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4 authors:

Douglas Lee Van Bossuyt
Naval Postgraduate School

Andy Dong
The University of Sydney

Irem Y. Tumer
Oregon State University

Lucila Carvalho
Massey University (Auckland, New Zealand)

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Douglas L. Van Bossuyt [*]
Complex Engineered Systems
Design Laboratory
School of Mechanical, Industrial
and Manufacturing Engineering
Oregon State University
Corvallis, OR 97331
Email: Douglas.VanBossuyt@gmail.com

Andy Dong
Faculty of Engineering and Information Technologies
University of Sydney
Sydney, NSW, 2006, Australia
Email: Andy.Dong@sydney.edu.au

Irem Y. Tumer
Complex Engineered Systems
Design Laboratory
School of Mechanical, Industrial
and Manufacturing Engineering
Oregon State University
Corvallis, OR 97331
Email: Irem.Tumer@oregonstate.edu

Lucila Carvalho
Faculty of Education and Social Work
University of Sydney
Sydney, NSW, 2006, Australia
Email: Lucila.Carvalho@sydney.edu.au

Risk management is a critical part of engineering practice in industry. Yet, the attitudes of engineers toward risk remains an unknown and is not measured. This paper presents the development of a psychometric scale, the Engineering-Domain-Specific Risk-Taking (E-DOSPERT) test, to measure engineers' risk aversion and risk seeking attitudes. Consistent with a similar psychometric scale to assess general risk attitudes, engineering risk attitude is not single domain and is not consistent across domains. Engineers have different risk attitudes toward five identified domains of engineering risk: Processes, Procedures and Practices; Engineering Ethics; Training; Product Functionality and Design; and Legal Issues. Psychometric risk profiling with E-DOSPERT provides companies a standard to assess domain-specific engineering risk attitude within organizations and across organizations. It provides engineering educators a standard to assess the understanding of engineering students to the types of risks they would encounter in professional practice and their personal attitude toward responding to those risks. Appropriate interventions can then be implemented to shape risk attitudes as appropriate. Risk-based design decisions can also be shaped by a better understanding of engineer and customer risk attitude. Understanding engineers' risk attitudes is crucial in interpreting how individual engineers will respond to risk in their engineering activities and the numerous design decisions they make across the various domains of engineering risk found in professional practice.

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 risks early in the design process to allow a product concept to fail, thereby enabling learning. On the other hand, risk aversion pervades certain industries, such as power generation and aerospace. There is no one correct risk attitude across all engineering sectors, and an action or event one engineer thinks is 'risky', another engineer may not [1]. Rather, risk is an issue that must be managed.

Risk and reliability engineers manage risks by identifying the potential sources of risks and then finding ways to mitigate those risks. Within engineering design, there is no shortage of methods to identify the risk of failure of components [2, e.g.]. Standards such as ISO 31000:2009 [3] prescribe a framework for managing risk. ISO 31000:2009 is the International Organization for Standardization 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. The standard identifies four aspects to risk management: risk identification, risk analysis, risk evaluation, and risk treatment. Having been implemented in the management of engineering, the framework has only recently been applied to risk management in product design [4]. 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 organizational and personal *attitudes* to engineering risk.

Understanding the risk attitudes of engineers is useful for several reasons. By understanding the risk attitudes of engineers, training can be conducted to harmonize an engineer's perception of risk – individual, subjective judgment of the severity and characteristics of a risk – and risk attitude – the amount of risk that is willingly taken on in order to realize a gain – with the company's

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risk perception and risk attitude. In systems engineering, understanding individual engineers' risk perception and attitude 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 [5]. Risk and reliability engineering stand to benefit from knowing risk attitude. Expert judgment is directly affected by how engineers perceive risk and their risk attitudes. By understanding individual risk perceptions and attitudes, risk experts can explicitly normalize their expert opinions with peers [1].

This paper presents the E-DOSPERT test, a psychometric scale to assess engineering risk attitude, which is an engineer's mental response to the perception of uncertainty of objectives that matter [6]. The research is motivated by an aim for a standard for the assessment of engineering risk attitudes to complement risk management frameworks. The E-DOSPERT test is modeled after the *Do*main-*Spe*cific *R*isk-*T*aking (DOSPERT) test [7, 8]. The DOSPERT test is quickly becoming the most preferred risk attitude scale in psychology for its predictive abilities of future actions based on risk attitude 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 while conclusively showing that a person's attitude toward risks associated with financial decisions will differ from their risk attitude toward social activities among several domains of risk. This paper addresses two research questions related to the development of E-DOSPERT. The first question is whether engineering risk is domain dependent. Version A of the E-DOSPERT test was constructed based upon principles and guidelines in the ISO 31000:2009 standard on risk management to address this question [3, 9]. If it is true that risk attitudes in engineering are domain dependent, the second research question concerns the domains of engineering risk. We identify these domains through an exploratory factor analysis of the results from Version A and Version B of the E-DOSPERT test.

The following sections present necessary background material on the DOSPERT test, the psychology of risk, and risk in engineering. A method for the creation of the E-DOSPERT scale is presented. 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 [10]. Utility functions are representations of the preference or value that individuals place upon event outcomes. The utility function of individuals is generally expressed as an exponential, quadratic, or logarithmic curve [10–12]. 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 [13]. The EU framework and related methods including prospect theory [14] 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 [15]. 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 [6] 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 the category "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 [16]. Further, individual respondents are not consistently risk averse or risk seeking across different risk domains [17]. 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 [18].

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 [19]. 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 [20].

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 [21]. Even with the limitations of EU-based survey instruments, many are still in use. A more recent method of determining risk attitude takes inspiration from the world of finance [22]. 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 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 [20, 23].

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 domain prefer caution [7]. 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 [24], 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 [25]. 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 [26].

Many studies have highlighted differences in the perception of the riskiness of decisions in individuals, between groups, and between cultures [27, 28]. Differences in risk perception have also been found due to outcome framing [29]. 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 [7, 23]. Rather than differences in risk attitude, risk-return models suggest that the way people perceive risk affects the choice outcomes.

To assess risk perceptions and attitude toward perceived risk in different domains of risk, Weber et al. developed the DOSPERT test and related scale [7, 8]. Six independent domains of risk 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 [30] while the fifth and sixth domains were found through analysis of survey results where the financial domain was split into investment and gambling domains [7], which were suggested in previous research [18, 31]. Risk-taking was found to be highly domain-specific between the identified domains. 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, which are consistent with risk-return based models [26]. Risk perception relates only to the extent to which a person sees risk in situations that contain uncertainty over the outcome or consequences whereas risk attitude refers to the likelihood in engaging in an activity or being in situations that contain uncertainty over the outcome or consequences. Previous risk attitude indices have been confounded by not distinguishing between the two psychological variables of risk perception and attitude toward perceived risk [32]. 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 [7].

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 [33] and with Zuckerman's sensation-seeking scale [34]. Paulhus' social desirability scale [35] 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 [36], a French-language DOSPERT scale [37], and others [8]. Other scales aiming to measure domain-dependent risk attitudes 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 [38]. Some researchers further break down uncertainty into multiple subcategories that often contain elements of risk, reliability, and robustness [39]. 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 [6]. 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 rather than simply whether the engineer perceives a situation as being risky.

To assess this behavior, the ISO 31000:2009 document for the standard of risk management was applied as the initial 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] specifically 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. 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 of risk.

3 Hypotheses and Scale Development

The first research question addressed by this paper is whether engineering risk is domain-dependent. If engineering risk is domain-dependent, then risk-adjusted utility curves should attend to the domain to which the curve is applied, and the risk adjustment should differ when considering, for example, product functionality or project completion. While the standard practice of reliability engineering is to use the expected value theorem, which dictates a risk-neutral approach, if domain differences in risk attitudes exist [7, 8], it is hypothesized that engineers will have risk attitudes that are not risk neutral and are, instead, specific to a domain of engineering risk.

Hypothesis 1. *Engineers will exhibit risk attitudes that differ by domain of risk.*

In order to test this hypothesis, the E-DOSPERT test was developed, as outlined in Section 4, based upon the ISO 31000:2009 standard for risk management. If this hypothesis is true, there will be statistically significant differences in risk attitude across domains.

The second research question concerns the domains of engineering for which engineers exhibit differences in risk attitude. For brevity, we refer to these as the domains of engineering risk. Given the importance of risk attitude for the effective implementation of a risk management framework, we based the initial E-DOSPERT test on each of the prescribed four key factors in risk management. We hypothesize four domains, which are risk identification, risk analysis, risk evaluation, and risk treatment, as defined in ISO 31000:2009. If these four are the correct domains of engineering risk, then items, that is, test questions regarding domain-specific risky activities, will load onto the appropriate factor in an exploratory factor analysis. Otherwise, other domains of engineering exist for which risk attitude will differ. Factor analysis is a statistical approach to group like items together on different dimensions. Independence between the different dimensions is achieved when the dimensions are orthogonal to one another in multi-dimensional space. Factor analysis is a statistical analysis technique that aims to explain how a number of variables are related to one another because they share one or more common factors. The analysis technique relies on identifying latent variables [40, 41].

Hypothesis 2. *Engineering risk attitude differs across the four content domains of engineering risk, which are risk identification, risk analysis, risk evaluation, and risk treatment as defined by ISO 31000:2009.*

Hypothesis 3. *Engineers have different risk attitudes across the four content domains of engineering risk.*

As the DOSPERT scale has been tested on individuals from various national cultures, we decided to examine whether engineering risk attitudes would likewise be consistent across national cultures. Engineering risk attitude data was collected from mechanical, industrial, and manufacturing engineering students at Oregon State University and students enrolled in a mechatronics program at the University of Sydney (Australia). There is no theoretical or empirical evidence to suggest that attitudes toward engineering risk would differ across national boundaries, and thus we predict that there would be no statistically significant difference in engineering risk attitudes between Australian and American engineers.

Hypothesis 4. *There are no major differences in engineering risk attitudes between Australian and American engineers.*

Finally, we confirm that the E-DOSPERT test establishes a unidimensional scale for risk attitude, ranging from risk-averse to risk-seeking. If the scale is unidimensional, then individuals would answer inversely worded paired questions consistently. That is, they would respond to a question worded as risk-seeking exactly opposite to the way that they would if the question were worded as risk-averse.

Hypothesis 5. *Engineering risk attitudes can be measured on a unidimensional scale (risk averse to risk seeking).*

In order to test Hypothesis 5, the initial version of the E-DOSPERT test contained paired inversely worded questions. A total of 25 questions were intentionally inversely phrased.

In Section 4, we present Version A of the E-DOSPERT risk-attitude scale, which consists of a number of items in the four content domains of engineering risk. In addition to addressing the first research questions and hypotheses related to the domain-dependence of engineering risk and national differences in engineering risk attitude, we document the reliability and unidimensionality of the E-DOSPERT test. We next perform an exploratory factor analysis to verify the item loadings onto the four domains. Study 2 documents Version B of the E-DOSPERT test based on the results of the exploratory factory analysis of Version A to address the second research question. The paper closes with a discussion of the significance of the research findings, implications for practitioners, and current and future research on the development of a scale for engineering risk attitude.

4 Initial E-DOSPERT Scale Development

This section documents the development of Version A of the E-DOSPERT test, 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 [42]. The authors conducted an exploratory factor analysis to determine whether the four domains identified from the ISO31000:2009 document underlie the risk behavior judgments (Hypothesis 2), to determine if engineers have engineering-specific risk attitudes that vary from the expected value theorem (Hypothesis 1 and between domains (Hypothesis 3, and to determine whether engineering students in Australia and America have similar engineering risk attitudes (Hypothesis 4). Further analysis was conducted to determine whether engineering risk attitude sub-scales are unidimensional (Hypothesis 5.

4.1 Initial Scale Development Method

Version A of the E-DOSPERT test contains survey questions (items) based upon the ISO 31000:2009 definitions of the four aspects of risk management and associated recommended activities. Questions associated with domain-specific risky activities were developed for each of the domains: risk identification, risk analysis, risk evaluation, and risk treatment. Respondents were asked to evaluate their likelihood of engaging in a risky or non-risky activity. Questions were worded such that a risk-averse activity would be based upon known best-practice and/or standards and a risk-seeking activity would violate generally accepted practices. Usefully, the ISO 31000:2009 standard provides descriptions of the types of activities that should be undertaken in an effective framework for risk management. Recommended activities, which are considered the risk-averse actions, associated with risk management become the basis for creating items in the E-DOSPERT test. Thus, if an engineer believes he/she is likely to engage in the non-risky activity, he/she would be more risk-averse, and vice-versa. In addition, the authors' knowledge of common professional mechanical and manufacturing engineering-related situations involving risk was utilized to develop items. The authors used an iterative peer-review process and limited pilot surveying in the development of the bank of questions, which is in line with standard survey development practices [7, 8]. The authors independently generated banks of candidate survey questions based upon the information found in the ISO 31000:2009 standard, critiqued one another's questions, edited the questions as they deemed necessary, and iterated upon the process until a bank of satisfactory questions was obtained. Outside review was conducted by a small group of research associates to cross-check the questions for errors and to ensure that the questions were worded as intended. A small pilot survey was conducted with the cooperation of a pool of interested graduate students and professors. Limited follow-up interviews were conducted to ensure that question meanings were correctly interpreted. Revisions to questions were made as necessary. The items in the test present respondents with typical scenarios or tasks they would encounter in relation to each of the domains of engineering risk. Their risk judgments toward these scenarios or tasks should be influenced by their risk attitude. For example, the engineer may (less risky) or may not (more risky) 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 (risky) instead of experimentation (less risky). In evaluating the risk based on this estimation, the engineer might place more weight on a regularly occurring minor fault (less risky) than a severe one that may never occur (more risky). To treat the risk, the engineer may operate the associated machinery far below the limits of safety (more risky) rather than seek repairs (less risky). The likelihood of engaging in any of these activities depends on the degree to which the engineer avoids or seeks out risk. Each domain and associated questions are briefly described below.

The risk identification portion of the ISO 31000:2009 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 Version A of the E-DOSPERT test, the original Likert scale [43] used in the DOSPERT test [7] 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", 4 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. We kept the mid-point as "not sure" to maintain consistency with the original 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 [44]. Offering both mid-point and not sure response options, termed Non-Substantive Responses (NSRs) [45], has been found to change the results of opinion surveys [46, 47]. 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 [6], 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 [6].

The Version A 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. Further, if the scales are unidimensional, Hypothesis 5 will be validated. A complete list of questions is presented in Appendix A.

The questions in the E-DOSPERT survey 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 subscales. However, for Version A of the E-DOSPERT survey, 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 constitute domains of engineering risk.

4.2 Initial Scale Implementation and Testing

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

At USyd, the participant population was comprised of undergraduate and graduate students in the Bachelor of Engineering (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.

4.3 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)*. The Shapiro-Wilks test, recommended for data sets with fewer than 2000 samples, was performed to test the normality. At the alpha = 0.05 level, the p-value for the risk averse dataset was 0.146 and the p-value for the risk seeking data set is 0.774, which indicates that we can accept that the risk-tolerant and risk-averse data sets are normally distributed. Based on a one-tailed ANOVA across the sub-scales, the means are significantly different *(p<0.001)*, meaning that the risk attitudes are domain-specific. The sub-scale means and standard deviations, and one-tailed ANOVA test clearly indicate that engineering risk attitude does exist and further that engineering risk attitudes do not follow the expected value theorem. These data strongly supports Hypothesis 1.

Table 1. Risk Averse and Seeking Means and Standard Deviations

Sub-scale	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)

Since the risk-attitude 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 [6]. 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. The authors believe this is an indication that more attention should be paid to educating engineering students on appropriate risk methods and practices.

Risk attitudes were compared between the OSU and USyd students. No statistically significant difference was found (two-tailed, independent samples t-test, Levene's Test of Equality of Variances satisfied for unbalanced population sizes), thus supporting Hypothesis 4. 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 sub-scale, 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 sub-scale. This imbalance in items is a flaw in Version A of the scale, which was addressed in Version B of the E-DOSPERT test.

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		

4.4 Initial Scale Results

Factor analysis is a statistical technique used to identify clusters of variables. In this research, it was important to investigate whether the items in the E-DOSPERT scale were measuring the underlying variables proposed in the engineering risk domains hypothesized. Several steps were taken in the exploratory factor analysis of the data collected from Version A of E-DOSPERT scale. First an exploratory factor analysis with oblique target rotation (oblimin) on the correlation matrix of the initial E-DOSPERT scale items was performed. 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 3 for the Risk Averse dimension and Table 4 for the Risk Seeking dimension [48].

Table 3. 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

Values in Table 3 and 4 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 could be composed by four sub-scales, the identified factors in the tables do not match the engineering risk domains initially proposed.

Table 4. 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

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. Thus the data supports Hypothesis 2 in that four factors are present but rejects

Hypothesis 2 that the four factors hypothesize are the correct four factors (four domains of engineering risk).

Table 5 summarizes the values of Cronbach's alpha for Version A of the E-DOSPERT test. The reliability values are shown for the Risk Averse and Risk Seeking Categories and are sufficiently high (>0.70) given the test length [49]. Table 5 strongly supports the hypothesis that risk tolerant and risk averse behavior is present in engineering risk attitude in a unidimensional scale (Hypothesis 5), and further supports the hypothesis that engineering risk attitude does not follow the expected value theorem (Hypothesis 5).

Table 5. Reliability Statistics

E-DOSPERT	Cronbach's Alpha	No of Items
Risk Averse	0.758	25
Risk Seeking	0.813	29

Table 6 summarizes the values of coefficient alpha and number of items for the initial E-DOSPERT scale under each of the originally proposed content domains. The values are shown for the Risk Averse and Risk Seeking dimensions on Version A of 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 (>0.70). This presents further evidence that Hypothesis 2 should be rejected. Respondents were consistent in answering replicated questions with nearly 100 % answering the questions in the same way.

Table 6. 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

Thus it can be concluded that the four factors originally proposed by the ISO 31000:2009 document are not the underlying domains of engineering risk.

4.5 Discussion

The results support the hypothesis that engineering risk attitude is domain-specific (Hypotheses 1, 2, and 3). The authors were able to obtain suitable reliability for at least two of the subscales, namely, risk identification and risk treatment, but not for risk analysis and evaluation. In the factor 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. This is evidence against Hypothesis 2 although analysis did show that four other potential domains of engineering risk exist.

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 were surveyed. That the students were "not sure" of their risk attitude suggests that this is an engineering awareness that should be developed.

Nonetheless, the reliability analysis allows the following conclusion about Version A of 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.

Given that the exploratory factor analysis did not show the items loading onto their respective factors, an alternative interpretation of the factors is made. An interpretation of the item-loadings in the exploratory factor analysis suggests a different set of factors, which could 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 [50].
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 [51] 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 [7] and are suggestive of the generic engineering risk to the engineer's reputation [51].

5 Revising the E-DOSPERT Test

Based upon the results of the initial E-DOSPERT scale, the authors revised, refined, and expanded the E-DOSPERT test to identify the correct domains of engineering risk, the second research question. We hypothesize six domains of engineering risk, which includes the four domains identified from Version A of the E-DOSPERT data and two additional potential domains identified from other research [50]. The six predicted domains of engineering risk include: engineering practice and processes, product functionality, legal, engineering ethics, product testing, and training. This section documents the development of Version B of the

E-DOSPERT test, its administration, analysis, and a discussion of the results.

5.1 Revised E-DOSPERT Test Development

Questions were developed for each of the six domains based upon professional engineering-related situations involving risk that practicing engineers commonly encounter. The engineering practices and processes portion of the scale is comprised of questions related to situations associated with project processes and the work of engineering. The authors consulted project management texts and professional engineering references when generating the questions. Sample questions include:

- *"not fully complying with company procedures in order to meet a project deadline"*
- *"having incomplete historical data on the performance of a component"*

The engineering ethics portion of the scale focuses on situations associated with professional and ethical engineering conduct. Classical engineering ethics case studies were reviewed for inspiration in developing the questions. Sample questions include:

- *"taking credit for work done by a colleague"*
- *"copying design work done for one client for another client"*

The testing portion of the scale focuses on product testing. The authors drew upon their backgrounds in product testing and upon relevant texts to develop questions that examine the thoroughness and completeness of testing plans. Specific attention was paid to several areas including verifying calculated data with testing. Sample questions include:

- *"not corroborating computational simulations with experimental results"*
- *"take reported product malfunctions at face value"*

The training portion of the scale was developed to examine how engineers are trained and how engineers train others. Attention was paid to new equipment, and upgraded equipment, and the need for additional training or in-depth training. Sample questions include:

- *"not providing training for upgraded machines"*
- *"not attending continuing education courses to learn new skills"*

The legal portion of the scale focused on situations associated with regulatory and legal requirements in the engineering profession and of professional engineers. Sample questions include:

- *"you are flexible about complying with engineering regulations"*
- *"not maintaining full written records of all product testing for compliance with relevant product regulations"*

The product functionality and design portion of the scale was based upon situations associated with the objectives, requirements, performance, or failure of engineered products [50]. Sample questions include:

- *"sub-contracting critical design work to a third party"*
- *"using an unknown component to perform a critical function because it less expensive than a known suitable component"*

In Version B of the E-DOSPERT test, a seven point Likert scale was used, as in the revised version of the DOSPERT test [8]. The scale ranged from 1 corresponding to "very unlikely" to 4 corresponding to "not sure" to 7 corresponding to "extremely likely." The full test is provided in Appendix B, with the questions ordered randomly.

Version B questions of the E-DOSPERT were all phrased in a manner similar to Version A. The authors intentionally did not include the consistency check of inversely worded questions that were present in Version A of the E-DOSPERT because the analysis of Version A of the E-DOSPERT scale already supported Hypothesis 5. Based upon the results of Version A of the E-DOSPERT scale and similar research [8], inversely worded questions are not needed to show that the factors are bidimensional (risk tolerant to risk averse). The questions were developed with the goal of being national origin independent. In other words, the questions relate to engineering matters that are expected to occur anywhere. A total of 65 questions were tested. The number of items can be reduced in future versions of the E-DOSPERT test. This large set of questions and resulting data allows exploratory factor analysis to be performed to determine if the six proposed factors are present or if other factors underlie risk behavior judgments.

5.2 Revised Scale Implementation and Testing

Version B of the E-DOSPERT test was administered to undergraduates and graduate students at OSU. The survey was administered using SurveyMonkey. Prior to full testing, the survey was administered to several small groups of students and researchers in order to validate and refine the questions.

The participant population was comprised of graduate and undergraduate students enrolled in courses or associated with in the School of Mechanical, Industrial, and Manufacturing Engineering. In total, 206 students responded. The age range was from 19 to 43, averaging 22 years old. A total of 22 women and 184 men responded to the survey. The administration of the survey and its contents were approved by the OSU Institutional Review Board.

5.3 Revised Scale Results

Factor analysis was performed on the resulting data in a manner similar to Section 4.4. An exploratory factor analysis with oblique target rotation (oblimin) and Maximum Likelihood Extraction (MLE) [52] was performed. The Kaiser-Meyer-Olkin (KMO) was sufficiently high (0.795) and Bartlett's test of sphericity was significant (<0.05) allowing factor analysis to proceed. Based upon the number of hypothesized sub-scales, a six factor model was specified. A six factor model explained 43.696% of the variance in the scale. Several iterations of purging items that loaded poorly or onto multiple factors and verifying item communalities were performed. However, the analysis ran into ultra-Heywood cases. This led the authors to reexamine the supposition of a six factor model. The scree plot indicated that a five factor model might also be present. A five factor model explained 40.617% of the variance in the scale. Several iterations of removing poorly loaded items and verifying communalities was performed. The resulting scale has a KMO of 0.806 and Bartlett's test of sphericity was significant. The goodness-of-fit test was not significant indicating that the model is a good match to the data. Table 8 provides additional statistics for the full scale. Table 7 presents the five factors that were identified and the associated values. Table 9 shows the reliability of each factor that was identified.

Table 7. Factor model structure for revised E-DOSPERT

	Component				
	1	2	3	4	5
Not documenting every single step that was taken to design a new component (PnP)	.740				
Not fully complying with company procedures in order to meet a project deadline (PnP)	.667				
Having incomplete historical data on the performance of a component (PnP)	.626				
Not having complete data on the probability of failure for each component in a system (PFnD)	.560				
Copying design work done for one client for another client (E)	.445				
Exaggerating your company's competencies in order to win a contract (E)		.813			
Accepting a weekend holiday(vacation) from potential contractors (E)		.612			
Use consumable work resources for home projects (E)		.543			
Reverse engineer a competitor's technology with the intent to bring to market a nearly identical copy (E)		.470			
Protect your client's confidentiality by not reporting to a regulatory agency a negligent behavior by the client (E)		.433			
Not giving much consideration about whether the product can be recycled or disposed of in a safe, secure and environmentally sound manner (E)		.428			
Not attending compulsory formal training for new machines (T)			-.778		
Not providing training for upgraded machines (T)			-.691		
Not following standard operating procedures systematically (PnP)			-.497		
Not investigating a suspected design flaw because you don't think it is likely to happen (PT)				.620	
Using an unknown component to perform a critical function because it less expensive than a known suitable component (PFnD)				.520	
Relying upon the risk management practices you learned at university rather than regular continuing education on new risk management techniques (T)				.513	
Going into detailed design with the first design concept you came up with (PFnD)				.441	
Verifying that your product is in compliance with all applicable environmental, health, and safety laws and regulations (L)					.590
Glance at the operating procedures for a new product prior to use (T)					.566
Placing higher emphasis on legal, regulatory, and other requirements over operating profitability (L)					.436

Note: (E) = Ethics, (PT) = Product Testing, (PFnD) = Product Functionality and Design, (L) = Legal, (PnP) = Processes and Procedures, (T) = Training. This represents the proposed six factors of engineering risk attitude.

Table 8. Scale Statistics

Mean	Variance	Std. Dev.	N	Cronbach's Alpha
73.02	188.074	13.714	21	0.800

Table 9. Factor Reliability

Factor	Cronbach's Alpha	N of Items
Factor 1	0.759	4
Factor 2	0.750	6
Factor 3	0.699	3
Factor 4	0.638	4
Factor 5	0.521	3

5.4 Discussion

The results of Version B of the E-DOSPERT analysis show strong evidence of a five factor scale. The authors were able to obtain suitable reliability for Factors 1 and 2 where Cronbach's alpha was significant (>0.70) [41] and marginal reliability for Factors 3 and 4 (>0.60) [40]. The reliability of Factor 5 is low, but there is evidence that a fifth factor exists. Based upon an interpretation of the items loading onto the five factors, the authors propose the following set of factors, or domains of engineering risk:

1. Processes, Procedures, and Practices: all five of the questions relate to the best processes, procedures, and practices that an engineer should follow in their professional lives.
2. Engineering Ethics: All six questions are based upon ethical dilemmas encountered by practicing engineers.
3. Training: The three questions that loaded onto Factor 3 relate to conducting training and following guidance given by training.
4. Product Functionality and Design: The four questions that loaded onto Factor 4 relate to the functionality and design of products.
5. Legal Issues: Two of the three questions that load onto Factor 5 relate to legal issues.

Additional analysis was conducted to verify that higher numbers of factors were not present. No additional interpretable factors appear in the data. While the pool of participants was lower than desired (N=206) and the reliability of several factors was lower than ideal, the evidence points toward a five factor model of domains of engineering risk. These five domains are consistent with factors predicted by the authors by other researchers. Further replication of the test should be performed with other sample populations to confirm and further strengthen these findings. A combined sample population in excess of N>400 is desireable [7].

6 E-DOSPERT Applications

The E-DOSPERT test in its current form and in future revisions is useful to the practitioner and researcher for several reasons. First, administering an E-DOSPERT test to an engineer can provide valuable insight into how that engineer will behave in engineering risk situations. This allows for targeted training to be given to the engineer in order to correct for any differences in engineering risk attitude from what the position requires.

Second, the E-DOSPERT could be used as part of a hiring process. Already many companies administer personality type tests such as the Meyers-Briggs Type Indicator (MBTI) [53] and others. With a proper understanding of the results of an E-DOSPERT test, hiring managers can be expected to make more informed choices on hiring engineers.

Third, stakeholder risk preference can be collected using the E-DOSPERT. Rather than requiring stakeholders to be present to provide input on their engineering risk attitude, design engineers can refer to the stakeholders' E-DOSPERT scores. This can be expected to save time and produce results more in line with what the stakeholders intrinsically desire.

To enable use in practice, a method can feasibly be developed based upon the E-DOSPERT survey to translate expert opinions from individual scales to a normative scale. In other words, judging the risk of a product failure on a scale of 1 to 10 might elicit a response of 7 from one expert and a response of 5 from another. Those two different numbers might simply be the result of different internal scales. Normalizing those expert opinions using the E-DOSPERT might result in the discovery that both experts mean the same thing.

Another area that is already being actively developed is using E-DOSPERT test results to generate utility risk functions. These utility risk functions can then be used to analyze early conceptual system design trade studies that contain risk as a tradeable parameter. Decision aids and decision automation can also take place using utility risk functions generated from E-DOSPERT results as shown in prior work [54].

7 Conclusion

This paper presented the development of a psychometric engineering risk-attitude test, the E-DOSPERT scale, to measure the risk aversion and risk seeking attitudes of engineers. Version A of the E-DOSPERT scale was first presented to test 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 suggested four other factors that may underlie the risk behavior judgments. Based upon further insight into the data, an additional two potential domains were added. Version B of the E-DOSPERT scale was then developed and tested.

Items in the revised E-DOSPERT scale are based on commonly encountered engineering risk scenarios and scenarios based in risk management. The results show that the scale is suitably reliable to measure engineering risk attitude in two domains including processes, procedures, and practices (five items); and engineering ethics (six items). The scale is marginally suitable to measure engineering risk attitude in two additional domains including training (three items), and product functionality and design (four items). A fifth domain, legal issues (two items), appears to be present but is not statistically reliable. The Version B E-DOSPERT scale is suitably reliable to measure general engineering risk aversion and risk tolerance.

In practice, the Version B E-DOSPERT scale can be used to assess engineering risk attitudes toward processes, procedures, and practices and engineering ethics; at the option of the practitioner, two additional domains including training, and product functionality and design may be assessed. Product functionality and design items could be reworded to relate to the industry context of the surveyed individuals, which may result in more reliable results. The authors suggest that users of the scale remove or refine items on legal issues domain in Version B of the scale. In future work, the authors will revise wordings on items in the training, product functionality and design, and legal sub-scales. A goal of six highly weighted items per sub-scale is targeted to ready the E-DOSPERT scale for unrestricted use by practitioners. Additional testing of the survey will be performed over larger sample populations to gain further statistical validity. Tests at multiple universities and in multiple countries will be performed. An examination of the role that educational level and engineering professional experience play will be examined in forthcoming research. A survey of engineers in different industries will be conducted in order to understand variation between industries and sub-disciplines. After further vetting, the E-DOSPERT will be made available in multiple languages. Once these further steps are taken, such an instrument can then be used as a standard to assess domain-specific engineering 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 in different domains of engineering risk.

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Appendix A: Version A of the E-DOSPERT Scale

Version A of the E-DOSPERT test presented in Appendix A 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

Appendix B: Version B of the E-DOSPERT Scale

Version B of the E-DOSPERT test presented in Appendix B 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	Moderately Unlikely	Somewhat Unlikely	Not Sure	Somewhat Likely	Moderately Likely	Very Likely
1	2	3	4	5	6	7

1. Accepting a weekend holiday(vacation) from potential contractors (E)
2. Adding many extra features to a product beyond original specifications (PFnD)
3. Assuming unfavorable test results from an early production prototype will improve after the next prototype is constructed (PT)
4. Certify a document as a qualified, professional engineer that is outside of your area of expertise (E)
5. Competent professional engineers need not be registered with a professional body that regulates appropriate professional practice (L)
6. Comply with your supervisor's instruction to withhold information from a client (E)
7. Consult the professional engineering code of conduct regularly (L)
8. Contracting product testing to a specialist outside firm (PT)
9. Copying design work done for one client for another client (E)
10. Designing a product in a manner that emphasizes profitability over protecting the environment, and the health, safety and security of end-users (E)
11. Developing only general but not detailed operation guidelines for a piece of equipment (PnP)
12. Disregarding the company Standard Operating Procedures on design processes when starting a new design (PnP)
13. Exaggerating your company's competencies in order to win a contract (E)
14. Glance at the operating procedures for a new product prior to use (T)
15. Going into detailed design with the first design concept you came up with (PFnD)
16. Having incomplete historical data on the performance of a component (PnP)
17. Including a component in a product for which there is only one supplier (PFnD)
18. Investigating product failures only when you think it is important (PT)
19. Leave it up to your customers to decide if they want to receive training on the safe operation of your product (T)
20. Let your workgroup discover new industry standards on their own (T)
21. Making decisions based on personal experience and intuition rather than evidence (PnP)
22. Not actively seeking information about the patent law in countries where you are operating (L)
23. Not assessing failure risk for incremental changes to a product (PFnD)
24. Not attend continuing education courses to learn new skills (T)
25. Not attending compulsory formal training for new machines (T)
26. Not consult legal counsel on how to proceed if accused of improper conduct related to an engineering matter (L)
27. Not corroborating computational simulations with experimental results (PT)
28. Not documenting every single step that was taken to design a new component (PnP)
29. Not following standard operating procedures systematically (PnP)
30. Not following the exact manufacturer-recommended maintenance strategies (PnP)
31. Not formally benchmarking your product against competing products (PFnD)
32. Not fully complying with company procedures in order to meet a project deadline (PnP)
33. Not fully understanding the limitations of "canned" calculations prior to using them (PT)
34. Not giving much consideration about whether the product can be recycled or disposed of in a safe, secure and environmentally sound manner (E)
35. Not having an independent person or department audit quality assurance programs (PnP)
36. Not having complete data on the probability of failure for each component in a system (PFnD)
37. Not investigating a suspected design flaw because you don't think it is likely to happen (PT)
38. Not maintaining full written records of all product testing for compliance with relevant product regulations (L)
39. Not providing training for upgraded machines (T)
40. Not testing a product for functionality beyond its intended purposes (eg: using a hammer handle as a lever) (PT)
41. Offer no follow-up, refresher training on how to operate equipment (T)
42. Placing higher emphasis on legal, regulatory, and other requirements over operating profitability (L)
43. Protect your client's confidentiality by not reporting to a regulatory agency a negligent behavior by the client (E)
44. Rely only upon the manual of a new product that your company is deploying to learn safe operating procedures (T)
45. Relying on unwritten knowledge rather than documenting minor changes to procedures (PnP)
46. Relying upon computer simulation models to predict product failure modes without confirming by empirical testing (PT)

47. Relying upon the risk management practices you learned at university rather than regular continuing education on new risk management techniques (T)
48. Reverse engineer a competitor's technology with the intent to bring to market a nearly identical copy (E)
49. Seeking legal counsel about tort(liability) laws that might have an impact on your product (L)
50. Selling a product claiming high reliability based upon calculations but without extended field testing to back up the computational models (PT)
51. Staying quiet about your company's cover up of a significant design flaw (E)
52. Sub-contracting critical design work to a third-party (PFnD)
53. Take reported product malfunctions at face value (PT)
54. Taking credit for the work done by a colleague (E)
55. Use consumable work resources for home projects (E)
56. Using a new technology with better functionality but that has a higher failure rate than a current technology (PFnD)
57. Using an unknown component to perform a critical function because it less expensive than a known suitable component (PFnD)
58. Verifying that your product is in compliance with all applicable environmental, health, and safety laws and regulations (L)
59. When serving as an expert witness, letting your previous experience with one of the litigating companies influence your testimony on the resolution of a dispute of a technical matter (E)
60. Withhold information from the general public about risks associated with a specific technology that is relevant to the public's health and welfare (E)
61. You are flexible about complying with engineering regulations (L)

Note: (E) = Ethics, (PT) = Product Testing, (PFnD) = Product Functionality and Design, (L) = Legal, (PnP) = Processes and Procedures, (T) = Training.