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ON MEASURING ENGINEERING RISK ATTITUDES

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ABSTRACT

Theories of rational decision making hold that decision makers should select the best alternative from the available choices, but it is now well known that decision makers employ heuristics and are subject to a set of psychological biases. Risk aversion or risk seeking attitude has a framing effect and can bias the decision maker towards inaction or action. Understanding decision-makers' attitudes to risk is thus integral to understanding how they make decisions and psychological biases that might be at play. This paper presents the *E*ngineering-*Do*main-*Sp*ecific *R*isk-*T*aking (E-DOSPERT) test to measure the risk aversion and risk seeking attitude that engineers have in four domains of engineering risk management: identification, analysis, evaluation and treatment. The creation of the instrument, an analysis of its reliability based on surveying undergraduate engineering students in Australia and the United States, and the validity of the four domains are discussed. The instrument is found to be statistically reliable to measure engineering risk aversion and risk seeking, and to measure engineering risk aversion and risk seeking to risk identification and risk treatment. However, factor analysis of the results suggest that four other domains may better describe the factors in engineers' attitude to risk.

1 INTRODUCTION

Risk is an integral part of engineering design. Risk propensity is often considered an essential ingredient for innovative design, perhaps best exemplified in the IDEO motto "Fail often to succeed sooner," implying a willingness to take the risk to allow a product concept to fail to enable learning. On the other hand, risk aversion pervades certain industries, such as power generation and aerospace. There is no one correct level of attitude to risk across all engineering sectors; rather, risk is a factor that must be managed in order for an organization to reach its objectives. Research by Van Bossuyt et al. in risk trading in engineering design has shown that what one engineer thinks is 'risky', another engineer may not [1].

Within engineering design, there is no shortage of methods to identify the risk of failure of components [2]. At the organizational level, standards such as ISO 31000:2009 [3] prescribe a framework for organizations to manage risk. The standard usefully identifies four aspects to risk management: risk identification (I), risk analysis (A), risk evaluation (E), and risk treatment (T). While the standard prescribes effective principles and guidelines for organizations to establish risk management policies and procedures, it, like formal engineering risk analysis methods, falls short in the assessment of

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organizational and personal *attitudes* to engineering risk.

This paper presents the E-DOSPERT test, which is designed to assess engineering risk attitude, an engineer's mental response to the perception of uncertainty of objectives that matter [4]. The E-DOSPERT test is modeled after the *Do*main-*Spe*cific *R*isk-*T*aking (DOSPERT) test [5,6] and is based on principles and guidelines in the ISO 31000:2009 standard on risk management [3]. The DOSPERT test is quickly becoming the most preferred risk attitude scale in psychology for its predictive abilities and ability to show whether observed risk behavior is based upon the person's perception of risk or the person's attitude toward the perceived risk. The DOSPERT test has demonstrated both a high level of reliability and construct validity. ISO 31000:2009 is the International Organization for Standards risk management principles and guidelines standard. The standard systematically lays out the principles behind risk management and outlines guidelines for risk management practitioners to follow.

Understanding the risk attitudes of engineers would be useful for several reasons. By understanding the risk attitudes of engineers, training can be conducted to harmonize an engineer's professional perception of risk – subjective judgment of the severity and characteristics of a risk – and risk appetite – the amount of risk that is willingly taken on in order to realize a gain – with the company's risk perception and risk appetite. In systems engineering, understanding individual engineers' risk perception and appetite holds the promise of helping engineers to collaborate more effectively and deliver a higher utility product with a lower development cost and shorter development time [7]. Risk and reliability engineering stand to benefit from knowing their risk attitude. Expert judgment is directly affected by how engineers perceive risk and their risk appetites. By understanding individual risk perceptions and appetites, risk experts can explicitly normalize their expert opinions with peers [1]. In terms of theory of decision-based design, it is already known that decision makers are subject to a set of psychological biases, one of which is a framing effect. If outcomes are framed in terms of gains, people tend to be risk averse; conversely, when outcomes are framed in terms of losses, people tend to be risk seeking. Thus, how engineering data is merely presented can bias decision makers, irrespective of the data presented.

For these reasons, the authors developed an instrument to assess engineering risk attitude with the aim that such an instrument can become a standard for the assessment of engineering risk attitudes. The following sections present necessary background material on the DOSPERT test and related psychology of risk research, and on risk in engineering. A methodology for the creation of the E-DOSPERT scale is presented. Initial testing and validation results are reviewed and discussed. This paper concludes with discussion of future work and implications of the E-DOSPERT scale.

2 Background

Risk can be defined in a variety of ways. Alternative definitions of risk and how those definitions relate to methods for assessing risk attitudes are briefly examined in the following section.

2.1 The Psychology of Risk Attitude

The 'classic' definition of risk is the parameter that differentiates between the utility functions of different individuals [8]. The utility function of individuals is often expressed as $-u''(x)/u'(x)$ where u' and u'' denote the first and second derivatives of an individual's utility function [8,9]. The Expected Utility (EU) hypothesis theorizes that the preference of an individual choosing between risky options can be determined by a function of the return of each option, the probability of that option coming to fruition, and the individual's risk aversion [10]. The EU framework and related methods including prospect theory [11] traditionally view the curves of an individual's utility function as denoting either risk aversion or risk seeking. The definition of risk aversion in the context of risk attitudes is framed in the context of someone who prefers to take the expected value of a gamble over playing the gamble as being a person who does not like to take risks [12]. As a result, risk attitude can be defined as a person's position on the risk aversion-risk seeking axis and is thought of as a personality trait. Hillson and Murray-Webster [4] further refine this risk aversion-risk seeking scale by inserting a mid-point "risk tolerant" as being comfortable with uncertainty and able to handle the uncertainty if necessary and by including "risk neutral" as taking necessary short-term actions to deliver certain long-term outcomes.

However, two issues have arisen that challenge the idea of risk attitudes in the context of EU being a personality trait: cross-method utility instability and inconsistent risk profiles across risk domains. When different methods are employed to measure people's utility, different classifications of risk-taking or risk aversion often result [13]. Further, individual respondents are not consistently risk averse or risk seeking across different risk domains [14]. For example, managers have been found to have different risk attitudes when evaluating financial and recreational risks, and when using company money versus personal money [15].

The concept of relative risk attitude was introduced in an attempt to identify the component of risk-taking that has cross-situational stability for individuals [16]. The hypothesis was that the domain differences in apparent risk attitudes might be as a result of domain-specific outcome marginal values. With the marginal values factored out, stability across domains was expected. However, this was not the case under further review. No evidence was found of cross-situational relative risk attitude stability in empirical studies [17].

The validity of EU-based risk attitude assessment is limited due to these issues. There has been little success in predicting individuals' choices and behaviors in domains not assessed by EU-based instruments [18]. Even with the limitations of EU-based survey instruments, many are still in use. For instance, the Choice Dilemma scale combines four different domains into one risk attitude score [19]. In spite of its flaws, the scale is widely used.

A more recent method of determining risk attitude takes inspiration from the world of finance [20]. The risk-return framework of risky choice assumes people's preferences for risky options reflects a trade-off between riskiness of a choice and the Expected Value (EV). The financial world equates riskiness of an option with its variance. In psychology risk-return models, perceived riskiness is treated as a variable that can be different between individuals due to differences in individuals' content and context interpretations [17, 21].

The risk-return framework allows for people to have similar perceptions of risk and return between different domains but in one domain prefer risk while in another prefer caution [5]. Having such preferences and perceptions would result in different outcomes, as the risk-return framework predicts. The term *perceived risk attitude*, previously conceptualized as risk-repugnance [22], was coined to reflect the assumption that risk in its pure form is negative and undesirable but that perceived risk might be attractive to some individuals in certain domains and circumstances [23]. Variances in perceived risk attitude are thus a result of discrepancies between the perception of the risks and benefits as determined by a decision-maker and an outside observer. This is exemplified in research conducted in the management field where what differentiates between entrepreneurs and managers is a highly optimistic perception of risk on the part of the entrepreneurs rather than a greater preference for risk, as one might expect [24].

Many studies have highlighted differences in the perception of the riskiness of decisions in individuals, between groups, and between cultures [25, 26]. Differences in risk perception have also been found due to outcome framing [27]. In the context of risk-return based models, perceived risk attitude has been found to have cross-situation and cross-group consistency when differences in the perception of riskiness are factored out [5, 21]. Rather than differences in risk attitude, risk-return models suggest that the way people perceive risk affects the choice outcomes.

In summary, risk attitudes vary by domain, so that the attitude to taking risks at work may differ from the attitude to taking risks at home. One may enjoy taking risks in leisure activities, but be risk averse handling of financial affairs. To assess risk perceptions and attitude toward perceived risk in different domains of risk, Weber et al. developed the DOSPERT test and related scale [5, 6]. Six independent domains were identified including ethical, investment, gambling, health/safety, recreational, and social domains. Four of the domains were originally identified based upon the risk-taking behavior literature [28] while the fifth and sixth domains were found through analysis of survey results where the financial meta-domain was split into investment and gambling domains [5], which were suggested in previous research [15, 29]. Risk-taking was found to be highly domain-specific between the identified domains where individual respondents were risk averse in some domains and risk-neutral or risk seeking in others. Respondents were found to not be consistently risk averse or risk seeking across the six domains.

It was also found that preference for risk seeking or risk aversion was influenced by the perceived benefits and risks of the activity in question. This resulted in identifying two psychological variables including risk perception and attitude toward perceived risk, as had been found in previous risk-return based models [24]. Previous risk attitude indexes have been confounded by not distinguishing between the two psychological variables of risk perception and attitude toward perceived risk [30]. Distinguishing between the risk perception and risk attitude variables is largely irrelevant if only prediction of future actions is desired. However, the distinction between these variables becomes important when risk-taking is assessed with the goal of changing risk-taking behavior [5].

Since the DOSPERT scale was developed and validated, many other studies have replicated the results. Strong correlation was found with the various subscales of Bunder's scale for intolerance [31] and with Zuckerman's sensation-seeking scale [32]. Paulhus' social desirability scale [33] was found to have significant correlation between the impression management subscale and the ethics and health/safety subscales of DOSPERT. Thus, the DOSPERT scale was found to have favorable correlations with established scales. The DOSPERT scale has also been translated into several different languages and contexts including the DOSPERT-G scale, a German-language version [34], a French-language DOSPERT scale [35], and others [6]. Other scales developed since DOSPERT was introduced have not found widespread adoption. The DOSPERT scale is quickly becoming the most preferred risk attitude scale in psychology for its predictive abilities and its ability to show whether observed risk behavior is based upon the person's perception of risk or the person's attitude toward the perceived risk, which allows for intervention and behavior modification.

2.2 An Engineering Definition of Risk Attitude

The definition and application of risk in engineering is more straight-forward than in psychology. The ISO 31000:2009 document [3] defines risk as the effect of uncertainty on objectives. An effect is a positive or negative deviation from the expected. Objectives are defined as having different aspects such as environmental, health and safety, and financial goals, and can be applied at different levels of a project or organization. The ISO 31000:2009 definition of risk is further defined as the probability of occurrence of an event multiplied by the severity of the consequences. It should be noted that uncertainty is often defined as a lack of knowledge about system specifications, and errors resulting from imperfect models [36]. Some researchers further break down uncertainty into multiple subcategories that often contain elements of risk, reliability, and robustness [37]. For the purposes of this research, the ISO 31000:2009 definition of risk shall be used in the context of engineering.

If this is used as the operating definition of risk, then risk attitude in engineering is the 'state of mind' of the engineer in response to the perception of uncertainty on objectives [4]. The engineer's attitude will influence actions, or inactions, taken. The behavior an engineer takes toward risk can be to retain, pursue, take, or turn away from that risk. In other words, when presented with a situation, it is important to determine how the engineer's risk attitude will influence behavior.

To assess this behavior, the ISO 31000:2009 document for the standard of risk management was applied as the basis for assessing behavior toward risk management, that is, the engineer's attitude to perceived risk and, simply, 'what they would do'. The ISO 31000:2009 document [3] prescribes four key factors in risk management: risk identification, risk analysis, risk evaluation, and risk treatment. Risk Identification is defined as the process of finding, recognizing, and describing risks. Risk Analysis is the process of comprehending the nature of a risk and determining the associated level of risk. Risk Evaluation is the process of comparing the results of risk analysis with the significance of the risk as compared to a reference risk scale. Risk Treatment is the process of dealing with a risk [3]. Each of these aspects of risk management may also be considered theoretical risk domains because they cover the range of conditions associated with increased probability of outcomes that compromise the certainty of objectives. Each domain has a direct effect on risk behavior and is a separate source for risk. The hypothesis is that engineers will have a different attitude toward risk depending upon the particular aspect of risk management. That is, each of these aspects is a separate content domain in the language of the psychology of risk. In the remainder of the paper, the development of the E-DOSPERT test and statistical analysis of initial survey data to test the reliability of the instrument and the validity of this hypothesis will be presented.

3 Methodology

In order to predict the behavior of engineers in their professional capacity and in order to change the risk-taking behavior of engineers within the field of engineering, a purpose-built scale must be constructed. This section documents the construction of a new risk scale specific to professional engineering, the E-DOSPERT scale, including respondent consistency tests using replicated and paired questions and reliability based on values of Cronbach's alpha. Cronbach's alpha is a measure of internal consistency of a set of related questions [38]. The authors' hypothesis on the testing scale is that engineers will show a difference in risk attitude across the four content domains. The authors conducted an exploratory factor analysis to determine whether the four domains underlie the risk behavior judgments.

Risk judgment questions were developed for each of the domains, risk identification, risk analysis, risk evaluation, and risk treatment, based upon common professional mechanical and manufacturing engineering-related situations involving risk. Usefully, the ISO 31000:2009 document provides descriptions of the types of activities that should be undertaken in an effective framework for risk management. Recommended activities associated with risk management become the basis for creating scenarios (items) in the E-DOSPERT test to assess how engineers would respond to them. Their risk judgments toward risk management activities are influenced by their risk attitude. For example, the engineer may have a process to identify risks by having a process in place to record all failure data for a component in a system. In order to estimate the likelihood of occurrence of an event, an engineer might trust informed estimation. In evaluating the risk based on this estimation, the engineer might place more weight on a regularly occurring fault than one that may never occur. To treat the risk, the engineer may operate the associated machinery far below the limits of safety.

The authors developed survey questions (items) by following the ISO 31000:2009 definitions of the 4 aspects of risk management and associated recommended activities. The items present respondents with typical scenarios or tasks they would encounter in dealing with each of these aspects. Each aspect and associated questions are briefly described.

The risk identification portion of the standard recommends comprehensive identification of risks. The identification of risks entails generating the set of events that may detract from the achievement of desired objectives. The authors considered ways in which risk events could be generated and how new risks may be introduced but not identified. Sample questions for risk identification include:

- *"not having complete data on the probability of failure for each component in a system"*
- *"introducing a design change (i.e., a new type of screw) without full documentation because you think it's a minor change"*

Risk analysis comprises the set of activities associated with understanding the risk factors, the magnitude of consequences, and the likelihood of consequences. The authors considered different ways in which this information could be generated, how divergent stakeholder opinions should be canvassed, and the types of instruments and technologies associated with engineering analysis and how they can introduce risk into risk analysis. Sample questions include:

- *"not trusting informed estimations of probabilities in a structured decision making process"*
- *"accepting the results of computational simulation and analysis without experimental corroboration of results"*

Risk evaluation examines the data from risk analysis by comparing the level of risk found during risk analysis to the acceptable level of risk. Acceptable levels of risk may come from company policy or industry standards. The authors generated sociotechnical methods for risk evaluation, considered ways in which evaluations can be biased, and simple, hypothetical situations of risk evaluation. Sample questions include:

- *"placing more weight on a major fault that occurs on a regular basis than one that may never occur"*
- *"using a technology with a lower failure rate than another one but at the expense of functionality"*

Finally, risk treatment deals with actions taken to mitigate, eliminate or modify the source of risk or its consequences. Sample questions include:

- *"staying quiet about your company's cover up of a significant design flaw"*
- *"operating machinery well below capacity and far within the limits of safety"*

In the E-DOSPERT test, the original Likert scale [39] used in the DOSPERT test was employed to measure the likelihood of engaging in a risky (or non-risky) behavior. The scale ranges from 1 to 5 with 1 corresponding to "very unlikely", 2 corresponding to "unlikely", 3 corresponding to "not sure", four corresponding to "likely", and 5 corresponding to "very likely" to engage in an activity related to risk identification, analysis, evaluation and treatment. The questions were not grouped by domain. The authors kept the mid-point as "not sure" to maintain consistency with the DOSPERT test. Some have argued that the middle-point should be "neutral" and an "undecided" or "not sure" option should also be available to respondents [40]. Offering both mid-point and not sure response options, termed Non-Substantive Responses (NSRs) [41], has been found to change the results of opinion surveys [42, 43]. In spite of the evidence that NSRs should be used in surveys, the middle point on the E-DOSPERT scale was chosen to be "not sure". This avoided confusion between the DOSPERT test and E-DOSPERT test in the event that both tests are administered in succession to respondents. Not using both NSRs allows for direct comparison between DOSPERT and E-DOSPERT results. Finally, the concept of "neutral" as in a risk neutral risk attitude is about taking short-term action to secure a certain long-term outcome [4], and this is not the same as being risk neutral in the EU framework. Thus, using the term "neutral" would not be appropriate. The term "not sure" more closely matches the situation of risk tolerant, which is considered the mid-point between risk seeking and risk averse in the Hillson and Murry-Webster framework [4].

The E-DOSPERT questions were phrased to measure risk averse and risk seeking attitudes along the Likert scale described above. 25 questions were intentionally phrased inversely. For example, the authors asked respondents' attitudes towards technology use. The risk averse version asked respondents to rate their likelihood of *"using a technology with a lower failure rate than another one but at expense of functionality."* The risk seeking version asked respondents about their likelihood of *"using a technology that has a higher failure rate than a current one but that has a better functionality."* Thus, the sub-set of inversely worded questions provides a consistency check. If the respondents are consistent and the scales are unidimensional (risk averse or risk seeking), then the coefficient alpha will be sufficiently high. A complete list of questions is presented in Appendix A. The questions were developed with the aim of being applicable to engineers regardless of national origin - that is, the questions relate to matters of engineering which would occur anywhere. Like the DOSPERT scale, the authors aimed to create an instrument with eight-item sub-scales. However, for this initial study, the authors constructed a larger set of sub-items (test questions), 25 risk averse, 29 risk seeking, and 54 questions in all. The number of items can be reduced in later versions, using questions with high inter-item correlations within a domain, once there is a better understanding of engineering risk attitude, the domains of engineering risk, and how to measure engineering risk attitude. This larger set also allows the authors to perform an exploratory factor analysis to determine if factors other than the four from the ISO 31000:2009 standard underlie risk behavior judgments.

4 Implementation and Testing (Case Study)

The E-DOSPERT scale was administered to undergraduate and graduate students at the University of Sydney (USyd) and Oregon State University (OSU). The survey contained two parts consisting of the DOSPERT test and the E-DOSPERT test. The survey was administered using SurveyMonkey. Prior to full testing, the survey was administered to several small groups of graduate students, undergraduate students, and researchers in order to validate the questions.

At USyd, the participant population was comprised of undergraduate and graduate students in the mechatronics program. A total of 23 students participated in the survey. They ranged in age from 18 to 34, averaging 20 years of age. Three women and 20 men responded to the survey. The participant population at OSU consisted of both graduate and undergraduate students in the school of Mechanical, Industrial, and Manufacturing Engineering. A total of 87 students responded. They ranged in age from 20 to 35 with an average of 23. Eight women and 79 men responded. The total sample population was comprised of 110 respondents completing the survey. The administration of the survey and its content was approved by the relevant review boards at USyd and OSU.

5 Results

5.1 Descriptive Statistics

Table 1 shows the sub-scale means (M) and standard deviations (SD) for the 110 respondents for the risk averse and risk seeking dimensions. For risk averse, the mean level of risk is *M = 3.16 (SD = 0.48)* and for risk seeking, the mean level of risk is *M = 2.84 (SD = 0.52)*. Based on a one-tailed ANOVA, the means are significantly different *($p<0.001$)*, meaning that the risk attitudes are domain-specific. Since the scale ranges from "very unlikely" to "very likely", the higher the mean for risk averse, the more risk averse the respondents are, and, conversely, the lower the mean for risk seeking, the less risk seeking the respondents are. The data shows that the population of respondents are quite unsure about their risk attitude, that is, they are in the category of "risk tolerant" according to Hillson and Murray-Webster's scale [4]. They either believe that they can handle uncertainty when they encounter it, or, given the undergraduate student status of respondents, may not have yet developed the capacity to assess their engineering risk attitude.

TABLE 1. Risk Averse and Seeking Means and Standard Deviations

Subscale	Risk Averse Mean (SD)	Risk Seeking Mean (SD)
Identification	3.42 (0.32)	2.61 (0.12)
Analysis	2.96 (0.39)	2.78 (0.63)
Evaluation	2.25 (0.38)	3.30 (0.51)
Treatment	3.47 (0.31)	2.80 (0.49)

Risk attitudes were compared between the OSU and USyd students. In general, no statistically significant difference was found (two-tailed, independent samples t-test). Table 2 summarizes the mean and standard deviation of the OSU and USyd response groups for the E-DOSPERT scale under risk seeking and risk aversion for all domains and sub-scales. The results show that risk attitudes are largely the same across the USyd and OSU respondents, except for on the risk averse-risk treatment subscale, which in turn affected the statistical difference between the USyd and OSU on the risk averse scale because of the higher proportion of items on the risk treatment subscale. This imbalance in items is a flaw in the scale, which should be addressed.

5.2 Reliability

Table 3 summarizes the values of coefficient alpha for the E-DOSPERT scales. The reliability values are shown for the Risk Averse and Risk Seeking Categories and are sufficiently high (>0.70) given the test length [44].

Table 4 summarizes the values of coefficient alpha and number of items for the E-DOSPERT scale under each content domain. The

TABLE 2. Comparison of the USyd and OSU respondent populations

Subscale	Uni	Mean (SD)
Risk Seeking Identification Domain	OSU	2.62 (0.984)
	USyd	2.58 (0.930)
Risk Seeking Evaluation Domain	OSU	3.30 (1.056)
	USyd	3.29 (0.977)
Risk Seeking Analysis Domain	OSU	2.77 (1.054)
	USyd	2.85 (1.096)
Risk Seeking Treatment Domain	OSU	2.81 (1.075)
	USyd	2.79 (1.042)
Risk Seeking All Domains	OSU	2.84 (1.069)
	USyd	2.85 (1.048)
Risk Averse Identification Domain	OSU	3.40 (1.043)
	USyd	3.50 (0.925)
Risk Averse Analysis Domain	OSU	3.12 (0.999)
	USyd	3.25 (0.958)
Risk Averse Evaluation Domain	OSU	3.40 (1.043)
	USyd	3.50 (0.925)
Risk Averse Treatment Domain	OSU	3.39** (1.036)
	USyd	3.59** (0.848)
Risk Averse All Domains	OSU	3.21** (1.051)
	USyd	3.34** (0.962)
** p-value is <0.05		

TABLE 3. Reliability Statistics

E-DOSPERT	Cronbach's Alpha	N of Items
Risk Averse	0.758	25
Risk Seeking	0.813	29

values are shown for the Risk Averse and Risk Seeking dimensions on the E-DOSPERT scale. Only the risk treatment and risk identification sub-scales have a sufficiently high reliability, although the reliability for assessing risk treatment along the risk seeking scale is below the generally accepted threshold. Respondents were consistent in answering replicated questions with nearly 100 percent answering the questions in the same way.

5.3 Factor Analysis

Factor analysis is a statistical technique used to identify clusters of variables. In this research, it was important to investigate whether the variables in the E-DOSPERT scale were measuring the underlying variables proposed in the engineering risk domains identified.

The authors analyzed the proposed engineering risk domains by conducting an exploratory factor analysis with oblique target rotation (Oblimin) on the correlation matrix of the E-DOSPERT scale items. Items on both the risk averse and risk seeking scales were removed where the anti-image correlations were <0.50. The KMO measure of sampling adequacy was sufficiently high (>0.70) and Bartlett's test of sphericity was significant, so that a factor analysis could proceed. Based on the number of hypothesized sub-scales, a four-factor model was specified. A four-factor model explained 49.683% of the variance in the Risk Seeking Category and 48.536% of the variance in the Risk Averse Category. Due to space limitations, and to make interpretation of the model simpler, only those items that load onto only one factor in the models' factor structure are shown in Table 5 for the Risk Averse dimension and Table 6 for the Risk Seeking dimension [45].

TABLE 4. Reliability Statistics

	Risk Averse		Risk Seeking	
E-DOSPERT	Cronbach's Alpha	N of Items	Cronbach's Alpha	N of Items
Identification	0.731	4	0.796	6
Analysis	0.289	8	0.469	9
Evaluation	-0.384	3	0.257	5
Treatment	0.726	10	0.614	9

Values in Table 5 and 6 show that four factors were identified in the data. The loadings are arranged from higher to lower values in each factor. Substantive loadings are considered those >0.40 when ignoring the minus sign. Although the analysis of these tables suggest that questions in the proposed scale would be composed by four sub-scales, the identified factors in the tables do not mirror the engineering risk domains initially proposed.

Each separate factor contains items from all four of the hypothesized content domains, suggesting that these four content domains as proposed by ISO 31000:2009 are not underlying factors in risk behavior judgment. Despite this discrepancy, there is some uniformity in the interpretation of the factor model structure. In the Risk Averse dimension, Factor 1 includes items about following established processes and procedures including maintenance and standard operating procedures, Factor 2 relates to professional ethics and conduct such as 'whistle-blowing' and relying on professional bodies to set standards for technical standards, Factor 3 relates to product testing and Factor 4 relates to training. In the Risk Seeking dimension, Factor 1 includes items on processes and procedures such as having a formal review process and following best practice in root cause analysis, Factor 2 contains one item related to legal matters, Factor 3 relates to professional ethics and conduct such as covering up a significant flaw and not documenting repairs to faults and Factor 4 includes items relating to product functionality and design.

6 Discussion

The results support the hypothesis that engineering risk attitude is domain-specific. The authors were able to obtain suitable reliability for at least two of the sub-scales, risk identification and risk treatment, but not for risk analysis and evaluation. In the fac-

TABLE 5. Factor model structure for risk averse dimension

	Component			
	1	2	3	4
Following standard operating procedures (replicated question)	0.902			
Following standard operating procedures	0.880			
Following maintenance strategies according to manufacturer's	0.752			
Having complete data on probability of failure	0.625			
Documenting all maintenance procedures	0.540			
Referring to authoritative source to check technical matter		0.586		
Miss deadline to complete experimental testing		0.565		
"Whistle-blowing" company's cover up of significant flaw		0.549		
Operating machinery below limits		0.464		
Not Upgrading Software		0.416		
Investigating unlikely to occur design flaw			-0.735	
No need for corroboration of experimental results			0.643	
Using new equipment after voluntary formal training				0.808
Regular training on risk management				0.764

TABLE 6. Factor model structure for risk seeking dimension

	Component			
	1	2	3	4
No formal review process	0.774			
Ensuring staff awareness of only of major risks	0.716			
Conducting root cause analysis only for major failures	0.639			
Cut experimental testing to meet deadline	0.523			
Not calculating loss at the minimum probability of failure	0.488			
Emphasis on legal, regulatory, and other requirements		0.332		
Not recording the repairing of a fault			0.750	
Never conducting root cause analysis for failures			0.736	
Not updating training on risk management			0.646	
Quiet about company's cover up of significant flaw			0.513	
Not Documenting all maintenance procedures			0.441	
Technology with higher failure but better functionality				-0.632
No full documentation				-0.580
Not having complete data on probability of failure				-0.579
Allowing minor flaws				-0.561
Accepting colleague's opinion on a technical matter				-0.520

tor analysis, items had moderate to high loadings on their specified factors, and these factors were not highly correlated, which supports the idea that risk attitudes are multi-faceted and cannot be captured by a single index.

The reliability values for the risk analysis and risk evaluation sub-scales were particularly low. This means that the respondents were not able to discriminate between situations that dealt with the analysis of a risk, which concerns understanding the nature and the degree of the risk through actions such as gathering empirical data, identifying sources of risk, running numerical simulations, and estimating likelihoods of occurrence, and questions dealing with the evaluation of risk, which entails reviewing data from the risk analysis. Given that the means and standard deviations for overall risk aversion and risk seeking were very close to 3, meaning "not sure", and that the population of respondents were undergraduate students who were unfamiliar with risk management, the authors speculate that the reliability values may improve if a population of engineering professionals familiar with engineering risk management was surveyed. That the students were "not sure" of their risk attitude suggests that this is an engineering attribute that should be developed.

Nonetheless, the reliability analysis allows the following conclusion about the E-DOSPERT scale:

1. The scale is suitable to measure engineering risk aversion and risk seeking.
2. The scale is suitable to measure engineering risk aversion and risk seeking along the subscales of risk identification and risk treatment.
3. The scale is not suitable to measure engineering risk aversion and risk seeking along the subscales of risk analysis and risk evaluation.

The premise of the E-DOSPERT scale is that the four aspects of risk management could provide commonly encountered content domains by engineers. The authors used these domains to draw out risk behavior judgments from respondents. While most of the items in the four factor model loaded onto one of the four factors, they did not load onto them in the predicted way, that is, onto the associated content domain. Generalizing from the interpretation of the factor models from the current data, the authors propose a different set of factors, which may provide better coverage of risk-taking situations encountered by engineers.

1. Engineering practice and processes: Situations associated with project processes and the work of engineering
2. Product functionality: Situations associated with the objectives, requirements, performance, or failure of the engineered product [46]
3. Legal: Situations associated with legal and regulatory requirements in engineering and of engineers
4. Engineering ethics: Situations associated with professional and ethical conduct

These factors correspond to domains of engineering risk identified by other researchers. The factors associated with engineering processes and product functionality have been identified by Eckert [47] as generic risk factors based on their study of design processes across disciplines. The engineering ethics factor has a correlation to the general risk domain of social risk [5] and are suggestive of the generic engineering risk to the engineer's reputation [47]. While the authors have chosen to conceptualize risk domains based on a risk management framework, since attitudes to risk management will determine the actions engineers choose to take to counter perceived risks, questions which link risk management more closely to known engineering risk factors in an objective way may be easier for engineers to assess for risk behavior judgment. In other words, rather than having engineers assess their likelihood of making a relatively tactical and strategic level decision about "Having formal review processes to review and analyze the history of design faults", this question could be better presented as a graph showing average availability for a device over a long period of time and asking for a subjective technical assessment whether the availability loss is significant enough to warrant further inspection.

7 Conclusion

This paper presented an instrument, the E-DOSPERT scale, to measure the risk aversion and risk seeking attitude of engineers. Items in the scale are based on commonly encountered scenarios in risk management. The results show that the scale is suitably reliable to measure risk aversion and risk seeking, and to measure risk aversion and risk seeking for risk identification and treatment, but not risk analysis and evaluation.

This initial version of the E-DOSPERT scale tested the validity of the ISO 31000:2009 standard and its recommended four content domains for risk management as the basis for risk behavior judgment. Two of the domains, analysis and evaluation, were found to be not easily discriminated, at least in a population of engineering undergraduates. Based on an exploratory factor analysis with oblique target rotation, the authors suggest four other factors that may underlie the risk behavior judgments.

Thus, in its current form, the E-DOSPERT scale can be used to assess risk aversion and risk seeking reliably, and the authors suggest that users of the scale remove items on risk analysis and evaluation. In future work, the authors will revise the items such that the questions will address these four factors more directly, and eliminate existing questions with low item-item correlation. Such an instrument can then be used as a standard to assess risk attitude across industries, within organizations, by gender and national origin, and as pre and post tests on the development of risk-assessment as an engineering attribute in engineering education. The authors believe that such information is crucial in interpreting how individual engineers approach design and design decision-making.

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Appendix A: The E-DOSPERT Scale

The E-DOSPERT test presented in this appendix was administered online using Survey Monkey. The questions were automatically randomized when presented to the respondents. Below the questions are presented in alphabetical order.

For each of the following statements please indicate the likelihood of engaging in each activity. Please provide a rating using the following scale:

Very Unlikely	Unlikely	Not Sure	Likely	Very Likely
1	2	3	4	5

1. “Whistle-blowing” your company’s cover up of a significant design flaw. (T)
2. Accepting the results of computational simulation and analysis without experimental corroboration of results. (A)
3. Accepting your colleagues opinion about a technical matter without checking the originating source. (A)
4. Adjusting standard operating procedures to handle a design flaw to better fix the flaw. (T)
5. Allowing minor flaws through on a production line to keep the line moving. (T)
6. Applying a new process recommended in a prestigious journal even if it is not an industry-wide standard. (A)
7. Calculating potential loss from a design fault at the minimum probability of failure. (A)
8. Conducting a root cause analysis every time that a failure occurs. (A)
9. Conducting a root cause analysis of major failures but not of minor failures. (A)
10. Conducting maintenance according to what you think is best rather than following manufacturer recommended maintenance strategies. (T)
11. Continuing to use an outdated but robust piece of software even if others in your group choose to upgrade to a new version. (A)
12. Cut back on experimental testing to meet a project deadline. (A)
13. Ensuring that all staff know about potential risks no matter how minor. (I)
14. Following maintenance strategies exactly according to manufacturer specifications. (T)
15. Following standard operating procedures word-for-word for the handling of any design flaw. (T)
16. Formally documenting all maintenance procedures. (T)
17. Fully documenting every design change, no matter how minor. (I)
18. Further investigating a design you suspect has a flaw that you estimate is not likely to occur. (I)
19. Halting a production line immediately if any flaw, no matter how minor, is identified. (T)
20. Having complete data on the probability of failure for each component in a system. (I)
21. Having formal review processes to review and analyse the history of design faults. (A)
22. Having no formal review process to analyse and review the history of design faults. (A)
23. Ignoring a colleague’s suggestion to investigate a major but unlikely design flaw. (A)
24. Informing staff only about potential major risks but not about minor risks. (I)
25. Introducing a design change (i.e., a new type of screw) without full documentation because you think it’s a minor change. (I)
26. Making a design change if a component’s failure rate is close to but below the industry standard for component failure. (T)
27. Miss a project deadline to conduct complete experimental testing. (A)
28. Never conducting root cause analysis for failures. (A)
29. Not bothering to calculate potential loss from a design fault at the minimum probability of failure. (A)
30. Not documenting all maintenance procedures. (T)
31. Not having complete data on the probability of failure for each component in a system. (I)
32. Not making a design change if its failure rate is close to but below the industry standard for component failure. (T)
33. Not trusting informed estimations of probabilities in a structured decision making process. (A)
34. Operating machinery at the limits of safety and availability. (T)
35. Operating machinery well below capacity and far within the limits of safety. (T)
36. Placing more emphasis on legal, regulatory, and other requirements over operating profitability. (E)
37. Placing more weight on a major fault that may never occur than a major fault that occurs often. (E)
38. Placing more weight on a major fault that occurs on a regular basis than one that may never occur. (E)
39. Recording a major fault but not a minor fault. (I)
40. Referring to an authoritative source to check your colleagues’ opinion about a technical matter. (A)
41. Relying on experience over formal processes when vetting decisions. (E)
42. Repairing a fault but not recording the number times you have needed to fix the fault. (I)
43. Staying quiet about your company’s cover up of a significant design flaw. (T)
44. Trusting experimental results even when they do not align with analytical calculations. (E)
45. Trusting informed estimation of probabilities in a structured decision making process. (A)
46. Upgrading your design analysis software as soon as a new version is available even if it is not used by others in your group. (A)
47. Using a new piece of equipment without optional formal training. (T)
48. Using a technology that has a higher failure rate than a current one but that has better functionality. (E)
49. Using a technology with a lower failure rate than another one but at the expense of functionality. (E)
50. Using an industry-wide standard rather than a new process recommended in a prestigious journal. (A)
51. Using risk management practices that were industry best practices when you learned them but not keeping up-to-date with current practices. (A, E, T, I)
52. Voluntarily attending formal training before using a new piece of equipment. (T)
53. Voluntarily taking formal training on a regular basis on industry best practices in risk management. (I)
54. Using risk management practices that were industry best practices when you learned them but not keeping up-to-date with current practices. (I)

Note: (A) = Risk Analysis, (T) = Risk Treatment, (E) = Risk Evaluation, (I) = Risk Identification