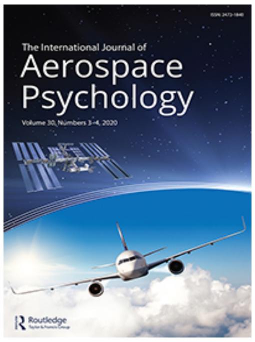

The International Journal of Aerospace Psychology

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/hiap21

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To cite this article: Tevfik Uyar & Mahmut Paksoy (2020) Framing Effect in Safety Risk Probability Assessment: A Prospect Theory Approach, The International Journal of Aerospace Psychology, 30:3-4, 119-129, DOI: 10.1080/24721840.2020.1774379

To link to this article: https://doi.org/10.1080/24721840.2020.1774379

Published online: 16 Jun 2020.

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THE INTERNATIONAL JOURNAL OF AEROSPACE PSYCHOLOGY
2020, VOL. 30, NOS. 3–4, 119–129
https://doi.org/10.1080/24721840.2020.1774379

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Framing Effect in Safety Risk Probability Assessment: A Prospect Theory Approach

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ABSTRACT

Objective: To understand the relationship between the presentation of risk expressions in terms of loss/gain and safety personnel's evaluation of risk probability in the context of prospect theory.

Background: One of the major topics of behavioral economics is the issue of decision-making under uncertainty, and prospect theory is the most prominent theory in the field. This theory claims that individuals' perceptions of losses are more severe than their perceptions of gains, and thus, the utility–value function is not symmetrical.

Method: Two studies (N = 39 and N = 49) were performed in which business aviation safety professionals were asked to assess several risk expressions. In each study, subjects were divided into two groups. One group assessed unframed risk events, while the other assessed positively framed ones. Average probability values of each group were compared to each other, in order to understand whether framing caused a shift in risk assessment.

Results: Positively framing the risk expressions caused risk assessors to focus on threats instead of existing measures and to show "risk aversion" for two out of five risks – notably, the two related to human factors.

Conclusion: These results show that prospect theory predictions regarding decision-making under uncertainty may not be limited to financial decisions and can be extended to safety risk assessment.

Background

The International Civil Aviation Organization (ICAO), the leading regulator for the aviation industry, mandates all airline operators of its member states to implement a safety management system (SMS) as part of the State Safety Programme (ICAO, 2013a). This framework is described in the Safety Management Manual (SMM), which was also published as a guideline by ICAO (2013b). The SMM describes what a safety risk is and recommends measuring it by multiplying the probability of a risk event and the severity of its consequences. Both probability and severity values are selected from 5-degree scales (1–5 for probability, A–E for severity) and these values combined to obtain the risk level (For example, 3 and A becomes 3A). Then, the resulting risk classifications are classified as acceptable, tolerable (requires mitigation and monitoring until it is reduced), or unacceptable (Table 1). Operators mitigate tolerable and unacceptable risks by developing corrective and preventive actions that decrease the risk level by reducing the probability of the event and/or the severity of its consequences.

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Table 1. Safety risk assessment matrix.

Risk Probability		Risk Severity				
		Catastrophic A	Hazardous B	Major C	Minor D	Negligible E
Frequent	5	5A	5B	5C	5D	5E
Occasional	4	4A	4B	4C	4D	4E
Remote	3	3A	3B	3C	3D	3E
Improbable	2	2A	2B	2C	2D	2E
Extremely improbable	1	1A	1B	1C	1D	1E

Note: Adapted from Safety Management Manual (pp. 2–29) *by* ICAO (2013b). Risk values in dark gray region (3A, 4A, 4B, 5A, 5B, 5 C) are considered "Unacceptable." The light gray region shows "Tolerable Risk" and the white region "Acceptable Risk" values.

Probability is one of the two components of risk. According to ICAO (2013b), "Safety risk probability is defined as the likelihood or frequency that a safety consequence or outcome might occur." When there are sufficient data, probability may be assessed rationally because the uncertainty is low. However, if the available data are insufficient, the uncertainty would be high, and the process would lead to an irrational result. Risk assessment is a decision-making process, and the safety management system aims to make this process more rational, leading to a realistic calculation of risks. Nonetheless, key safety personnel must sometimes make intuitive risk assessments under conditions of high uncertainty, leading their evaluation of likelihood to be prone to error. Indeed, ICAO's SMM does not present a clear solution for probability assessment in low-data, high-uncertainty conditions, and assumes that the risk assessors are unbounded rational decisionmakers (Uyar, 2019).

The problem of decision-making under uncertainty is the core topic of behavioral economics, and the Cumulative Prospect Theory (CPT) is the most influential theory in the field. In groundbreaking work on this topic, Kahneman and Tversky (1979) found that the utility curve is not symmetrical; instead, it is steeper for losses than gains. In other words, the perceived utility of losses is more severe than the perceived utility of gains (Figure 1), in contrast with expected utility theory, which suggests that this curve is symmetric.

Tversky and Kahneman originally demonstrated this phenomenon with a series of simple but convincing experiments. Both the creators of the theory and other behavioral economics researchers contributed to the theory over time, and Tversky and Kahneman (1992) made modifications to its original form, resulting in cumulative prospect theory (CPT), the most influential theory in this area of behavioral economics.

CPT predicts four phenomena affecting an individual making decision under risk (as reviewed in Barberis, 2012): First, that perceived utility depends on gains and losses derived from a point of reference rather than an absolute point. This tendency is called *reference dependence*. Second, individuals are more sensitive to losses than to gains of the same amount (*loss aversion*). Third, in contrast to loss aversion, when faced with high-probability gains, people lean toward being risk averse. This tendency is called *diminishing sensitivity* (or *risk aversion*). Finally, individuals do not weigh consequents by their objective and absolute probabilities; instead, they rely on a psychologically transformed probability curve that overrates extreme probabilities and outcomes.

Each of these phenomena has been demonstrated with numerous experiments (e.g., Druckman, 2001; Gonzalez & Wu, 1999; Harbaugh et al., 2002; Kahneman et al., 1990; Knetsch & Sinden, 1984). In fact, its neural origin has also been identified (Tom et al., 2007),

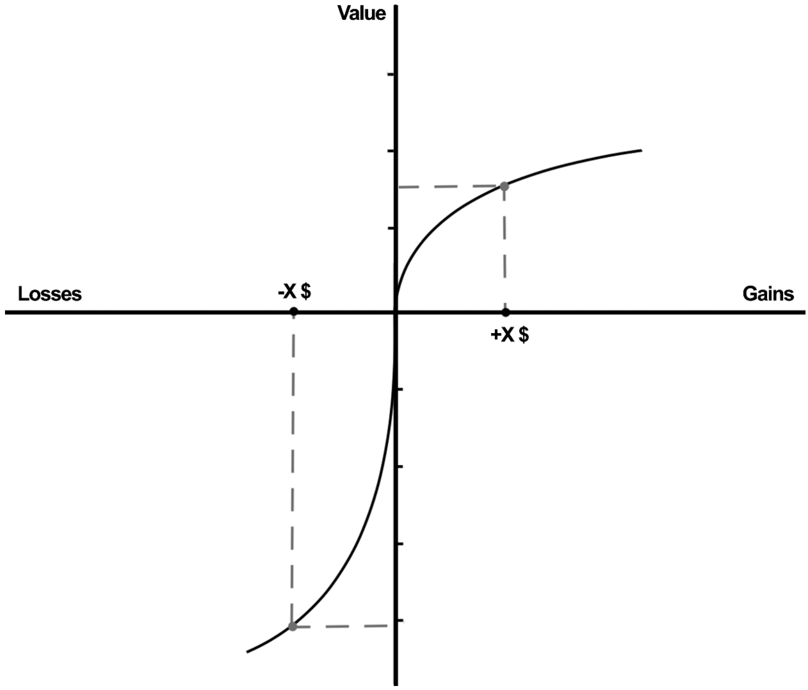

Figure 1. A hypothetical value function, adapted from Tversky and Kahneman (1981).

and found to be in effect even in monkeys, indicating it has an evolutionary basis (Lakshminarayanan et al., 2011).

The main core of prospect theory can be interpreted as meaning that people tend to prefer "more certain" choices while gaining (risk aversion) but continue to seek risk while losing (loss aversion). Accordingly, this theory predicts that framing a choice in terms of gains and losses may create a shift in the preference of decision-makers. In other words, the psychological principles that govern the interpretation and analysis of chances and outcomes create predictable, preferential changes when the same problem is presented in different ways (Tversky & Kahneman, 1981).

To prove that experimentally, Tversky and Kahneman (1981) asked two separate groups the same question with options framed in a manner similar to risk assessment problems. The problem was, "Imagine that the U.S. is preparing for the outbreak of an unusual Asian disease, which is expected to kill 600 people. Two alternative programs to combat the disease have been proposed. Assume that the exact scientific estimate of the consequences of the programs are as follows. Which of the two programs would you favor?" (Tversky & Kahneman, 1981). The first group (N = 152) was presented with the following options:

> If Program A is adopted, 200 people will be saved.
>
> If Program B is adopted, there is 1/3 probability that 600 people will be saved, and 2/3 probability that no people will be saved.

The second group (N = 155) was presented with the following options:

> If Program C is adopted 400 people will die.
>
> If Program D is adopted there is 1/3 probability that nobody will die, and 2/3 probability that 600 people will die.

Each option has the same *expected value*; the options for Program A & C and Program B & D were identical except in the manner of description of the outcome (the former describing people would "be saved" and the latter the likelihood people "will die"). Nevertheless, the majority of the first group behaved in a risk-averse manner by choosing Program A (72%); surprisingly, though, the majority of the second group showed loss aversion by selecting Program D (78%). The authors referred to this shift as the "framing effect," meaning the change in preference resulting from re-structuring the sentences (without changing their expected value) to emphasize either losses or gains.

Tversky and Kahneman (1992) suggested that actors weigh options according to a reference frame that is assumed by them to be neutral, and that therefore their preferences may shift according to how positive or negative their base framing perception is. As established above, this phenomenon has been well tested and illustrated often with monetary decisions, but to the best of our knowledge, its consequences for safety management have not been studied before. The original prospect theory experiments were performed with financial or gambling problems, involving a choice between alternative outcomes with known probabilities, as seen above. Therefore, the rationality (or optimality) of the decision can be evaluated by comparing the expected values of the preferred and not-preferred options.

In contrast, a risk probability assessment problem does not include probability information. Instead, decision-makers are asked to assess the probability of the known possible outcomes. In other words, it is not a problem of a "choice between alternatives." Nevertheless, risk statements can be framed in this context, and the effects of the framing can be measured by comparing the assessments of different groups.

In this study, we tested the effect of framing on risk probability assessment, part of the formal safety management method suggested in the ICAO SMM. We have indeed found a significant effect of framing on risk assessment.

Method

Objective and Assumptions

We sought to measure the effect of framing on risk probability assessment, which is part of formal safety management methods, with the following assumptions:

First, a safety risk assessor is a person placing a bet on a risk event. If he/she underestimates the risk of a particular event, this underrating will lead to imprudence and accidents. Hence, there is a strong similarity between an economic actor (making monetary decisions) and risk assessor (making safety decisions) when a decision is made under conditions of uncertainty. Second, a risky event statement is a "loss statement" because it is expressing an undesired consequence. To make it a "gain statement," which consists of positive terms, its structure can be converted to "Occurrence of event not-X" or "Nonoccurrence of event X."

These two assumptions lead to the conclusion that framing can result in risk-averse conduct, which means that when framed, people are more cautious and predict a higher probability implicitly for a specific event.

Hypothesis and Data Collection

Mathematically, if the probability of an X event is "*P*," then the probability of the event not-X (X') is "1-*P*." When there is no uncertainty and subjectivity, under fully rational decision-making conditions – for example, with the presence of full, reliable data on the likelihood of an engine part failure, the probability of occurrence of this failure can be measured; for the sake of illustration, assume the probability is 0.002. Then, the nonoccurrence probability can be inferred from this number by simply subtracting the probability value from one (in this example, resulting in 0.998).

If the uncertainty created by a lack of data does not affect the safety risk assessment process, there will not be any significant difference between the assessed probability of an X event and its complement (not-X event), just as in the example of engine failure data. However, if prospect theory is in effect, there must be a difference. Hence, the hypothesis tested in this study:

H_0: *There is no significant difference between the probability assessment of the unframed and framed expression of the same risky event.*

We have conducted two studies to test this hypothesis. The first was a pilot study, which included only one event for pre-assessment, checking the clearness of our approach and attempting to understand respondents' reasons for their responses. The second study included five events and was performed to gather more data for hypothesis testing.

The respondents in this research were business aviation professionals involved as key personnel in safety management. In each study, we presented two groups two different forms of risk assessment: One group was given unframed event statements, while the other was given framed event statements. Framing was done in three ways: (i) by adding "not" to the unframed risk expression (not-X event, a positive expression since X is an undesired event), (ii) by using the antonym of X's verb and (iii) by restructuring the expression to refer to the complement of event X. Respondents were asked to express their probability estimation on a 5-point scale, as recommended by the ICAO SMS. To prevent ambiguity and assist the respondents, the 1- and 5-point fields on the scale were labeled "very low" and "very high" (Table 2).

Table 2. General structure of risk probability assessment forms.

	Probability Scale (1–5)				
Group A: *Please select the probability of the (undesired) X event*	(Very Low) 1	2	3	4	(Very High) 5
Group B: *Please select the probability of the (desired) not-X event (or Y event)* *(Which Y event: Framed-X* *by using the antonym of the verb in the X event* *OR* *by restructuring the statement to express the complement of X event)*	(Very Low) 1	2	3	4	(Very High) 5

Results

Study 1 (Pilot Study)

We first performed a pilot study that asked just one question of business aviation professionals involved in safety management. Respondents were selected from a list of business jet operator safety managers obtained from Turkish Directorate General of Civil Aviation (Turkish DGCA). We chose business jet operators because they generally operate a small fleet with low flight hours, and the volume and accuracy of the data they generate is inadequate for accurate statistical inference (Uyar, 2019). In other words, they operate under constant conditions of high uncertainty.

The questionnaire was made up of three questions:

(1) What is your title in your company?
(2) Consider that you are evaluating the risk of oil leaks from the undercarriage. Please assess the following by selecting the best number from the 5-point scale:
  - (For Group A) The probability a pilot or technician CANNOT FIND the oil leak during the preflight check (5-point scale, as shown in Table 2).
  - (For Group B) The probability a pilot or technician CAN FIND the oil leak during the preflight check (5-point scale, as shown in Table 2).
(3) Please describe the reasons for your choice in 1 or 2 sentences.

Both versions of questionnaire were created using *Survey Monkey* (Survey Monkey, n.d.) and the link was e-mailed to 40 safety managers. They were asked not only to fill in the form but also to share the link with other key safety personnel working at their company and taking part in safety management. Respondents were randomly distributed between groups by the system. Group A (N = 22) was presented with the unframed questionnaire, while Group B (N = 17) was presented the framed one. Risk expressions for the pilot study were framed by using the "CANNOT/CAN" contrast. The responses are summarized in Table 3.

To compare the two groups' responses, the framed results must be inversed by taking its mirror symmetric positions on the 5-point risk scale. For example, if a respondent from Group B selected the option "1 (Very Low)" for the not-X event, it would be interpreted as "5 (Very High)" for event X. Similarly, "2" is converted to "4," but "3" is not converted, since it is the middle value (note that results are reported without mirroring in Tables 3 and 6, while the average values of inverse results are indicated in parentheses).

Evaluation of the Group A responses revealed that respondents thought the probability that a pilot or technician could not find an oil leakage during the pre-flight check was very

Table 3. Distribution of risk assessments in pilot study.

Group A (Unframed)										
1 (Very Low)		2		3		4		5 (Very High)		Mean
13	59.09%	6	27.27%	3	13.64%	0	0.00%	0	0.00%	1.55
Group B (Framed)										
1 (Very Low)		2		3		4		5 (Very High)		Mean
0	0.00%	0	0.00%	7	41.18%	5	29.41%	5	29.41%	3.88 (2.12*)

* Inverted mean values are indicated in parentheses.

low (mean 1.55). The mean group B response was 3.88, meaning that the group indirectly assessed the same probability: 2.12 (when inverted).

Due to the small sampling size, non-parametric statistical tests were needed. We tested the normality of our sample with Kolmogorov–Smirnov and Shapiro–Wilk tests and confirmed that it was not normally distributed. Because the scale was ordinal, we used the Mann–Whitney U test to determine whether the difference between the groups was significant and found that the framing effect significantly increased the perceived probability of this event ($p < .05$).

We then analyzed the respondents' explanations and classified them as Positive or Negative according to the following criteria:

For Group A (... CANNOT FIND):

- **Positive (+)**: Explanation for low probability assessment of failure due to positive measures (Such as "I think he/she is more unlikely to fail because of [positive aspects]").
- **Negative (-)**: Explanation for high-probability assessment of failure due to negative measures (Such as "I think he/she is more likely to fail because of [negative aspects]").

For Group B (... CAN FIND):

- **Positive (+)**: Explanation for high-probability assessment of success due to positive measures (Such as "I think he/she is more likely to succeed because of [positive aspects]").
- **Negative (-)**: Explanation for low probability assessment of success due to negative measures (Such as "I think he/she is more unlikely to succeed because of [negative aspects]").

In this context, we have categorized all responses as positive or negative (Table 4). One of the answers was unclear (a normative phrase like "Pre-flight check is done and had to be done") and it was excluded.

These explanations were important to understand how respondents rationalize their preferences, which could be a key factor to match the preference with the loss/risk aversion behaviors. According to our inferences from prospect theory, framing (by positive terms) must create risk aversion behavior which manifests itself by deciding that the probability of positive event is low because of focusing to the negative aspects (means preferring high probability for an undesired event indirectly).

We confirmed with chi-square and Mann–Whitney U tests that responses to Group B were less positive than Group A ($p < .05$); Group B respondents were indeed more cautious and risk-averse.

This difference may have resulted from the risk-assessor's desire to falsify the expression, in order to behave in an independent and rational manner. In other words, Group A respondents

Table 4. Distribution of classified responses to question regarding the reasoning behind the opinion of likelihood.

	Positive	Negative	Total
Group A (... Cannot Find)	17 (77.27%)	5 (22.73%)	22 (100%)
Group B (... Can Find)	7 (43.75%)	9 (56.25%)	16 (100%)

may have tried to falsify the claim that the "pilot or technician will not find the oil leakage," and therefore may have focused on current measures. Therefore, their reasoning may have been built on strengths, which decreases the likelihood of this undesired consequence. On the other hand, Group B respondents may have focused on threats that falsify the claim that the "pilot or technician will find the oil leakage," and their reasoning may have been built on the weaknesses perceived by these respondents. It can be speculated that thinking of weaknesses rather than strengths causes a more cautious attitude and risk aversion. The pilot study showed us that framing can be effective in likelihood perception. To rigorously test and confirm this tendency, we designed a new study including questions about additional risky events.

Study 2

In the second study, the previous participants' list was extended with 30 new key aviation safety personnel gathered from various industrial resources. The questionnaire was modified by removing the question asking respondents to describe their reasoning and by adding questions asking respondents to assess the risk of four additional events (Table 5). The risk assessment question used in the pilot study was retained, with a minor modification (the use of a "missing/finding" contrast instead of "cannot/can"). Seven months passed between the two studies to ensure that respondents exposed to both questionnaires forgot their responses from the pilot.

We selected a variety of events with different properties. The first (E1) and fifth (E5) events were directly related to human factors. It was clear from the pilot study that the framing was significantly effective on the first event; therefore, we added a similar but potentially more probable event to this questionnaire (E5). E2, E3, and E4 asked about technical and environmental issues, and E2 was expected to involve lower uncertainty than the others because its risk is strictly technical, with no human element.

In total, 49 voluntary responses were collected from Groups A and B (N = 24 and N = 25, respectively) with the responses distributed as shown in Table 6.

The first event was the same as in the pilot study. We again found that framing significantly increased the perceived risk of missing an oil leak during the pre-flight check ($p < .01$). It is notable that the average risk attached to this event in its unframed form is almost identical to that of the pilot study (1.55 & 1.58), though the significance of the difference increased in Study 2 ($p < .05$ vs. $p < .01$).

The second event (E2) was a potential engine failure on take-off (EFTO) and framed by restructuring the sentence in order to obtain its complement event. Both groups of

Table 5. Unframed and framed forms of risk expressions.

	Unframed (Negative Risk Expressions)	Framed (Positive Risk Expressions)
E1	The probability of a pilot or technician MISSING an oil leak during pre-flight check ...	The probability of a pilot or technician FINDING an oil leak during pre-flight check ...
E2	The probability of HAVING A CRITICAL ENGINE FAILURE during take-off ...	The probability of TAKING OFF WITHOUT A CRITICAL ENGINE FAILURE ...
E3	The probability of someone BEING INJURED during severe turbulence ...	The probability of GETTING OVER severe turbulence without any injuries ...
E4	The probability of ENCOUNTERING BIRDS during final approach ...	The probability of completing final approach WITHOUT ENCOUNTERING BIRDS ...
E5	The probability of a pilot or technician MISSING A CHECKLIST ITEM while experiencing fatigue ...	The probability of a pilot or technician COMPLETING A CHECKLIST PRECISELY while experiencing fatigue ...

Table 6. Distribution of risk assessments for unframed and framed expressions.

	Group A (Unframed)										
	1 (Very Low)		2		3		4		5 (Very High)		Mean
E1	12	50.00%	10	41.67%	2	8.33%	0	0.00%	0	0.00%	1.58
E2	12	50.00%	9	37.50%	3	12.50%	0	0.00%	0	0.00%	1.63
E3	5	20.83%	7	29.17%	8	33.33%	3	12.50%	1	4.17%	2.5
E4	7	29.17%	7	29.17%	9	37.50%	1	4.17%	0	0.00%	2.17
E5	2	8.33%	6	25.00%	8	33.33%	6	25.00%	2	8.33%	3
	Group B (Framed)										
	1 (Very Low)		2		3		4		5 (Very High)		Mean
E1	1	4.00%	3	12.00%	9	36.00%	8	32.00%	4	16.00%	3.44 (2.56)*
E2	1	4.00%	1	4.00%	10	40.00%	2	8.00%	11	44.00%	4.04 (1.96)
E3	6	24.00%	2	8.00%	5	20.00%	7	28.00%	5	20.00%	3.12 (2.88)
E4	1	4.00%	3	12.00%	6	24.00%	10	40.00%	5	20.00%	3.60 (2.40)
E5	6	24.00%	9	36.00%	6	24.00%	4	16.00%	0	0.00%	2.32 (3.68)**

* p <.01. **p <.05. Inverted mean values are indicated in parentheses.

respondents assessed this event's probability as low – as was expected from aviation experts. However, one respondent rated the probability of taking off without a critical engine failure as "very low," which seems like an anomaly for aviation personnel. Though this response appeared to be an outlier, and reduced the significance of the difference, it was retained.

The third event (E3) was built on the potential of being injured during severe turbulence. Severe turbulence can often be foreseen thanks to en-route meteorology information and avionics; everyone onboard may receive early warning of potentially turbulent periods. Nonetheless, there may still be occasional unexpected severe turbulence. Thus, these responses were widely distributed, but there was no significant difference between the two groups.

The fourth event (E4) was about the potential for a bird encounter during final approach. Responses from the two groups were remarkably similar, as shown in Table 6, with no significant difference between the two groups.

The fifth event (E5) was about fatigue, currently one of the most common factors contributing to aviation accidents. It was assessed as the most probable event of this study by both groups. No respondent chose "very high" when the question was framed, and no respondents indicated high odds of completing a checklist precisely when fatigue is in play. However, Group B found the event significantly more probable ($p < .05$).

Conclusion

Remarkably, significant differences between respondents for two groups with different framings were observed only for the events related to human factors (E1 & E5). Aviation personnel receives more training about human factors than those in any other industry, and therefore might feel more uncertainty about these events – or at least may be aware that human factors contribute to the uncertainty of such events. In contrast, purely mechanical events (e.g., E2) might be deemed "known risks," with a profoundly low uncertainty level, because there are clear technical statistics about such events provided by the manufacturers. As expected, the assessed probability of E2 was as low as for E1, but unlike for E1, the framed version of E2 was not more found more probable, and did not lead to risk aversion. This result is consistent with the predictions of CPT, which claims that greater uncertainty leads to higher loss/risk aversion.

It was also remarkable to understand that framing may lead risk-assessors to consider weaknesses instead of preventive measures. In other words, experts faced with negative phrasing seem to focus more on the preventive measures against negative outcomes that are currently in place. On the other hand, when faced with framed expressions, they seem to focus more on factors that may prevent them from reaching a desirable or positive outcome. This tendency might result from the risk-assessor's desire to falsify the expression itself. In other words, positive measures must be found against a claim that "unwanted X event will occur," while weaknesses must be found to falsify statements that claim "the desired non-X event will occur." Inevitably, thinking about weaknesses rather than measures will result in a more cautious attitude and greater risk aversion. We think that this finding is also in parallel with prospect theory's predictions for monetary decisions. Thus, the predictions of prospect theory on decision-making under uncertainty are not limited to monetary decisions and can be applied for safety risk assessment.

Discussion

The perceived likelihood of all risk events increased when framed, but only two to a significant extent under the conditions examined in this work. This result may be a product of the most important limitation of this study – its small sample size, due to the limited geography of the research and the small population of key safety personnel in business aviation in Turkey.

If appropriate framing can force safety personnel to consider weaknesses more than measures, it can be suggested that evaluating framed expressions is better than evaluating unframed ones. For a safe beginning, the decision makers can use both forms in formal risk assessment processes on the condition that they consider the greater risk value that results from both assessments. However, this effect was demonstrated with only one question in this study; therefore, further research, and more importantly, evaluation of the efficacy of this approach in everyday use, will be required. The following questions can be answered after long-term monitoring: Can the use of framed expressions in safety management increase overall safety? Or does it lead to overprotection or underestimation?

This study not only suggests new findings but also poses new questions by its linking of two major fields: safety management and behavioral economy. Does the presence of human factors make the greatest contribution to the framing effect due to its role in uncertainty? Do individual and demographic factors such as experience, gender, or familiarity with the risk being considered to affect respondents' aversive behavior when faced with framed expressions? This research will require replication with larger sample sizes to address these questions.

Disclosure Statement

No potential conflict of interest was reported by the authors.

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