IEEE Access
Multidisciplinary : Rapid Review : Open Access Journal

Received March 4, 2022, accepted March 24, 2022, date of publication March 28, 2022, date of current version April 5, 2022.
Digital Object Identifier 10.1109/ACCESS.2022.3162832

Implications for Risk Taking Behavior Leading to Crashes or Disasters-Effects of Perceived Risk on Risk Taking Decision

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ABSTRACT The aim of this study was to investigate the effects of the outcome in a risk averse sure option and the perceived risk of the worst outcome on risk taking behaviors and to get insights into prevention of disasters or crashes caused by risk taking. Because of cognitive biases to optimistically underestimate a risk, it is generally difficult to recognize rationally a risk and its consequence leading to a disaster or crash. Therefore, the recognition of the gap between the perceive risk and the real risk is a very important issue, because such a gap might cause risk taking behaviors or decisions, leading to a disaster or crash. Using three decision-making situations with different scenarios, we measured the perceived risk at which the decision changed from a risk averse alternative to a risk taking one as a function of the outcome in a sure risk averse alternative and the frame (positive or negative frame in a scenario of decision making). The perceived risk at which the decision shifted from a risk averse alternative to a risk taking one decreased with the increase of the outcome in a risk averse alternative. The perceived risk was lower when the decision-making scenario was positively framed. Irrespective of the difference of decision-making scenarios, there existed a self-reported risk (probability) that changed a decision from a risk averse alternative to a risk taking one. Applying the framework of decision making of this study to a few cases of crashes or disasters, some implications for preventing disasters or crashes were given.

INDEX TERMS Crash or disaster, irrational behavior, perceived risk, risk averse, risk taking, outcome of sure alternative.

I. INTRODUCTION

Bounded rationality must be assumed in decision making, because decisions cannot be made rationally, thereby resulting in cognitive biases [1]–[3]. Our cognition is controlled through either System 1, where the operation is quick, automatic, without much time consumption and intuitive, with little or no effort, or System 2, which requires effortful, demanding and deliberate mental activities. However, it should be noted that such heuristic approaches through System 1 constantly lead to cognitive biases.

One of the major causes of the Challenger space shuttle disaster [4]–[6] is regarded to be groupthink, specifically, the illusion of unanimity [7], [8]. Although the manufacturer recognized the risk of malfunction of O-ring under the severely cold temperature, the manufacturer agreed with the launch of the Challenger space shuttle because of illusion of unanimity. Becker [9] and Murata, Nakamura, and Karwowski [10] discussed how cognitive biases distorted decision making and induced serious crashes or disasters.

After some serious crash occurs, one tends to overestimate the occurrence probability of such an event. We hesitate to be on board a plane immediately after a serious crash due to the overestimation of a fatal crash. This type of cognitive bias is called the hindsight bias and is suggested to makes it impossible to objectively analyze incidents, crashes, or disasters. Judgmental heuristics and biases become potential risk factors of wrong decisions or behaviors leading to unfavorable or unexpected incidents [11]. However, Reason [11] did not provide quantitatively a systematic explanation of

The associate editor coordinating the review of this manuscript and approving it for publication was Baoping Cai.

how cognitive biases became a trigger of incidents, crashes, or disasters. Dekker [12] pointed out a situation of developing a vicious circle of repeated occurrences of similar unfavorable incidents and suggested that the cause of such a vicious circle was hindsight bias, pointed out by Fischhoff [13], or outcome bias, noted by Mackie, Worth, and Allison [14], which places greater emphasis on outcomes than processes. The analysis of incidents, crashes, or disasters conducted without hindsight bias or considering outcomes, but with foresight or in consideration of processes, will be helpful for proper safety management and for drastically disconnecting a situation of a vicious circle of repeated occurrences of similar incidents.

As it stands, such approaches are not put into practice adequately. As cognitive biases [1]–[3], [9], [10] mentioned above accelerate the enlargement of the gap between the real and the perceived risk [15]–[18], people tend to be optimistic about a risk and to misunderstand that a risk will not occur even if the real risk is as a matter of fact higher than expected. Such a difficulty to recognize rationally (accurately) a real risk causes a shift from a rational risk averse behavior to an irrational risk taking one leading to a disaster or a crash. It is well recognized that a success makes a subsequent success appear more probable owing to cognitive biases [15], [16]. If successes continue, we irrationally perceive that the probability of success (risk of failure) is higher (lower). We cannot rationally judge that a success does not increase (decrease) the probability of subsequent successes (risk of failure), and it is true that our behavior is affected by a perceived risk. Risk attitudes are based on our perceived risk and can be classified broadly into a risk averse and a risk taking one. From the perspective of safety, it is rational and appropriate that we should avoid risk taking behaviors or decisions. However, our behavior changes according to our perceived risk that is affected by a variety of factors such as the present state of organizations or individuals [15]. March and Shapira [15] stated that whether individuals or organizations were above a performance or achievement target affected the perceived risk and whether they became risk averse or risk taking. As pointed out by March and Shapira [15], Freudenberg [16], Freudenberg [17], Starbuck and Milliken [18], the enlarged gap between the real risk and the perceived risk caused by cognitive biases is a crucial factor that triggers a crash or disaster. It is more plausible that such a gap leads to risk taking if the perceived risk is felt lower and lower than the real risk. If such risk taking propensities are dominant, individuals or organizations tend to ignore events with very low probability (risk) and critical consequences and choose a risk taking behavior, are surprised by the occurrence of such event, and are not well prepared for such events. This might lead to irreparable disasters or crashes. In this manner, the difficulties exist in recognizing risks because of cognitive biases (underestimation of risks), and the enlarged gap between the real and the perceived risk might lead to a risk taking behavior and become a trigger of disasters like the Challenger explosion [5], [6].

It is well known that even if the scenarios of decision making are equivalent, we tend to choose an alternative depending on whether the alternative in a decision is presented in a positive or negative frame. When we are provided with alternatives that are framed positively (with a gain), we tend to choose a risk averse alternative. When we are given alternatives that are framed negatively (with a loss), we tend to choose a risk taking alternative. In other words, we generally tend to be risk averse within a positive frame (gain frame) and risk taking within a negative frame (loss frame). This phenomenon is called the framing effect. Since the publication of Tversky and Kahneman [3], numerous studies verified the framing effect [19]–[22].

In Tversky and Kahneman's Asian disease framing problem [3], the outcome (X: 200 people saved) in a risk averse alternative and the probability of success (P: 1/3) in a risk taking alternative were set to constant values to demonstrate the framing effect. The procedure required participants to choose either a risk averse or risk taking alternative to show that a risk averse alternative tended to be dominantly chosen when framed positively while a risk taking alternative tended to be dominantly chosen when framed negatively. The framing effect was evidenced by collective data analysis that compared the percentage choice of a risk averse alternative in a positive frame (72%) with that of a risk taking alternative in a negative frame (78%). Based on such comparative data, it has been generally concluded that while we tend to choose a risk averse alternative in a positive frame, we tend to choose a risk taking alternative in a negative frame. This does not necessarily mean that while a risk averse alternative is certainly chosen in a positive frame, a risk taking alternative is certainly chosen in a negative frame. The studies above mentioned have not investigated how the perceived risk induce the switch from a risk averse alternative to a risk taking one.

Although Schneider [23] investigated the similar effect of the probability of success in a risk taking alternative given by the experimenter, this study did not deal with the perceived risk at which the risk averse choice changed to a risk taking one. The findings on the framing effect cannot be directly applicable to real-life situations of decision making where the likelihood of outcomes is usually unknown and must be estimated or evaluated by a decision maker. Whether individuals choose a risk averse or risk taking alternative seems to be more strongly affected by the perceived risk of a decision maker or the outcome of an alternative than by the frame (positive or negative).

Although the studies above investigated factors that affected the occurrence of framing effect, they cannot be applied to real situations of decision making because they did not examine how the perceived risk affected the decision or behavior. As already stated, it is possible that if the perceived risk is lower, this might trigger a risk taking decision or behavior that potentially leads to a disaster or crash [9], [10], [15]–[18]. However, few studies clarified how the perceive risk changed our decision or behavior from a risk averse choice to a risk taking one.

This study empirically and quantitatively investigated how perceived risk affected a risk attitude (risk averse or risk taking) as a function of the difference of scenario of decision making, the outcome in a sure alternative of decision making, and the fame in a scenario of decision making. We hypothesize that risk taking behavior more readily occurs in the negative frame than in the positive frame. It is also hypothesized that the shift from a risk aversive decision to a risk taking one occurs irrespective of the difference of decision-making scenarios and that perceived risk is affected by the outcome in a sure alternative of decision making. If the present state is above a target or objective that can be viewed from a positive or gain frame, it is expected that risk averse tendencies are dominant and smaller perceived risk is necessary for altering a risk averse behavior to a risk taking one. If the present state is below a target or objective that is viewed from a negative or loss frame, risk taking tendencies are expected to be dominant. Risk taking behaviors are more strongly affected by perceived risk and outcomes in a sure alternative in a scenario of decision making than by a frame in a scenario of decision making. The decrease of perceived risk leads to the ignorance of worse or worst outcomes that triggers risk taking behaviors or attitudes. Consequently, individuals or organizations are not well prepared for such an outcome with a low perceived risk.

Throughout the three scenarios of decision making, this study aimed to investigate the effects of the difference of scenario of decision making, the outcome in a risk averse alternative, and the frame of decision scenario on perceived risk that gave rise to the switch from a risk averse attitude to a risk taking one. The perceived risk at the switch of choice from a risk averse alternative to a risk taking one was measured for the frame and a variety of outcome in a sure alternative in the decision scenario. We also examined how the perceived risk was affected by the difference of scenarios in decision making. In order to demonstrate how the switch from a risk averse decision to a risk taking one is linked with and applicable to the analysis of actual crashes or disasters, we applied the decision making framework of this study to a few cases of crashes or disasters and gave some implications for preventing disasters or crashes that stemmed from risk taking behaviors.

II. METHOD

From the viewpoint of safety, the rational choice is to accept a risk averse alternative and not to pursue a risk taking one. However, it is well recognized that people do not always behave rationally. As several studies have demonstrated cognitive biases directly underlying disasters, crashes, or collisions, it is plausible that the deviation from a rational behavior triggers crashes or disasters [9], [10], [24], [25]. Becker [9] has shown that cognitive biases, such as self-serving bias, overconfidence, and confirmation bias, existed in judgments made under uncertainty and in emergencies in the Great Bear Wilderness disaster.

This study investigated the effects of perceived risk and outcome of a risk averse choice on tendencies of risk taking decisions or behaviors using an experimental paradigm that incorporated the outcome X in a sure alternative (Alternative 1 or 3 mentioned below) as an experimental factor. This study aimed at demonstrating the tendency of taking a risk as the perceived risk deceases and getting some insights into risk taking behavior that potentially trigger a disaster or crash.

A. PARTICIPANTS

A total of 211 (205 males and 6 females) undergraduate or graduate students at Okayama University, Japan agreed to take part in the survey shown below. Ninety-three (90 males and 3 females), fifty-nine (57 males and 2 females), and fifty-nine (58 males and 1 female) undergraduate or graduate students were allocated to the Scenarios 1, 2, and 3 below, respectively. This study was also approved by the Ethical Committee of the Dept. of Intelligent Mechanical Systems, Okayama University (approval number: 2021-sys-01). None of them had expertise in behavioral economics or psychology.

The participant must estimate the probability (risk) of the worst outcome of the scenarios and make decision. We judged that basic knowledge of risk and risk and safety management was necessary for performing the safety-related decision making. Therefore, we adopted undergraduates or graduates in engineering who acquired basic knowledge of probability (risk) and safety and risk management in their educational curriculum. Although six females were included in the participants, we judged that the gender difference would not affect the choice between a risk averse alternative and a risk taking one.

B. TASK

The scenarios below are based on Asian disease problem [3]. As the risk of the worst outcome P and the desirable outcome X in decision making were provided in the original Asian disease problem, it was difficult to investigate how the choice changed as a function of P and X and understand how a risk averse choice changed to a risk taking one leading to a crash or disaster. Therefore, incorporating the variables P and X above into the framework of decision making to choose between a risk averse choice and a risk taking one, we explored how the switch of decision occurred. The three scenarios related to safety issues were used to demonstrate that risk taking behaviors could occur irrespective of the difference of scenarios. In other words, the three safety-related scenarios below were used so that the results could be more generalized.

It is rational to continue to choose a risk averse alternative as far as safety issues are concerned. However, it is plausible that a decision maker's choice irrationally changes from a risk averse alternative to a risk taking one if the outcome X is large enough and the perceived risk of a decision maker is felt remarkably low. Therefore, it is assumed that the decrease of perceived risk triggers a risk taking behavior under uncertainty where both X and P are unknowable and cannot be accurately estimated.

As it is difficult to estimate accurately the values of X and P under uncertainty, the decision making scenario of original Asian problem where X and P were provided cannot be regarded as an uncertain situation. The decision maker must estimate P somehow and make decision based on the estimation of P under uncertainty. Based on such a point of view, we developed the following three scenarios of decision making.

The participants were asked to make decision according to the design and procedure mentioned below.

1) SCENARIO 1

Each participant was provided with the following scenario in either a positive or a negative frame: imagine that the US is preparing for the outbreak of an unusual Asian disease that is expected to kill 600 people. Two alternative programs have been proposed to combat the disease for each frame:

(Positive frame)

Alternative 1: If Program A is adopted, X people will be saved.

Alternative 2: If Program B is adopted, there is a probability, 1-P, that 600 people will be saved and a probability, P, that no one will be saved.

(Negative frame)

Alternative 3: If Program C is adopted, 600-X people will die.

Alternative 4: If Program D is adopted, there is a probability, 1-P, that nobody will die and a probability, P, that 600 will die.

Alternatives 2 and 4 correspond to a risk taking one under an uncertain situation where the value of P is not given like an original Asian disease problem [3] and is unknowable. Each participant must judge whether the decision can be changed according to the self-estimated value of P (risk (probability) of worst outcome). This is also true for the Scenarios 2 and 3.

2) SCENARIO 2

Each participant was provided with the following scenario in either a positive or a negative frame: imagine that a nuclear power plant must undertake a vent operation to prevent radioactivity from diffusing out of the plant and polluting the environment surrounding the plant. Two alternative vent operations have been proposed to ensure safety:

(Positive frame)

Alternative 1: If Safety measure A is adopted, the vent operation succeeds in $X\%$ of the surrounding areas.

Alternative 2: If Safety measure B is adopted, there is a probability, 1-P, that the vent operation in all areas will be successfully executed and a probability, P, that the vent operation in all areas will not be successfully executed.

(Negative frame)

Alternative 3: If Safety measure C is adopted, the vent operation fails in (100-X) % of the surrounding areas.

Alternative 4: If Safety measure D is adopted, there is a probability, 1-P, that the vent operation will not fail in all areas and a probability, P, that the vent operation will fail in all areas.

3) SCENARIO 3

Each participant was provided with the following scenario in either a positive or a negative frame: imagine that older residents who need nursing care support must be evacuated to an evacuation shelter due to the increase in river water level caused by torrential rain. Two alternative programs have been proposed to evacuate safely the older residents in need of nursing care support:

(Positive frame)

Alternative 1: If Program A is adopted, $X\%$ of the older residents who need nursing care support will be evacuated safely.

Alternative 2: If Program B is adopted, there is a probability, 1-P, that all older residents who need nursing care support will be evacuated successfully and a probability, P, that no older residents in need of nursing care support will be evaluated successfully.

(Negative frame)

Alternative 3: If Program C is adopted, the safe evacuation of (100-X) % of older residents who need nursing care support will fail.

Alternative 4: If Program D is adopted, there is a probability, 1-P, that the safe evacuation of all older residents in need of nursing care support will not fail and a probability, P, that the safe evacuation of all older residents who need nursing care support will fail.

For each of Scenarios 1-3, the participants were required to report the probability, P_s, of the worst outcome through Program B (or D) at which they judged that they could switch their choice from a risk averse alternative (Alternative1 (Alternative 3)) to a risk taking one (Alternative 2 (Alternative 4)) for each frame and X (20%, 40%, 60%, and 80% of the most desirable outcome). The aim of this experiment was to investigate the perceived (self-reported) risk P_s at which each participant judged that their choice could be changed from a risk averse alternative (Alternative 1 (Alternative 3)) to a risk taking one (Alternative 2 (Alternative 4)).

C. DESIGN AND PROCEDURE

The experimental factors were the difference of scenarios of decision-making (Scenarios 1-3: three levels), the frame (positive and negative: two levels) and the percentage of the most desirable outcome (X: four levels). While the frame and the percentage of the most desirable outcome were within-subject variable, the difference of scenarios of decision-making was a between-subject variable. As the structure of scenario was nearly the same for Scenarios 1-3 above, we used the difference of scenarios of decision making as a between-subject variable to avoid the issue of habituation.

The X in Scenario 1 corresponded to the number of people saved (X) by Program A (or C), and was set to 120, 240, 360, and 480. The values of X corresponded to 20%, 40%, 60%, and 80% of the most desirable outcome ($X = 600$). In Scenario 2, X corresponded to the percentage of surrounding areas in which the vent operation is successfully executed by Program A (or C). The values of X were set to 20, 40, 60, and 80% of the most desirable outcome (All of the surrounding areas were successfully vented). The value X in Scenario 3 corresponded to the percentage of older residents in need of nursing care support who were evacuated safely through Program A (or C). The values of X were set to 20, 40, 60, and 80% of the most desirable outcome (all older adults were safely evacuated).

The self-reported probability, P_s, at which the choice changed from a risk averse (sure) option (Alternative 1 or 3) to a risk taking one (Alternative 2 or 4) was measured for each participant. The probability P_s represents perceived risk of the worst outcome. Throughout Scenarios 1-3, the values of X were set to 20%, 40%, 60%, and 80% of the most desirable outcome to enable us to track how the perceived (self-reported) risk P_s changed as the achievement in a sure alternative moved closer to the most desirable one.

Each participant allocated to either of Scenarios 1-3 was asked to report the value of P_s at which he or she could switch their choice from a risk averse alternative (Alternative 1 (Alternative 3)) to a risk taking one (Alternative 2 (Alternative 4)) for a total of eight conditions. The order of performance of eight conditions consisting of frame (two levels) and X (four levels) was randomized across the participants. The time constraint was not imposed on the participants and the participant was required to contemplate the situation and make decision carefully.

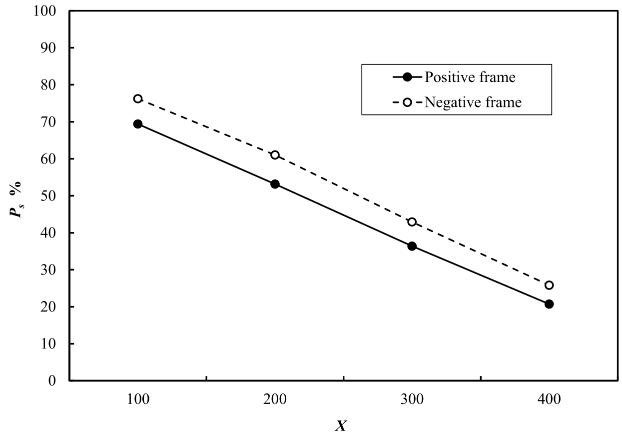

FIGURE 1. Self-reported P_s at which a choice switched from a risk averse alternative to a risk taking one as a function of frame and X (number of people saved in a sure alternative) in Scenario 1.

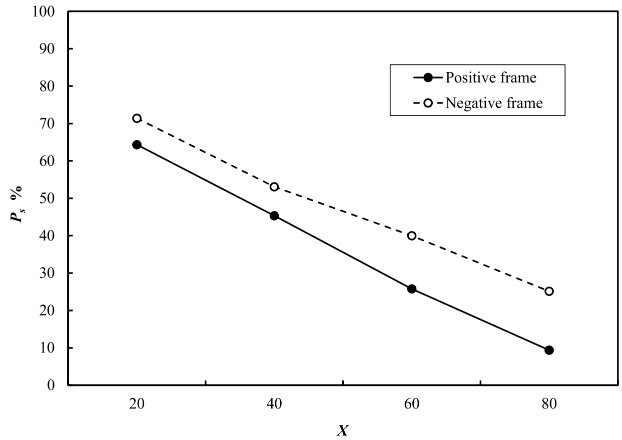

FIGURE 2. Self-reported P_s at which a choice switched from a risk averse alternative to a risk taking one as a function of frame and X (percentage of the surrounding areas succeed in vent operation) in Scenario 2.

III. RESULTS

As a result of a three-way (difference of scenarios by frame by X) ANOVA conducted on P_s, main effects of the difference of scenarios of decision-making ($F(2, 208) = 4.622$, $p < 0.01$), the frame ($F(1, 208) = 82.871$, $p < 0.01$) and the percentage of the most desirable outcome ($F(3, 624) = 1456.619$, $p < 0.01$)) were significant. A significant difference of scenarios by frame interaction ($F(5, 624) = 2.476$, $p < 0.05$) was also detected. Therefore, a two-way (frame by X) ANOVA was conducted on P_s for each of the three scenarios.

As a result of a two-way ANOVA conducted on P_s of Scenario 1, we detected significant main effects of the frame ($F(1, 92) = 28.652$, $p < 0.01$) and X ($F(3, 276) = 694.923$, $p < 0.01$). No significant frame by X interaction was detected. Tukey-Kramer multiple comparisons revealed significant differences of P_s ($p < 0.01$) between all six pairs of X. For each value of X, a paired t-test between the positive and negative frames was conducted on P_s. For each X, P_s of the positive frame was significantly ($p < 0.01$) higher than that of the negative frame. P_s was affected by both the frame and X. Figure 1 depicts P_s as a function of the outcome X (number of people saved) in a sure alternative and the frame (positive and negative).

Conducting a similar two-way ANOVA on P_s for Scenario 2, we detected significant main effects of the frame ($F(1, 58) = 46.759$, $p < 0.01$) and X ($F(3, 174) = 411.694$, $p < 0.01$). No significant frame by X interaction was detected. Tukey-Kramer multiple comparisons revealed significant differences of P_s ($p < 0.01$) between all six pairs of X. For each value of X, a paired t-test between the positive and negative frames was conducted on P_s. For each X, P_s of the positive frame was significantly ($p < 0.01$) higher than that of the negative frame. As well as in Scenario 1, P_s was affected by both the frame and X. The probability, P_s (P_{s+} and P_{s-}), at the switching point is plotted as a function of X (percentage of surrounding areas in which the vent operation is successfully executed) and the frame (positive and negative) in Figure 2.

Conducting a similar two-way ANOVA on P_s for Scenario 3, we detected significant main effects of the frame ($F(1, 58) = 27.447$, $p < 0.01$) and X ($F(3, 174) = 401.431$,

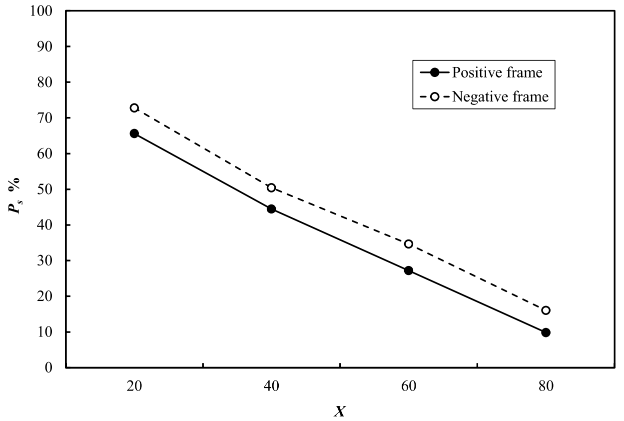

FIGURE 3. Self-reported P_s at which a choice switched from a risk averse alternative to a risk taking one as a function of frame and X (percentage of older people in need of nursing care support who were evacuated safely) in Scenario 3.

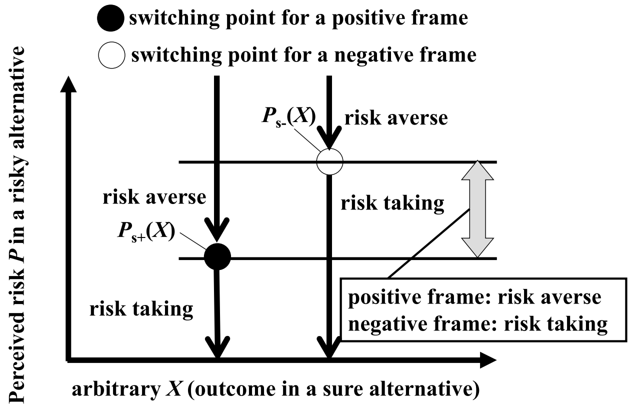

FIGURE 4. Schematic explanation of switch from a risk averse alternative to a risk taking one as a function of X and frame through Scenarios 1-3.

$p < 0.01$). No significant frame by X interaction was detected. Tukey-Kramer multiple comparisons revealed significant differences of P_s ($p < 0.01$) between all six pairs of X. For each value of X, a paired t-test between the positive and negative frames was conducted on P_s. For each X, P_s of the positive frame was significantly ($p < 0.01$) higher than that of the negative frame. As well as in Scenarios 1 and 2, P_s was affected by both the frame and X. The perceived risk P_s is plotted as a function of X and the frame in Figure 3. Similar results to those of Scenarios 1 and 2 were obtained.

IV. DISCUSSION

Irrespective of the difference of decision-making scenarios, the following properties were observed in common to the results of decision making for Scenarios 1-3. It must be noted, however, that the values of P_s were significantly different according to the scenarios of decision making. P_s was significantly higher when framed positively than when framed negatively for all values of X. If the perceived risk P was smaller than P_s, as plotted in Figures 1-3, the risk taking choices became dominant in both negative and positive frames. This means that the switching of a choice from a risk averse alternative to a risk taking one did not occur and that a risk averse choice (alternative) continued to be chosen if P was higher than P_s as shown in Figures 1-3.

The outcome X (the percentage of people saved to the most desirable outcome in Scenario 1, the percentage of surrounding areas in which the vent operation is successfully executed to the most desirable outcome in Scenario 2, and the percentage of older residents in need of nursing care support who were evacuated safely to the most desirable outcome in Scenario 3) in the sure alternative also affected P_s. The increase of X functioned such that the switch from a risk averse choice (Alternative 1 (Alternative 3)) to a risk taking one (Alternative 2 (Alternative 4)) did not occur if P_s did not decrease accordingly, as shown in Figures 1-3, in both positive and negative frames. With the increase in X, P needed to be smaller for the switch from a risk averse choice to a risk taking one to occur. When the outcome in the sure alternative became larger, smaller P (in other words, smaller values of 1-P, that is, the low risk) in a risky alternative was necessary so that a choice switched from a risk averse alternative to a risk taking one.

As schematized in Figure 4, P, when smaller than P_{s+}, represents that a risk taking alternative (Alternative 2) tended to be chosen. The symbols P_{s+} and P_{s-} represent the values of P at the switching point in the positive and the negative frame, respectively. When P was larger than P_{s+}, participants' decision became risk averse and participants continued to choose a risk averse alternative (Alternative 1). Similarly, when P was smaller than P_{s-}, a risk taking alternative (Alternative 4) tended to be chosen. When P was larger than P_{s-}, participants continued to choose a risk averse alternative (Alternative 3). If P was between P_{s+} and P_{s-}, the risk averse alternative (Alternative 1) was dominantly chosen in the positive frame and the risk taking alternative (Alternative 4) was dominantly chosen in the negative frame. This corresponds to what is called the framing effect: even if the scenarios of decision making are equivalent, we tend to choose a risk averse alternative in a positively framed scenario and choose a risk taking alternative in a negatively framed scenario.

The aim of this study was to empirically show the effects of X and the frame on the perceived risk at which switch of choice from a risk averse alternative to a risk taking one occurred so that the decrease of perceived risk less than P_s potentially led to risk taking behaviors that might trigger a disaster or crash. As summarized in Figure 4, it is possible that the behavior changed from a risk averse to a risk taking one when the perceived risk was lower than P_s. Such a phenomenon might potentially make organizations or managers ignore very low probability events that has the effect of leaving organizations or managers unprepared for such events and makes it impossible to manage appropriately the unexpected. This happened in disasters or crashes such as the Fukushima Daiichi disaster [26], [27]. The results also indicate that individuals tend to make risk taking decisions and ignore possible events that are below their perceived risk and judged to be very unlikely to occur regardless of their consequences (worst outcome).

V. GENERAL DISCUSSION

The results showed the following relations (i)–(ii) irrespective of the difference of scenarios of decision making. Here, $P_{s+}(X)$ and $P_{s-}(X)$ represent perceived risk P_{s+} and P_{s-} as a function of X, respectively.

(i) $P_{s+}(X)$ and $P_{s-}(X)$ are decreasing with X.

(ii) $P_{s+}(X) < P_{s-}(X)$ for all X.

Relation (i) above indicates that the larger the outcome X in a sure alternative becomes, the lower the perceived risk in a risky alternative must be so that the switching of choice from a sure alternative to a risky alternative occurs. It must be noted that in a real-world situation of decision making, it is difficult to frame the situation of decision making as positive (gain) or negative (loss) like three scenarios in this study.

When we are provided with alternatives that are framed positively (with a gain), we tend to choose a risk averse alternative. When we are given alternatives that are framed negatively (with a loss), we tend to choose a risk taking alternative. In other words, we generally tend to be risk averse within a positive frame (gain frame) and risk taking within a negative frame (loss frame). The most important thing included in this finding is not the framing effect itself that is representative of human's irrational behavior but the characteristics that the decrease of perceived risk and the outcome X received by a risk averse alternative affected a switch from a risk averse behavior to a risk taking one that might trigger a crash or disaster mentioned below (see Figure 4).

The limitation of this study is that the results cannot be generalized to take into account the cross-cultural difference in risk perception or risk taking behaviors. It has been recognized that cultures affect the risk perception or risk taking behaviors [28]–[34]. Gardner [33], referring to cultural theory of risk proposed by Douglas and Wildavsky [35], mentioned that while the risk posed by guns were rated to be low by hierarchists and communitarians, egalitarians felt the risk was high. Slovic [34], referring to the complex and subjective nature of risk, concluded that cultural factors were correlated with risk judgments. Choi *et al.* [30] pointed out the cross-cultural differences in judgment and decision making. Booth and Nolen [28] suggested a gender difference in risk taking behaviors.

Many studies suggested the cross-cultural differences of risk taking behaviors in corporate management, finance, investment, or traffic [36]–[40]. Weber and Hsee [39] found that P.R.C., U.S.A., Germany, and Poland were found to differ in risk preference measured by buying prices for risky financial options and concluded that differences in risk preference were associated primarily with cultural differences in the perception of the risk of the financial options. Kai *et al.* [37] showed that culture affected corporate risk taking in managerial decision making. Mihet [38] also discussed the cross-cultural difference of risk taking behaviors and suggested that risk taking by firms was affected by cultural factors of their own country. Sivak, Soler, and Trankle [41] investigated differences in risk taking behavior in driving among U.S., Germany, and Spain, and found that German participants attempted fewer crossings, had a higher probability of success, and had greater safety margins as compared to US and Spanish participants. Kopp [42] pointed out the risk adverseness of Japanese people.

As a limitation of this study, we must acknowledge that it is difficult to control the limited resources or the stressed sate in case of making important decisions. Although this study, using a population of Japanese undergraduate or graduate students, suggested that the decrease of perceived risk and the outcome X triggered a switch from a risk averse behavior to a risk taking one, it is plausible that risk taking behaviors are not only affected by perceived risk and outcome X but also by a variety of factors such as cultural differences, differences of educational background, or differences of professional experience as mentioned above. Risk taking behaviors were observed even in an experiment with a population of Japanese undergraduate or graduate students. Although it is true that risk taking behaviors are affected by cultural differences, educational background, or professional experience, it is expected that similar results to this study (the properties (i) and (ii) above) will hold irrespective of cultural difference, educational background, or professional experience. However, it must be noted that the actual values of $P_{s+}(X)$ or $P_{s-}(X)$ is expected to be different among cultural difference, educational background, or professional experience.

As far as this study is concerned, the results might remain true only in the population of Japanese engineering students with basic knowledge of risk (probability) and risk and safety management. Future research should be conducted to enhance the generality of this study and identify quantitatively the difference of properties (i) and (ii) above among cultural differences, among differences of educational background, and among differences of professional experience.

VI. IMPLICATIONS FOR CHOICE OF IRRATIONAL RISK TAKING BEHAVIOR LEADING TO CRASH OR DISASTER

Using the three cases below, an attempt is made to show that the results can be linked to actual cases of crashes or disasters and to validate the results. Some implications of this study are stated using the following cases of a crash or disaster: JR West Fukuchiyama line crash, Boeing 747 KLM Flight 4805 crash, and Fukushima Daiichi disaster.

A. JR WEST FUKUCHIYAMA LINE CRASH

JR West Fukuchiyama line crash [43]–[45] is discussed based on the results above. On 25 April 2005, a train derailed between Tsukaguchi and Amagasaki station, and hit an apartment building. This resulted in deaths of 106 people and injuries of 562 people. The excessive speed of the train was the cause of the collision of the first and second cars with the apartment building. JR West did not equip the track of the crash with the automatic train stop system. As the train had overshot the predetermined stopping position at Itami station before leaving for Amagasaki station, the train was delayed by 90 s from the schedule. The train driver broke the speed limit (70km/h) and attempted to recover from the delay.

According to the rule enforced at JR West, train drivers were forced to face financial penalties for the delayed train service and participate in harsh and humiliating retraining programs known as ''Nikkin Kyoiku.'' As the train driver had already been reprimanded for overshooting a station platform ten months before the crash, he must have worried about the punishment for having overshot the platform and have not been in a state to concentrate on safe driving. Insufficient communication among the station staff, the conductor and train driver, and the general command center of operation management must have forced the train driver to speed, because the train driver feared the blame by the general command center for the delay and thus attempted to overspeed to compensate for the delay [27].

In real-world situations, it is not so easy to describe the scenarios of decision making as positive or negative like those in this study. The situation of decision making (choice of risk averse or risk taking alternative) that the train driver faced is formulated as follows.

Risk averse alternative: The train driver obeys a rule, keeps in mind safety driving, and accepts the punishment for the delay.

Risk taking alternative: The train driver underestimates the crash risk by excess speed, ignore the crash risk with low probability, and judge that such risk taking will not lead to a crash. Therefore, the train driver judges that the delay can be certainly recovered by excessive speed to prevent punishment with high probability.

The lower the perceived risk is and the more outcome individuals feel to receive, the stronger the urge for risk taking becomes. As mentioned above, the train driver must have perceived that the risk of crash by excessive speed was lower and the outcome (avoid financial penalties and harsh and humiliating retraining education program) obtained by risk taking was large. Such a feeling (perceived risk) must have led to choose the risk taking alternative, which eventually caused the crash. The decision to choose a risk taking alternative above is similar to the results of this study summarized in Figure 4. Although the perceived risk of crash by the train driver is unknown, the risk taking behavior of the train driver must have been caused by the perceived risk below $P_{s+}(X)$ or $P_{s-}(X)$ (see Figure 4) of the train driver.

B. KLM FLIGHT 4805 CRASH

As a terrorist bomb exploded at a flower shop in Las Palmas Airport, Boeing 747 KLM Flight 4805 bounding for Las Palmas Airport landed Tenerife Airport in a hurry in March, 1997. The flight was forced to wait for clearance from the air traffic controller (ATC) to take off. The clearance from the ATC was delayed because of reduced visibility caused by fog. The captain, however, attempted to take off without permission from the ATC. A Pan Am 747 plane was unfortunately parked across the runway as the KLM Flight 4805 approached it at the take-off speed. This resulted in the loss of the lives of all crew and passengers of the KLM plane and many passengers of the Pan Am plane.

This crash was attributed to the irrational decision making of the captain [10], [24]. Loss aversion strongly contributed to the KLM Flight 4805 crash [10]. The losses for the captain included a reduced mandated rest period due to the flight delay, the cost of accommodating the passengers at a hotel until the situation improved, and a series of consequences from the flight delay, such as stress imposed on the captain and a blot on the captain's reputation of punctuality. The more of a negative frame our mental state is in, the more loss averse and risk taking we tend to be. The captain must have been preoccupied with the urge to reach the destination as early as possible and must have perceived that the risk of a crash was not so high. He thus made the irrational decision not to choose a risk averse alternative (wait for clearance to take off from the ATC) but to choose a risk taking one, resulting in his decision to take off without clearance from the ATC.

It is possible to describe the situation of decision making of the captain as follows.

Risk averse alternative: The captain accepts flight delay and a series of consequences of flight delay such as cost for passenger's hotel stay and tries not to be too stressful for the delay. According to the safety-first principle, the captain waits for the take-off until safe take-off clearance is permitted by ATC.

Risk taking alternative: The captain needs to avoid flight delay and a series of consequences of flight delay such as cost for passenger's hotel stay. Thus, based on judgement that ignoring a very low risk of crash does not actually impair air traffic safety, the captain determines to take off soon without take-off clearance by the ATC and attempts to arrive at the destination as early as possible.

Although the results of this experiment cannot be directly applied to this case, the experimental results indicates that the lower the perceived risk is, the stronger the urge to take a risk and obtain a more desirable outcome becomes. This forces individuals or organizations to ignore an event with very low occurrence probability but with worst consequence, which prevents individual or organizations from preparing for and expecting a crash or disaster. The captain must have perceived that the risk of crash by choosing the risk taking alternative above was very lower and the outcome (suppress the delay and the cost accompanied by the delay to a minimum) obtained by risk taking was large. Such perceived risk must have led to the risk taking behavior of the captain of KLM Flight 4805 crash. As well as the Case A, the captain's perceived risk of crash must also have been below $P_{s+}(X)$ and $P_{s-}(X)$ in Figure 4 and the gap between the perceived and the real risk was larger.

C. FUKUSHIMA DAIICHI DISASTER

According to Murata [26] and Murata and Karwowski [27], the situation of organizational decision making in the Fukushima Daiichi disaster is stated as follows.

Risk averse alternative: Tokyo Electric Power Company (TEPCO) invests in safety equipment and accept sure loss of money associate with investment so that they can prepare for emergencies such as a station blackout (SBO).

Risk taking alternative: TEPCO does not invest in safety equipment at all based on the judgment that ignoring events such as an SBO with very low risk (probability) of occurrence will not impair plant safety at all.

As already mentioned, it is true that the lower the perceived risk of a disaster is, the stronger the urge to ignore the unexpected event with very low probability and take a risk is. TEPCO must have judged that the plant would not experience a severe damage even if they took the risk above and ignored the risks of major disasters such as an SBO with a very low risk of occurrence, and did not invest in safety equipment and appropriately prepare for such a worst event. The gap between the real risk and the perceived risk (usually estimated to be lower than the real risk) is well recognized [15]–[18]. It is more plausible that the enlargement of such a gap between the real risk and the perceived risk leads to risk taking behaviors. This experiment quantitively demonstrated that the enlargement of such a gap led to a risk taking decision, and thus might trigger a crash or disaster.

Even in the Case C, the risk taking behavior of the government and TEPCO must have been caused by the perceived risk below $P_{s+}(X)$ and $P_{s-}(X)$ in Figure 4.

D. SUMMARY

As demonstrated above, risk taking behaviors accompanied by the decrease of perceived risk might cause a crash or disaster. Preventive countermeasures for suppressing the switch from a risk averse behavior to a risk taking one leading to a crash or disaster are discussed. Successes make a subsequent success appear more probable, and people tend to falsely believe that a normal state of success continues. This property and the feeling (psychology) of loss aversion accompanied by a series of successes further makes people estimate that perceived risk is lower, which eventually enlarges the gap between the perceived and the real risk. Such a gap between the perceived and the real risk must be recognized by all individuals and organizations especially placed in a state below the standard achievement, for these individuals or organizations remarkably tend to perceive the risk much lower than it is. It is expected that people or organizations under such a low achievement are stressed and urged to take a risk. As mentioned by Weick [46], the stressed state of the captain at KLM Flight 4805 further accelerated the risk taking behavior.

Although it might be difficult to classify the state of decision making clearly as positively or negatively framed, the state of a decision maker who is eager to avoid loss as the captain at KLM Flight 4805 is regarded as negatively framed. As shown in this study, the negatively framed situation is more vulnerable to risk taking behaviors as summarized in Figure 4. Environment and situations surrounding us must be monitored carefully to inspect the enlargement of a gap between the perceived and the real risk and whether the state of loss aversion exists so that we are always alert to such states leading to risk taking behaviors and triggering a crash or disaster. The results that there existed perceived risk P_s that changed the decision from a risk averse alternative to a risk taking one throughout Scenarios 1-3 suggest that risk taking decisions happen according to the situations surrounding us and potentially triggers a major crash or disaster, although not directly applicable to the three cases above. We never fail to encounter decision making situations mentioned in Scenarios 1-3 and the three cases. The formulation of decision making between a risk averse alternative and a risk taking one in the process of safety management might be effective to recognize a risk taking situation leading to a crash or disaster and to remove it.

Another limitation of this study is that the results may not be directly used to explain actual risk taking behaviors. As the participants were limited to undergraduate or graduate students, the results are not necessarily applicable to the actual risk-taking behavior. However, the risk-taking property clarified through the Scenarios 1-3 might suggest that the perceived risk of individuals might make decision shift from a risk averse alternative to a risk taking one that potentially triggers a crash or a disaster. Adopting a wider and various populations other than undergraduate or graduate students, future research should be conducted to take into account cross-cultural differences, differences of educational background, and differences of professional experiences, and get further generalized insights into how risk taking behaviors or decisions lead to a crash or disaster.

The Cases A-C were appropriately formulated as a decision making situation similar to the three scenarios in this experiment that forced the people or organization involved in the crash or disaster to choose a risk-taking decision. However, it must be noted that self-reported risk P_s is unknown in Cases A-C. In summary, the findings that there existed a self-reported risk P_s that forced a decision maker to choose a risk taking decision in the three scenarios reflect, to some extent, real-world cases of decision making leading to crashes (Cases A and B) or a disaster (Case C).

VII. CONCLUSION

This study attempted to empirically show how the decrease of perceived risk led to risk taking behavior as a function of the outcome X in a sure option and the frame. Perceived risk P_s tended to decrease with the increase in outcome X in a sure option and to be lower in the positive frame than in the negative frame irrespective of the difference of scenarios of decision making. The perceived risk to trigger risk taking behaviors or choices was lower when the decision making or choice was framed positively than when it was framed negatively.

The results might empirically imply that the decrease of perceived risk potentially forces individuals or organizations to ignore a worst outcome with a low probability and to choose risk taking behaviors. Even in actual situations to make decisions related to safety, it is more plausible that individuals or organizations tend to shift their choices or decisions from risk averse to risk taking ones if the perceived risk decreases below P_{s+} or P_{s-}.

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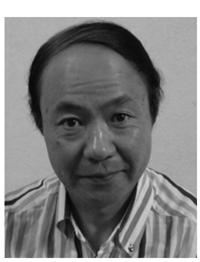

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