

## Article

# Irrationality of Attitudes toward Safety under Complexity and Uncertainty Leading to Asymmetry of Information

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**Abstract:** This study investigated how complexity and uncertainty, the probability of accidents, and the probability of financial trouble affected individuals' recognition of validity of irrational risk-seeking decisions. As a result of conducting a multiple regression analysis on the validation score for irrational risk-seeking alternative obtained by a questionnaire survey, we found that the validity score for an irrational risk-seeking alternative was higher when both complexity and uncertainty were high than when both complexity and uncertainty were low, which means that high complexity and high uncertainty in the situation of decision making more readily leads to an irrational risk-seeking behavior that might trigger a major accident. Beyond complexity and uncertainty, the damage of major accident  $\alpha$ , the decrease of the probability of major accidents and the increase of the probability of financial trouble (economic factor) were also found to promote the choice of irrational risk-seeking alternatives. Some implications for safety management under high complexity and uncertainty are discussed.

**Keywords:** complexity; uncertainty; asymmetry of information; probability of accidents; probability of financial trouble; cognitive bias; risk-seeking



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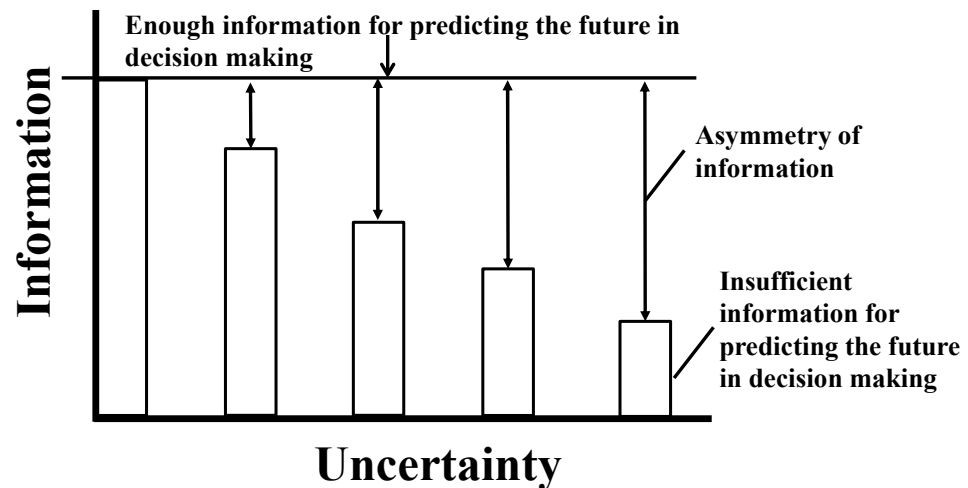
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## 1. Introduction

Many large-scale, complex systems exist, such as nuclear power plants, railway transportation systems, and air transportation systems. Nuclear power plants consist of many components that interact in a complicated manner. Perrow [1,2] has proposed a concept of normal accidents in which accidents are inevitable in complicated high technology settings. Failures occur unexpectedly when interactions between components cannot be predicted accurately and managed rationally in complex systems. Gladwell [3] has also indicated the inevitability of these unexpected accidents caused by human's irrational risk-seeking behavior within the framework of normal accidents. Therefore, clarifying how people behave irrationally (take a risk-seeking behavior that potentially triggers major accidents) under complex states and managing complexity appropriately is important to prevent crashes or disasters in complex systems.

Whereas the behavior of automobile plants with comparatively low complexity is readily recognizable, recognizing the behavior of systems in nuclear power plants with high complexity is difficult. In this manner, the complexity of a system affects human's behavior, especially in case of an emergency. In addition to high complexity, uncertainty in large-scale and complex systems must also be considered. Uncertainty is a state that hinders accurate judgment of the future state or situation and prevents individuals and organizations from easily recognizing how things will proceed in the future, because a decision-maker does not have enough information on how things will proceed in the future under an uncertain situation. Such a state makes prediction of the future and appropriate decision-making on

the future impossible. The concept of asymmetry of information [4], as first proposed in economics, represents a situation in which one group has more information than another. Such a group with less information cannot make a decision accurately and rationally due to the lack of information necessary for smooth communication. Uncertain states can be regarded as corresponding to asymmetry of information between the information that people have to predict the future and the information that is necessary for predicting the future accurately and rationally (see Figure 1). As uncertainty increases, it becomes more and more difficult to make decision on the future appropriately due to the enlargement of asymmetry of information as shown in Figure 1.



**Figure 1.** Schematic summary of relevance of uncertainty to asymmetry of information.

It has been pointed out that decisions or behaviors under uncertainty are likely to be vulnerable to cognitive biases [5–7] and to become irrational, because uncertainty increases asymmetry of the information where a decision-maker has less information necessary for predicting the future rationally. With the increase in uncertainty, it is uncertain how the future proceeds and it is difficult to predict the future with insufficient information of decision-maker. Therefore, it becomes more and more difficult to predict the future accurately and decide accurately and rationally on the basis of the information that a decision-maker has. An irrational decision such as risk-seeking caused by uncertainty sometimes is expected to induce crashes or disasters.

A few cases of crashes or disasters have been reported to stem from such irrationality under uncertainty (asymmetry of information) [8–10]. These studies are based on the analysis after crashes or disasters occurred. Irrational risk-seeking behaviors under uncertainty are empirically identified in the field of finance, business, economy, and psychology [11–16]. Bazerman and Watkins [12] showed that irrational risk-seeking behavior led to financial or business failures. However, such properties leading to irrational risk-seeking behavior have not fully investigated in the field of safety management or engineering. Until now, human's behavior or attitude under uncertainty has not been empirically investigated in the field of safety management or engineering, and few studies have investigated how uncertainty leads to irrational attitudes toward safety that potentially trigger crashes or disasters. Therefore, individuals' irrational behavior must be explored empirically to gain insights into how such behaviors lead to difficulties in managing safety appropriately and rationally and induces an irrational risk-seeking behavior that trigger major accidents.

This study, using a decision-making scenario related to plant safety to choose between an alternative of risk-seeking and that of sure loss, addresses how the complexity and uncertainty of the plant situation affected human's irrational decision-making to choose an irrational risk-seeking behavior. In other words, this study, through a questionnaire survey, attempts to investigate vulnerability to an irrational risk-seeking behavior with the increase in the complexity and uncertainty of a decision-making situation that is related

to a plant's safety and economy. We investigated how individuals perceive the validity of an irrational risk-seeking decision alternative when the complexity and uncertainty in the scenario of decision-making changed from low to high. We also investigated the effects of the damage of major accident, the probability (risk) of crashes or disasters and the probability of financial trouble when a risk-seeking decision was chosen on the irrational risk-seeking behavior. Finally, we provided some implications for safety management to avoid disasters or crashes under high complexity and uncertainty.

## 2. Method

### 2.1. Participants

Sixteen (15 men and 1 woman) undergraduates or graduates in engineering at Okayama University, Japan, agreed to take part in the survey. This study was approved by the Ethical Committee of the Department of Intelligent Mechanical Systems, Okayama University. As mentioned below, the scenarios include the probabilistic expressions of financial trouble and major accidents. The concept of complexity and uncertainty are also included in the scenarios (Sections 2.2.1 and 2.2.2). The participant must recognize the probability of financial trouble and major accidents and the difference of complexity and uncertainty on the basis of the scenarios. Therefore, we decided to adopt undergraduates or graduates in engineering who were judged to master basic knowledge or concepts of probability, complexity, and uncertainty in their educational curriculum. Although one female was included in the participants, we judged that the sex difference would not affect the obtained results (validity score of irrational risk-seeking alternative A).

### 2.2. Scenario of Decision-Making

We originally developed the two decision-making scenarios with low complexity and without uncertainty (Section 2.2.1) and with high complexity and high uncertainty (Section 2.2.2). These conditions (low complexity, low uncertainty) and (high complexity, high uncertainty) are denoted by (low, low) and (high, high), respectively. Based on this questionnaire survey, we investigate how the (complexity, uncertainty) condition led to irrational risk-seeking behavior. In other words, we investigated how individuals perceive the validity of an irrational risk-seeking decision alternative as the complexity and the uncertainty in the scenario (situation) of decision-making increased. We also investigated how the probability (risk) of accidents and the probability of financial trouble for a risk-seeking behavior triggered vulnerability to irrational (distorted) behavior (risk-seeking behavior).

The complexity and the uncertainty of the two scenarios below were controlled as follows. The complexity was defined by the scale and the number of components in the plant. When the scale and the numbers of components in the plant are small, the interactions between components and the behavior of plant are readily recognized. We judged that the complexity is low under such a situation. When the scale of plant is large, the behavior of plant cannot be readily recognized. We judged that the complexity is high.

The uncertainty was defined by the difficulty to predict how things proceed in the future due to less information. As uncertainty in plant situations increases, asymmetry between the information that a decision-maker has for predicting the plant situation and the information necessary for predicting the future situation of plant accurately magnifies. If we have enough information, we can predict readily how the failure will progress and it is possible to accurately predict the plant situation in the future. If we have less information to recognize how the failure will progress, it is not possible at all to accurately predict the plant situation in the future. If uncertainty is low and there is no asymmetry of information, we have enough information to investigate how the failure will affect the progress of manufacturing in the future and to identify accurately the cause of the failure. If uncertainty is high and there is asymmetry of information, it is very difficult to investigate how the failure will affect the progress of manufacturing and to identify accurately the cause of the failure due to less information of a decision-maker. Based on

such discussion, we assume that the (high, high) condition leads to higher validity scores of irrational risk-seeking alternative.

We also assume that the increase of  $\alpha$  and  $p_1$  decrease the validity of irrational risk-seeking alternative, and the increase of  $p_2$  increases the validity of irrational risk-seeking alternative. For both (low, low) and (high, high) conditions, the parameter  $\alpha$  in damage  $10\alpha X$  when a major accident occurs, the probability  $p_1$  of a major accident, and the probability  $p_2$  of financial trouble were incorporated into the scenario.

Taking into account (complexity, uncertainty) condition,  $\alpha$ ,  $p_1$ , and  $p_2$ , the following two scenarios of high and low (complexity, uncertainty) condition were prepared.

### 2.2.1. Scenario with (Low, Low) Condition (Automobile Assembly Plant)

The following scenario of automobile assembly plant was prepared as a (low, low) condition. It was assumed that if uncertainty is low, it is readily possible to investigate how the failure will affect the progress of manufacturing and to identify accurately the cause of the failure. According to such an assumption, the following scenario of system characteristics of (low, low) condition was prepared.

The number of components is comparatively small, and the scale of the plant is not large. The design and equipment operation are consistent and unified, because of the small scale of the plant. Therefore, the system as a whole can easily be grasped, and the state of the system can be recognized visually. Because the control room gathers information from the assembly lines, and the state of the plant can be readily recognized, the manufacturing process can be controlled and managed without difficulty, even by non-experts. The communication among workers and managers proceeds smoothly, and support from outsourcing companies is unnecessary.

Imagine that you have been reported by your subordinate as follows. Some of the manufacturing lines are stopped because of a failure. Therefore, the cause of the failure must be investigated. Your subordinate asks you to assess whether all the manufacturing lines should be stopped to verify and identify the cause of the failure.

The system has the following characteristics (1)–(3):

(1) System characteristics of (low, low) condition:

Although such a failure apparently affects the manufacturing lines as a whole, the failure is not expected to affect systems other than the manufacturing line, even if time is needed to completely restore the manufacturing lines. Therefore, the complexity of the plant is judged to be low. Under a situation without uncertainty, it is readily possible to judge that halting all manufacturing lines to investigate the cause of the failure prevents a serious accident at the plant and ensures safety. Therefore, a thorough investigation of the cause of the failure is desirable even if manufacturing cannot resume for some time.

(2) Cost of stopping the manufacturing line completely and identifying the cause of the failure:

Because a variety of investigations and analyzes are needed to identify the cause of the failure, the manufacturing line must be completely stopped. However, the investigation and analysis cost  $X$  million \$, and the factory might experience financial trouble with a probability of  $p_2$ . Last year's annual sales were  $100X$  million \$, and the investigation and analysis cost of  $X$  million \$ cannot be ignored. Generally, the automobile assembly plant can successfully identify the cause of the failure and restore manufacturing to the state before the failure with a probability greater than 0.99 even if the plant is not stopped completely. This also suggests that the plant situation is not uncertain, because a decision-maker has enough information, readily recognize how the plant failure progresses, investigate its effect, and identify the cause of failure.

(3) Information on the past history of failures or problems:

Although the plant has experienced minor failure several times, a major failure has never happened. Similar failures have occurred in other companies' plants and have not

led to major accidents. These rival companies invest in up-to-date equipment and have succeeded in preventing major accidents. This plant also owns similar up-to-date equipment.

The participant was asked to imagine that you are faced with the following decision to avoid a loss caused by stopping the manufacturing lines. On the basis of characteristics (1)–(3), the participant were required to evaluate the validity of the risk-seeking alternative A below using an integer from 1(not valid at all) to 100 (completely valid).

Alternative A (risk-seeking):

Decide that the failure will not lead to a major accident, and address the failure without stopping the manufacturing lines, so that the cost of  $X$  million \$ is avoided. This choice leads to a major accident with a probability of  $p_1$ . When a major accident occurs, the corresponding damage is estimated to be  $10\alpha X$  million \$.

Alternative B (sure loss):

Consider the possibility of a major accident and invest  $X$  million \$ to thoroughly investigate and identify the cause. Decide to invest and thoroughly identify the cause of the failure (problem) and to accept the possibility of financial trouble with a probability of  $p_2$ .

It must be noted that not alternative A, but instead alternative B, must be chosen if people think and make decision rationally. However, whether people choose risk-seeking alternative A or sure loss B seems to be affected by many factors such as the complexity and uncertainty of the decision-making situation.

### 2.2.2. Scenario with (High, High) Condition (Chemical Plant)

The following scenario of chemical plant was prepared as a (high, high) condition. As already mentioned above, uncertainty in plant situations increases as asymmetry of information increases. If uncertainty is high, it is very difficult to investigate how the failure will affect the progress of manufacturing and to identify accurately the cause of the failure due to less information of a decision-maker. Based on such an assumption, the following scenario of system characteristics of (high, high) condition was prepared.

The number of components is very large. The plant is large in scale and handles hazardous chemicals. Many types of equipment are used for manufacturing chemical products. The operation of equipment is not consistent. Therefore, visually recognizing the state of the plant is difficult. Although the control room remotely gathers information from chemical processes, the state of the plant cannot be recognized readily, and in several cases, workers cannot fully confirm the state of the plant. Moreover, operators might make mistakes when reading the display in the central control room. Controlling and managing the chemical process, and completely understanding the system, are difficult even with sufficient expertise and experience. Communication among workers and managers does not proceed smoothly because the plant operation is supported by outsourcing companies.

Imagine that you have been reported by your subordinate as follows. Some processes are stopped because of the failure. This failure might lead to a major accident. Therefore, the cause of the failure must be investigated. Your subordinate asks you to assess whether all the chemical processes in the plant should be stopped to investigate and identify the cause of the failure. Therefore, the complexity of the plant is judged to be high as compared to the scenario in Section 2.2.1.

The system has the following characteristics (1)–(3):

(1) System characteristics of (high, high) condition:

The failure is expected to affect other components of the process in an unpredictable manner. Therefore, identifying the cause of the failure, recognizing the present state, and predicting how the process will proceed if the plant is not completely stopped are difficult. Therefore, the plant should ideally be completely stopped to fully address the failure.

(2) Cost of stopping the manufacturing line completely and identifying the cause of the failure:

Because a variety of investigations and analyzes are needed to identify the cause of the failure, the chemical process must be completely stopped. However, the investigation

and analysis will cost  $X$  million \$, and the factory might potentially have financial trouble with a probability of  $p_2$ . Last year's annual sales were  $100X$  million \$, and the investigation and analysis cost of  $X$  million \$ cannot be ignored. Generally, the chemical plant can successfully identify the cause of the failure and restore the manufacturing to the state before the failure with a probability of 0.1 when the plant is not stopped completely. This also suggests that the plant situation is uncertain because it is not possible to recognize how the plant failure will progress, investigate its effect, and identify the cause of failure due to less information.

(3) Information on past history of failures or problems:

Although the plant has experienced such minor failures several times, a major failure has never happened. Similar failures have occurred in other companies' plants, which have not led to major accidents. These rival companies invest in up-to-date equipment and have successfully prevented major accidents. This plant also owns similar up-to-date equipment.

Imagine that you are faced with the following decision to avoid a loss caused by stopping the manufacturing line. On the basis of properties (1)–(3), you are required to evaluate the validity of risk-seeking alternative using an integer from 1(not valid at all) to 100 (completely valid).

Alternative A (risk-seeking):

Decide that the failure will not lead to a major accident, and address the failure without stopping the manufacturing line, so that the cost of  $X$  million \$ is avoided. This choice leads to a major accident with a probability of  $p_1$ . When a major accident occurs, the corresponding damage is estimated to be  $10\alpha X$  million \$.

Alternative B (sure loss):

Consider the possibility of a major accident and invest  $X$  million \$ to thoroughly investigate and identify the cause. Decide to invest and thoroughly identify the cause of the failure (problem) and to accept the possibility of financial trouble with a probability of  $p_2$ .

As mentioned in Section 2.2.1, many factors such as the complexity and uncertainty of the decision-making situation affect whether people choose risk-seeking alternative A or sure loss B.

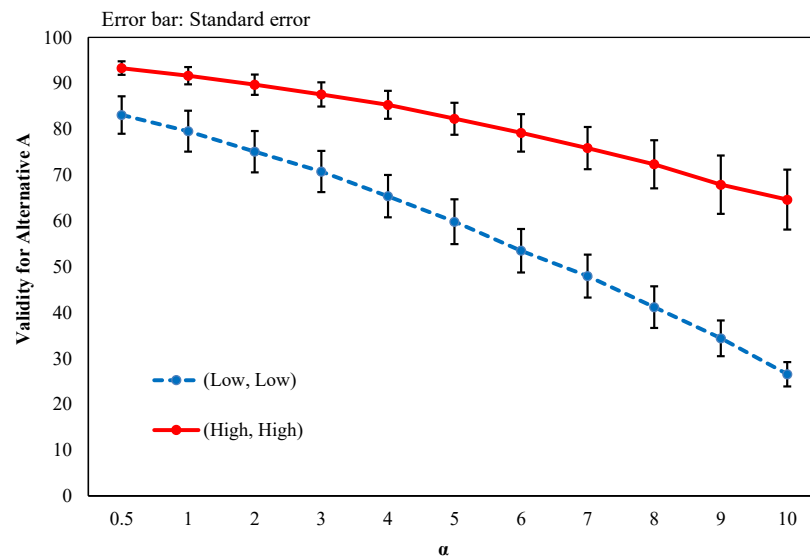
### 2.3. Design and Procedure

Participants were allocated to two groups: the scenario with high complexity and uncertainty (seven participants), and the scenario with low complexity and without uncertainty (eight participants). Therefore, the difference in complexity and uncertainty was a between-subject factor. The uncertainty of the plant state is described in the system characteristics (1) in both the above scenarios. The information on past history of failures or problems (3) described above was added to investigate whether participants would become trapped in availability bias. The participants were asked to imagine that they was in charge of decision-making regarding the response to the plant failure. The participants' task was to assess the validity of choosing risk-seeking alternative A, by using an integer from 1(not valid at all) to 100 (completely valid).

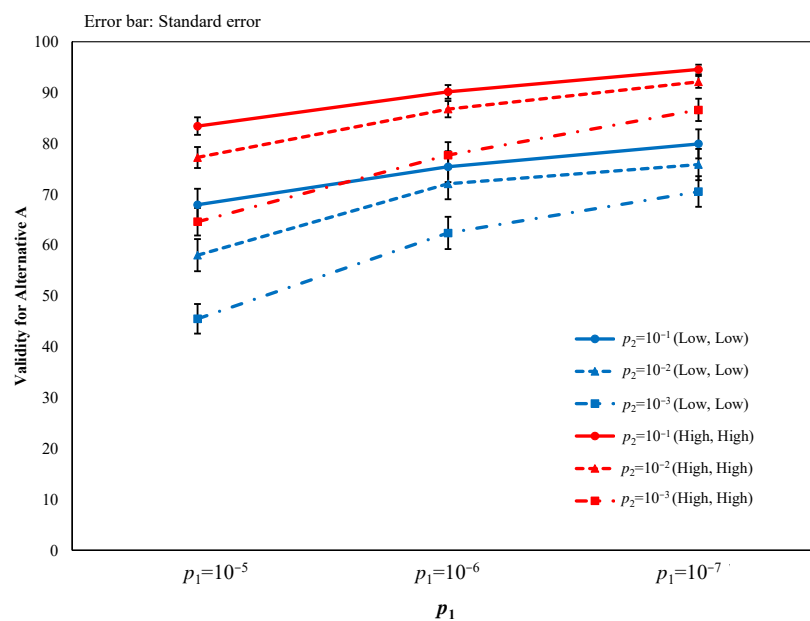
The parameter  $\alpha$  in damage  $10\alpha X$ , the probability  $p_1$  of a major accident, and the probability  $p_2$  of financial trouble were as follows:  $\alpha = 0.5-10$  (0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10),  $p_1 = (0.00001, 0.000001, 0.0000001)$ , and  $p_2 = (0.1, 0.01, 0.001)$ . For each combination of  $p_1$  and  $p_2$ , the validity score of alternative A were assessed as a function of  $\alpha$ . The order of six combinations of  $p_1$  and  $p_2$  was randomized across the participants.

The data (validation score of irrational risk-seeking scenario A) were statistically analyzed as follows. We conducted a multiple regression analysis where the validity score of irrational risk-seeking choice A corresponded to a dependent variable and (complexity, uncertainty) condition,  $\alpha$ ,  $p_1$ , and  $p_2$  were independent variables. The purpose of this analysis was to explore the effects of (complexity, uncertainty) condition,  $\alpha$ ,  $p_1$ , and  $p_2$  on the validity evaluation score of irrational risk-seeking decision for each of the complexity

and uncertainty condition. The results of the questionnaire survey are summarized in Figures 2 and 3 below.



**Figure 2.** Mean validity score compared among conditions of  $\alpha$  and between conditions of (complexity, uncertainty).



**Figure 3.** Mean validity score compared among conditions of  $p_1$  and  $p_2$ , and between conditions of (complexity, uncertainty).

### 3. Results

The results of the multiple regression analysis are summarized in Table 1. The multiple regression models were statistically significant, which means that (complexity, uncertainty) condition,  $\alpha$ ,  $p_1$ , and  $p_2$  were effective for explaining the variation of the validity score of irrational risk-seeking choice A. Low values of variance inflation factor (VIF) (<2) further supported the effectiveness of the multiple regression model. As shown in Table 1, the contribution of (complexity, uncertainty) condition and  $\alpha$  to the validity score of risk-seeking choice A was larger than that of  $p_1$ , and  $p_2$ . It must be noted that  $p_1$  and  $p_2$  also affected significantly to the validity score of irrational risk-seeking choice A, although the effects were not so strong as compared to that of (complexity, uncertainty) condition and  $\alpha$ .

**Table 1.** Results of multiple regression analysis for the validity score of irrational risk-seeking alternative A.

Predictors	<i>b</i>	SE	$\beta$	95% Confidence Interval of <i>b</i>		<i>t</i>	
				Lower Limit	Upper Limit		
Complexity and uncertainty (dummy variable: (High, High) = 0, (Low, Low) = 1)	−22.958	1.266	−0.514	−25.455	−20.462	−18.138	**
$p_1$	−185,240.449	14,158.928	−0.371	−213,166.551	−157,314.348	−13.083	**
$p_2$	13.539	1.416	0.271	10.747	16.332	9.562	**
$\alpha$	−4.390	0.205	−0.608	−4.794	−3.987	−21.455	**
Constant (intercept)	104.860	1.554		101.795	107.926	67.464	**

\*\**p* < 0.01. *b*: Partial regression coefficient. SE: Standard error.  $\beta$ : Standard partial regression coefficient. *t*: *t* value.

The result of comparing the mean validity score between the (complexity, uncertainty) conditions is summarized in Figure 2. This figure also shows how the validity score decreased with the increase in  $\alpha$ . The (high, high) condition led to a higher validity score of risk-seeking alternative A, which means that the (high, high) condition is more likely to give rise to an irrational risk-seeking behavior. The validity score of irrational risk-seeking alternative tended to decrease with the increase in  $\alpha$ . Figure 3 shows the mean validity score of risk-seeking alternative A compared between the (complexity, uncertainty) conditions, among three conditions of  $p_1$ , and among three conditions of  $p_2$ . The lower the probability of major accident  $p_1$  was, the higher the validity score of risk-seeking choice was. The higher the probability of financial trouble  $p_2$  when the sure loss B was chosen, the higher the validity score of risk-seeking choice.

The confidence intervals in Table 1 represent the theoretical 95% confidence interval of partial regression coefficient *b* of each independent variable ((complexity, uncertainty),  $p_1$ ,  $p_2$ , and  $\alpha$ ). It must be noted that the validity score for the lower  $p_2$  does not necessarily lead to a lower value than that for the higher  $p_2$  with 95% confidence when  $p_1$  was, for example,  $10^{-5}$  (see Figure 3).

#### 4. Discussion

As shown in Figure 2, the validity score was higher in the high complexity and high uncertainty condition than in the low complexity and low uncertainty condition, thus potentially indicating that the high complexity and high uncertainty condition is more vulnerable to the choice of irrational risk-seeking alternative A. The damage of major accident  $\alpha$  tended to reduce the validity of risk-seeking alternative (see Figure 2). Murata and Karwowski [8] have indicated that inappropriate communication triggers major accidents or incidents if asymmetry of authority or information exists. Asymmetry of information in this study corresponds to the following situation (see Figure 1): When the information of decision-maker is not sufficient to predict the future due to uncertainty, it is impossible to predict the future accurately and rationally. In such a situation, less information tends to make a decision maker value the validity of irrational risk-seeking alternative optimistically. Such a tendency to pursue an irrational risk-seeking alternative might trigger a major accident. This study's findings are consistent with that suggestion (Murata and Karwowski [8]) because uncertainty can be regarded to include asymmetry of information. As also indicated by Murata and Karwowski [8] and Murata [10], high complexity and high uncertainty trigger organizational failures, thus leading to major disasters or crashes. This study definitely suggests that high complexity and uncertainty should be managed cautiously as safety inhibitors, to avoid major disasters or crashes.

The validity score tended to decrease with increasing  $\alpha$  for both the (high, high) and the (low, low) condition (see Figure 2). The decrease of  $p_1$  contributed to the increase of the validity score of irrational risk-seeking alternative (see Figure 3). The increase of  $p_2$  contributed to the increase of validity score of irrational risk-seeking alternative (see Figure 3). A low probability of major accidents ( $p_1$ ) more readily led to higher validation of irrational risk-seeking behavior irrespective of complexity and uncertainty, whereas a high

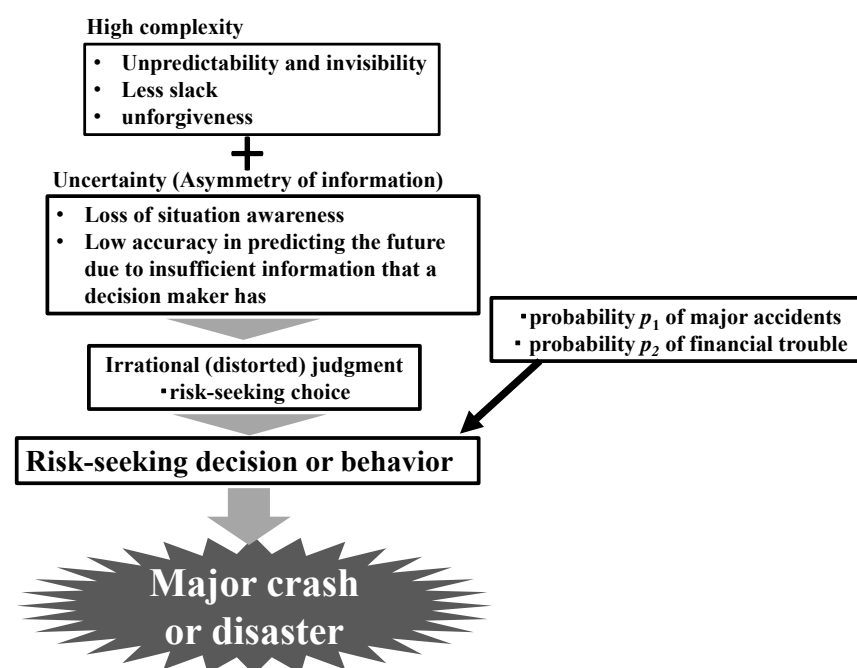


probability of financial trouble ( $p_2$ ) more readily led to risk-seeking behavior irrespective of complexity and uncertainty (see Figure 3).

Because economics assumes that people can behave and make decisions rationally, the validity for alternative A should be zero. As described in the results, people do not necessarily make decisions rationally but instead can be irrational. This study indicates that high complexity and high uncertainty readily leads to irrational risk-taking behavior. The parameters  $p_1$ ,  $p_2$ , and  $\alpha$  must also be considered to prevent irrational risk-seeking behavior that could potentially trigger major crashes or disasters. The (low, low) condition was less vulnerable to risk-seeking behavior and had lower validity to alternative A than the (high, high) condition.

Because predicting future events under high complexity and high uncertainty is difficult due to asymmetry of information, that is, less information of a decision-maker than that a decision-maker must have for predicting the future accurately and rationally, people may become trapped in cognitive biases that force individuals or organizations to behave irrationally and make risk-seeking choices, such as alternative A in this study. When  $p_2$  was high in the high complexity and high uncertainty condition, the validity score maintained high values. This finding indicates that the combination of high complexity and high uncertainty with the high risk of financial trouble forces individuals or organizations to avoid the loss accompanied by investment in safety enhancement, and to eventually choose risk-seeking alternative A.

Figure 4 summarizes the implications of this study. High complexity and high uncertainty trigger inaccurate and irrational (distorted) judgment, decisions, or behavior, thereby leading to major disasters or crashes. Of note, the probability  $p_1$  of major accidents and the probability  $p_2$  of financial trouble accompanied by safety investment also affect risk-seeking irrational behavior. The undesirable flow from high complexity and uncertainty to irrationality to major disasters or crashes must be appropriately managed to prevent future disasters or crashes.



**Figure 4.** Undesirable flow from high complexity and high uncertainty to irrationality to major disasters or crashes.

## 5. Conclusions

The conclusions can be summarized as follows. The validity score for irrational risk-seeking alternative A differed between the (high, high) condition and the (low, low)

condition. The (high, high) condition led to higher validity score for irrational risk-seeking alternative A. The decrease of probability (risk) of a major accident (probability  $p_1$ ) and the increase of economic factor (probability  $p_2$  of financial trouble) also contributed to the increase of validity score of irrational risk-seeking alternative A. The damage of major accident  $\alpha$  contributed to decrease the validity of risk-seeking alternative A.

The results suggest that complexity and uncertainty should be managed appropriately together with the damage of major accident  $\alpha$ , the risk of a major accident (probability  $p_1$ ) and the probability of financial trouble (probability  $p_2$ ) so that an irrational risk-seeking decision or behavior is avoided.

Although this study empirically showed that the (high, high) condition triggered a risk-seeking choice more readily than the (low, low) condition, the limitation of this study is that the approach was based not on an actual situation but on a questionnaire survey of imagined (virtual) situation. Therefore, future work should verify that high complexity and high uncertainty trigger a risk-seeking decision in an on-site plant so that major accidents that stem from an irrational risk-seeking behavior can be prevented. The rather smaller sample size should also be addressed by accumulating more data in future work. Another limitation of the study is that it is difficult to express quantitatively the complexity and the uncertainty in the scenario of decision-making. Future work should attempt to quantify the complexity and the uncertainty in the decision-making scenario.

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**Informed Consent Statement:** All participants provided written informed consent.

**Data Availability Statement:** Not applicable.

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