contain a D and (N or FS)?	IF (D & (N or FS)) Then M.2=True

**Table 6. Risk Element Categories of Function Approach**

Communication Function	Description	Risk Questions	Risk Attributes Concerned	Property Specific Questions		Logical Relationships
Informative	Language is used to convey information to other people about things not visible in the immediate environment.	Does the risk element convey information about mission risks?	P D N FM FS	F	Does the risk element contain a location for a problem (P or D) and a potential cause of the problem (N or FM or FS)?	IF {(P or D) & (N or FM or FS)} Then F=True

**Table 7. Risk Element Categories of Relevance Theory**

Relevance-Theory Principle	Description	Risk Questions	Risk Attributes Concerned	Property Specific Questions		Logical Relationships
Positive Cognitive Effect	Other things being equal, the greater the positive cognitive effects achieved by processing an input, the greater the relevance of the input to the individual.	How well does the risk element add to the knowledge about potential concern for the mission?	P D N FM FS	RT.1	How many risk element attributes does the risk element contain?	Count (P,D,N,FM,FS) for each risk element.
Processing Effort	Other things being equal, the greater the processing effort expanded, the lower the relevance of the input to the individual at that time.	Does the risk element provide only enough information to easily comprehend the mission risk?	P D N FM FS	RT.2	Does the risk element contain too little risk property information or extraneous information?	If {Count (P,D,N,FM,FS) ≥ 3, then RT.2 = True

**5.0 RESULTS**

The sample of risk elements cover two mission types: earth orbit and moon missions. Generally, the documented risk elements are highly variable in their level of specificity as indicated with the examples in Section 4.1.1. The analysis presented here shows the particular ramifications of this variable degree of specificity as it relates to how well the risk element is being communicated and potentially how well it is understood.

**5.1 Gricean Cooperation Principle**

Each risk element is subjected to the logical relationships associated with each portion of the maxims listed in Table 1. If the logical result is true, then that portion of the risk specific maxim is satisfied. A score of all trues implies the risk element is cooperative, which according to Grice is the goal of normal discourse. The results of this analysis are displayed in Figure 1. This figures shows that the maxim

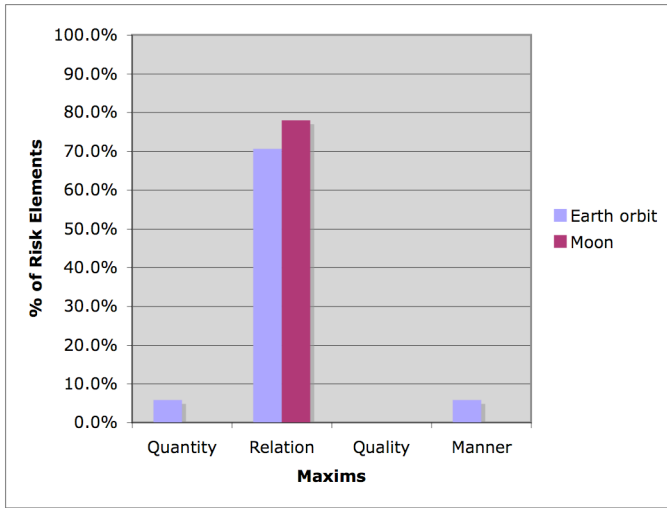


Figure 1. Gricean Risk Element Analysis

satisfied by most risk elements is *relation*. Quantity, Quality, and Manner are the least satisfied. A thorough examination of the results of each logical test for the least satisfied maxims provides insight as to exact deficiencies.

The Quantity maxim results are shown in Figure 2. This figure depicts that the Earth orbit mission only had one risk element that satisfied both of the requirements for quantity; therefore, the risk elements that satisfied the first portion of the quantity requirements had a design parameter and failure mode repeated in the other risk element which satisfied the first quantity requirement. Moreover, the moon mission did not have any risk elements that satisfied any portion of the quantity maxim. This is because there were no failure modes recorded in any of the Moon risk elements.

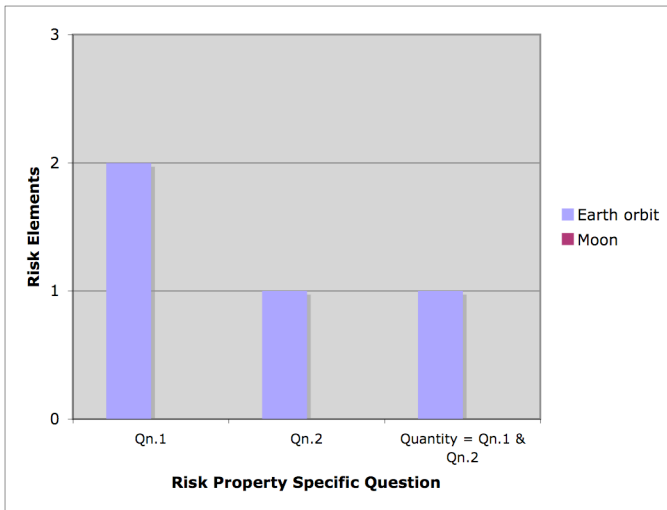


Figure 2. Gricean Risk Element Analysis – Quantity

The Quality Maxim is also deficient, according to Figure 1. A breakdown of the requirements for the quality maxim is shown in Figure 3. This figure demonstrates that the quality maxim had poor results due to requirements Q.1.3, Q.2.1, and Q.2.2 for the Moon mission and had poor Earth orbit results on all requirements except Q.1.2. As in the Quantity case, this is also due to lack of Failure Mode information.

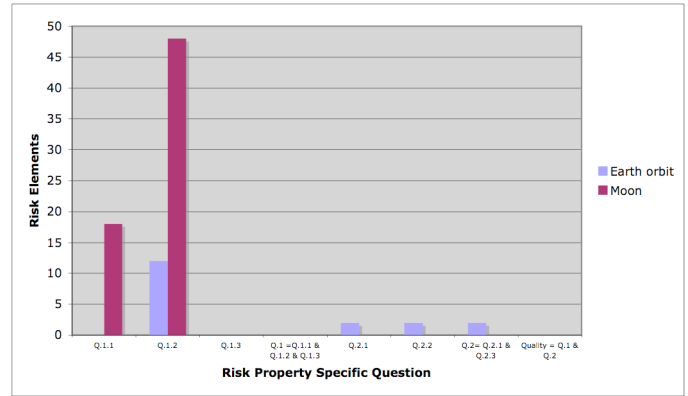


Figure 3. Gricean Risk Element Analysis – Quality

The last of the Gricean maxims is Manner and the breakdown of its results are shown in Figure 4. These results indicate that M.1 fails to satisfy the criteria in all but one case. This is again due to the lack of Failure Mode information. Also, M.2 is true more of the time; therefore, the risk elements tend to be unambiguous and are not totally clear with respect to performance parameters and failure modes. It appears that from these results the absence of failure mode data is preventing the risks from being clear.

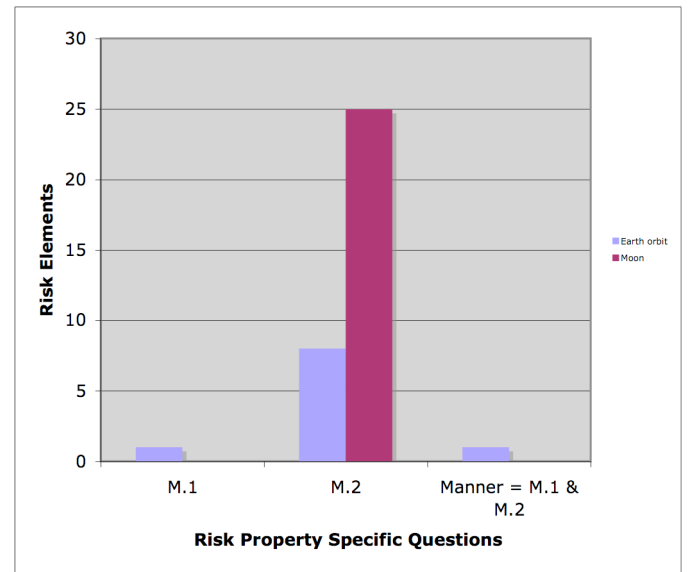


Figure 4. Gricean Risk Element Analysis – Manner

## 5.2 Functional Approach

As in the Gricean approach, each risk element was subjected to the logical relationships associated with each portion of the maxims listed in Table 2. If the logical result was true, then the risk element satisfied the requirement for the informative function of communication. The results from the Functional Approach are displayed in Figure 5. The results indicate that 47% of the Earth orbit and 30% of the Moon risk elements satisfy the informative communication function. These risk elements present a *location* for a problem (performance or design parameter) and a *potential source* (noise parameter, failure mode, or failure scenario) of the problem.

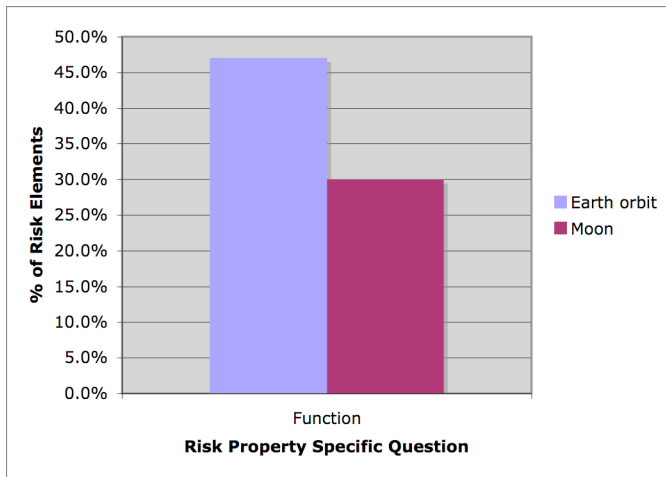


Figure 5. Function Risk Element Analysis – Percentage

### 5.3 Relevance Theory

The relevance theory results differ slightly from the Gricean and Functional Approach results in that there is a count of the risk elements that separates the level of positive cognitive effect (or degree of satisfaction of RT.1) rather than a logical relationship. This portion of the relevance theory is concerned with maximizing positive cognitive effect; therefore, the results presented here demonstrate the various levels of positive cognitive effect (which is greater for a risk element which is described by the most risk element attributes) demonstrated by the risk elements: see Figure 6. Of the Earth orbit mission risk elements, 35% have at least 4 of the 5 risk element attributes. However, the Moon mission risk elements have at maximum, 3 risk element attributes.

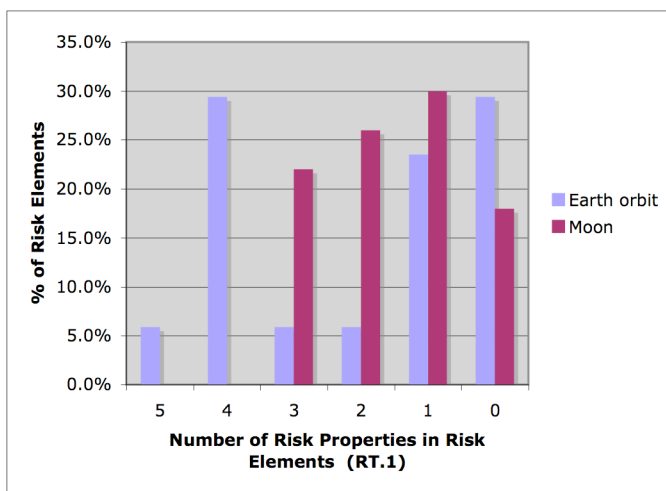


Figure 6. Relevance Theory Risk Element Analysis- Percentage

Also, with respect to the second portion of the relevance theory, processing effort, we argue that a risk element with at least 3 of the risk element properties satisfied the processing effort portion of the relevance theory. 20% of the moon mission risk elements meet this criteria while 35% of the Earth orbit mission risk elements meet this requirement.

### 5.4 Discussion of Analysis Results

The approach and results of this work are based on two key assumptions. First, we assume that the elicitation, discussion, and consideration of risk are activities subject to the principles of pragmatics and that an engineer should address risks in a manner consistent with these principles. Further, we assume that the risk attributes developed in 4.1.2 are one solution toward specifying the context of a risk, which is an inherently key component of the meaning of risk. With these assumptions, the analysis in the above sections is i) an evaluation of the degree to which a sample of risk elements accounts for these risk attributes and ii) an evaluation of the conformance of the risk element samples to the principles of pragmatics.

Although three different theories of pragmatics are used in this work, an evaluation of risk elements according to these theories and with respect to the five risk attributes shows that the sample of risks examined are deficient in terms of these pragmatic theories. For example, of all the attributes for which there is data (from the sample of risk elements), the lack of failure mode identification is significant because this means the basic problem (failure mode) is not identified. In addition, there were a low number of risk elements for which some affected functionality was identified. Beyond the lack of completeness in accounting for the risk attributes, Figures 1-6 provide evidence for claiming deficiencies for particular aspects of the three pragmatic theories.

It is important to note that the property specific questions and logical relations in Tables 5-7 are from one interpretation of how a sample of risk elements can be evaluated with respect to a given theory of pragmatics. A different interpretation may yield different results and is a potential source of error in this work. Nonetheless, the sample of risk elements clearly do not fully account for the risk element attributes which we assume to be important in a discussion of risk. This assumption is established by considering the importance of context in the basic meaning of risk.

Overall, it is reasonable to expect that the consistency and descriptiveness of risk elements can be improved through adoption of a risk element format that requires specifications for a reasonable set of attributes such as those used in this work. This is in contrast to present conditions where the results clearly show the potential for greater clarity in documenting risks. Enforcement or other regulation of Team adherence to these types of attributes seems to be an opportunity for improvement. Taking the importance of the attributes one step further, next we present a method (a worksheet) that incorporates these attributes.

### 5.5 Functional Template Extension: A Risk Worksheet

In addition to studying a sample of risk elements, here we propose a method, a risk worksheet, to aid engineers in improving risk communication through specification of risk attributes. Specifically, this worksheet incorporates the risk element attributes developed in section 4.1.2. This worksheet is essentially a derivative of the functional templates presented in the appendix.

The template data in the appendix is a new contribution that helps illustrate the high level systems used in space

missions in the language of the functional basis. Given the relatively low evidence of function and other references from the risk data analyzed in this work, these templates are suggestive of potential avenues to improve not only the reference of function, but inclusion of all five risk element attributes during risk elicitation, exploration, and documentation. The following provides a sketch of how this might occur using a worksheet.

### 5.5.1 Basic Concept

Given the results of this work that indicate a need for increasing the reference and consideration of risk element properties, a central goal for developing tools for risk assessment, is to facilitate user awareness of these five risk attributes.

Upon developing preliminary versions of the templates in the appendix, it became apparent that arranging a matrix with rows of functions and columns of flows is a convenient, although abbreviated and not visually appealing, layout for describing the functions and flows associated with physical systems. It follows from this layout that such an arrangement can be modified to explicitly include all five risk attributes. Figure 7 illustrates this concept.

Function		System of Interest					
Primary	Secondary	Flow	P	N	FM	FS	Risk
Branch	Separate						
	Distribute						
Channel	Import						
	Export						
	Transfer						
	Guide						
Connect	Couple						
	Mix						
Control Magnitude	Actuate						
	Regulate						
	Change						
	Stop						
Convert	Convert						
Provision	Store						
	Supply						
Signal	Sense						
	Indicate						
	Process						
Support	Stabilize						
	Secure						

Figure 7. Function Based Risk Worksheet

This concept is a snapshot of how the five risk attributes can be taken into account. As shown, the design parameter (*D*) attribute is represented by the rows of functions. With this layout, a system of interest can be documented in terms of its functionality, flows, performance parameters (*P*), noise parameters (*N*), failure modes (*FM*), failure scenarios (*FS*), and risk title or description (*R*).

### 5.5.2 Features and Scenarios of Use

Many alternative levels of sophistication are conceivable with this worksheet concept. A simple example is direct use of

a layout like Figure 7 in a spreadsheet where a separate document is used for each system of interest. A more elaborate concept is an interactive worksheet with the capability for advanced features (searching, navigating, and reusing data from other sources). Example features might include the ability to navigate within hierarchies of physical systems, which is the case with the repository based Function-Failure Design tool (FFDt) under joint development between UMR and NASA-Ames Research Center. Another example of other features includes linking between this Risk Worksheet and other applications such as Work Breakdown Structures (WBS), the RAP tool, and repository tools like the FFDt in order to support informed searches based on an appropriate blend of archived, perhaps quantitative, risk and function data with specific parameters relevant to the mission design at hand. For instance, performance parameters relevant to the mission are found in abundance in the WBS (eg. mass budget, etc.), which is continuously updated during Team X sessions. Integrating a risk worksheet concept with other tools such as the WBS therefore seems logical in order to reuse data.

Finally, outlines of two usage scenarios are considered in order to illustrate how the function based risk worksheet concept offers potential advantages over the current process of dealing with risk. An assumption is that users are either the Team X member dedicated to risk issues (ie. the “Risk” chair) or potentially other Team X members depending on the overhead necessary to perform the task.

In the simple scenario of implementing the worksheet in a spreadsheet manually for each system, the user can reference the functional templates in order to first identify flows associated with a given system. These flows can be directly used to aid in identifying (*P*) since these performance parameters are often measures of flow variables. A set of (*N*) can be generated because noise parameters are often implied if the objective / desired parameter (*P*) is established. This is analogous to playing devils advocate when finding the parameters (*N*) that will disturb system performance (*P*). Given this context of function, flow, performance parameter, noise parameter, the user is primed for generating relevant failure modes, failure scenarios with the intent of ultimately collapsing these factors into a statement of risk in terms of likelihood and consequence.

An advanced scenario of implementing the worksheet involves the same overall process as the simple case except that enhanced functionality of the worksheet tool facilitates greater user flexibility in terms of their task process and greater support by reusing data from other sources. Here the user may begin with navigating to, or creating a system of interest through a browse feature. The user has an option of displaying parameters that are currently active from other tools such as the WBS. Based on these cues as well as ongoing discourse in the design room, the user gradually populates the worksheet, perhaps multiple worksheets at various system levels concurrently as information becomes more available and more concrete. All the while, the worksheet tool prompts the user, allows searches, or otherwise provides data from archived designs that is relevant to the current design. The final result of a set of risks in terms of likelihood and failure used for making further engineering decisions.

### 5.5.3 Corrective Actions for Addressing Risk

These features and scenarios are suggestive of an improved environment for eliciting, exploring, and documenting risk. Development of these concepts is an outcome of our improved understanding of how risk is addressed, based on the analysis described in section 4 and direct observations of Team X sessions. Specifically, our results demonstrate deficiencies in the content of risk elements in terms of the principles from pragmatics. The use of risk attributes, functional templates, the function based risk worksheet concept, and the processes described in the above scenarios are our proposed solution for taking corrective actions in order to improve how risk is addressed currently in Team X sessions. While the advanced tools outlined above require development, the simple case as described is deployable using the results presented here. Specifically, interested users can simply use Figure 7 as a starting point for spreadsheets and implement the process described in the first scenario of section 5.5.2.

## 6.0 CONCLUSIONS AND FUTURE WORK

This paper focuses on how designers communicate risks, and particularly how function is addressed in risk elements. Five attributes for risk elements were developed and an analysis of a sample of risk elements was performed. Due to the importance of context in effective communication which is the focus of the pragmatics sub-field of linguistics, the analysis used three theories from this area: i) Gricean, ii) Relevance Theory, and Functional Analysis. The results indicate that the risk elements are generally deficient with respect to the five attributes and fall short of any of the three perspectives in the analysis. Thus, one direction for improvement is to improve the how the context of risk is addressed in discussions of risk. Use of the five attributes developed here is one solution toward this improvement since these attributes each clarify the context of risk discussion.

A practical means for taking this approach is by using the risk worksheet developed here. Given the function based nature of this worksheet, the functional templates in the appendix should help initiate use of such worksheets. These templates relate very high level physical systems generally used in space missions with functions from the functional basis. The function based risk worksheet should assist designers in effectively eliciting, exploring, and documenting with risk with respect to the standards of the three linguistic principles.

A tool that helps develop a preliminary set of mission risks is useful to the engineering team by reducing the initial dependence of the risk chair on other design team members. Future work should investigate the development of advanced tool features described in section 5.5.2.

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## Appendix: Functional Templates

### Nomenclature for Flows

Primary	Secondary	Notation
Material	Human	HM
	Gas	GS
	Liquid	LQ
	Solid	SD
	Plasma	PL
	Mixture	MX
Signal	Status	SS
	Control	CS
Energy	Human	HE
	Acoustic	AE
	Biological	BE
	Chemical	CE
	Electrical	EE
	Electromagnetic	EM
	Hydraulic	HD
	Magnetic	MG
	Mechanical	ME
	Pneumatic	PE
	Radioactive/Nuclear	NK
Thermal	TH	

