UNIT FOR RISK MEASUREMENT

Norikazu Hara[†]

Risk is currently evaluated by an indexing measure and not by the risk value itself. This is, however, not an appropriate method of evaluation because risk indexing does not correspond to the risk proper. The most appropriate definition of risk is the expectation of loss because it is necessary to be a dimensional value for comparison. Two components of risk are severity and probability of occurrence. Severity is the amount of loss measured in units of value. The probability, which should be defined as the degree of belief, has no dimension. Accordingly risk has also a dimension of value and should be measured in units of value. Although the entities of risk matrix should be risk itself measured in monetary unit such as dollars, it is clever to use the common logarithm for them. This notion can apply to all other fields where risk is evaluated. As an example, the Risk Priority Number (RPN) currently used in Failure Mode and Effects Analyses (FEMAs) should be replaced. A sound foundation for Quantitative Risk Analysis (QRA) is provided by assuring that risk measure is additive and that risk is evaluated not only relative but also absolutely.

INTRODUCTION

Understanding of the risk associated with human activities is one of the most important concepts to be recognized before these activities are undertaken. Human beings create and recognize value, and a rational human should act so as not to lose this created value. Risk is an important consideration because it provides assurance that the potential value created by undertaken activities is not eroded by the risk associated with their implementation.

Risk has recently been addressed as a resource in the development of new activities[1] or designs. However, the use of risk as a resource is hampered by the fact that there appears to be no unique definition of risk. The term "risk" might apply to an item of concern but these risk items are discriminated from risk in a conceptual sense. The former definition is more properly applied to a "hazard" or an item with the "potential" for risk impact as used in the field of safety analysis.

The most important activity for any project manager is the management of the project risk. This is because the essence of project management is the allocation of scarce project resources in a manner required to best assure the successful development of the project. Therefore to properly manage this allocation of resources the manager must

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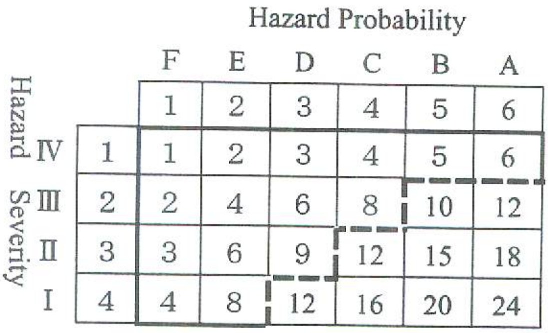
[†] National Space Development Agency of Japan (NASDA), Tokyo, Japan.

identify all the project risk areas, evaluate the potential value erosion impact of each, and continually apply project resources so as to best avoid this potential erosion. However proper risk management requires the proper definition of the risk index used for evaluation and control. Unfortunately, at least at present, the risk index used is somewhat ambiguous.

CURRENT RISK INDEX

Figure 1 shows a typical example using risk index for the safety analysis risk evaluation as provided in the somewhat dated document (NASDA-STD-12).[2] In this example case, severity is categorized into four rows as I: Catastrophic, II: Critical, III: Marginal, and IV: Negligible. The highest score 4 is given to I, and the lowest 1 to IV. The probability of occurrence which is sometimes called likelihood or frequency is categorized into six columns as A: Frequent, B: Reasonably Probable, C: Occasional, D: Remote, E: Extremely Impossible, and F: No Possibility. The highest score 6 is given to A, and the lowest 1 to F. Elements of this evaluation matrix are the products of mathematical multiplication of two kinds of score values. The resulting product values are referred to as "risk indexes." In other situations, such as the effect of the environment or the Risk Priority Number (RPN) in the Failure Mode and Effect Analysis (FMEA), the indexes are essentially given by the same "multiplied scores" definition. A typical decision criterion would be; "The value of risk index greater than or equal to 10 is not acceptable. It is required to take some action for reducing risk of the hazard."



Hazard Severity		Hazard Probability					
		F	E	D	C	B	A
		1	2	3	4	5	6
IV	1	1	2	3	4	5	6
III	2	2	4	6	8	10	12
II	3	3	6	9	12	15	18
I	4	4	8	12	16	20	24

Figure 1 Typical Example of Risk Evaluation for Safety Analysis.

After all hazards are identified, severity and likelihood (or frequency) of each hazard is studied. Then the risk of each hazard is evaluated in terms of its position in the evaluation matrix. The higher values of the risk index are obviously not acceptable items, and conversely the lower value is obviously negligible. The focus of the project manager's is always on items whose risk index value is just inside of the boundary line in the matrix. This area of concern is sometimes referred to as the: as low as reasonably practical (ALARP) area.

However, the question is; does this risk index correspond to the amount of risk? In addition, the numbers of columns and rows are arbitrarily established? Therefore care should be taken in drawing this boundary line, because this is the critical area for the decision for the program manager. Additionally, it should be noted that this evaluation method does not use the risk itself.

DEFINITION OF RISK

There are many definitions for risk in the world. However, we can group them into two types. The first one is "Risk is the concept of combination of degree of loss when the accident happened and degree of likelihood (frequency) of the accident." This type of definition is typically found in the NASA documents. For example, "Exposure to the chance of injury or loss. It is a function of the possible frequency of occurrence of an undesirable event and the potential severity of the resulting consequences,[3] or "An undesirable situation or circumstances that has a realistic probability of occurring and an unfavorable consequences on overall program success."[4] ESA provides a definition that is essentially the same as the NASA's: "an undesirable situation or circumstance that has both a likelihood of occurring and a potential negative consequence on a project."[5]

The other type is found, for example, in US DoD documents. For example, "a measure that takes into consideration both the probability of occurrence and the consequence of a hazard to a population or installation. Risk is measured in the same units as the consequence such as number of injuries, fatalities, or dollar loss. For Range Safety, risk is expressed as casualty expectation or shown in a risk profile."[6] In this definition, risk is casualty expectation and can be measured in the same units as the consequences.

If NASA's or ESA's definition is adopted, another item needs to be defined, namely the evaluation function for the risk. Since, risk is meaningful when it is compared as high or low, and since these comparisons can be made using a value that has only a single dimension, we can compare risks by using only a single dimensioned value. This fact can be easily envisioned by considering the comparison of two rectangles. In this case, an evaluation function could be defined to allow for meaningful comparison. Such a function might be the diagonal length, the peripheral length, the area, or the ratio of length to height.

In the case of risk evaluation, the expectation of loss is the appropriate function. Expectation is the weighted average of the consequences using probability as the weight. This consideration allows the definition of "risk" by NASA as mentioned above to be seen more properly as the definition of a "risky item." "Expectation of loss" as US DoD adopts is the most appropriate for definition of "risk."

It may be said that the word "risk" is used with various adjective words such as "safety risk," "schedule risk," "radioactivity risk," etc. However, all of these are items of concern and these adjectives are no more than the expressions for the severity of the potential consequences due to the identified risky items. Therefore, severity of these must also be accounted for. Even for schedule risk the amount of loss for the schedule delay must be expressed with the unit of value by conversion. This is because the same one month of delay may have a different impact according to the particular time of occurrence and circumstances.

UNIT FOR SEVERITY

Risk is, in other words, the potential for losing value. That is, the two elements in its definition dichotomy are the value lost and its possibility. It is the two concepts together which compose a risk. The former is called severity of the consequence and it is the amount of loss that would be incurred if the accident happened. Many types of loss might be associated with a risky item. In the case when an item is an end unto itself or specifically, in the case of spacecraft, when there are many alternative launch opportunities, even if there is a failure, the loss amount is limited almost to the cost of replacing the item or mission. However, in the case of a one time chance unmanned mission, such as one to the outer planets, or when the launch is not an end to itself but rather is transporting human beings, then the loss incurred due to failure would be much more than the cost of the mission, it could be the value of human life. Although the value for human life may vary with the times and with social background it must be evaluated as every insurance company does. In the case of unmanned missions, the amount of loss may be evaluated in a relatively straight-forward manner. However it usually would be evaluated as much more than the cost. The loss would include the value of the lost opportunities which would have been enabled if the mission had been successful comparable to a value that might be lost in any accident.

In general, there are many values, which might not be considered to be convertible into monetary units. It might be said that human life might not be accounted for in this way. However, this is a somewhat religious or emotional issue rather than an engineering issue. Project managers always have to judge rationally and unemotionally which actions should be taken. They have to estimate the amount of loss when they think of risk. This is because they need to know if they will have to pay a large amount of loss for the accident or if the loss might be considered marginal. Even if the loss is human life, the value assigned should not be infinite. Even if the exact estimation is difficult this is no excuse to use only four ranks, negligible, marginal, critical and catastrophic to measure the risk.

A new unit for severity is suggested here. However any new unit of value might require the conversion to monetary value. Therefore, it is better to use a monetary unit for severity from the beginning. It is not essential to have exact estimation for severity. Just the order of magnitude of the amount of dollars will suffice.

DEFINITION OF PROBABILITY

The definition of probability defined by von Mises has been used in the engineering field up to now.[7,8] This is the limit value of relative frequency. It may be natural and statistical definition because our confidence is formed after many observations. On the other hand, it is difficult to apply this relative frequency definition to one time only events.

Savage defined the probability as the degree of belief on the truth of a proposition.[9] Since in this description the degree of belief a measure of the state of the human heart, a probability so defined is properly called a subjective probability. This definition of probability can also satisfy the three axioms for mathematical probability defined by Kolmogoroff.[9] Therefore, all of the theorems in mathematical probability theory can be applied as in the case of the relative frequency probability definition. If the concept of changing of the degree of belief as new information becomes available is combined with this subjective definition of probability then the approach is referred to as the Bayesian statistical approach. The theory of subjective probability was established early. In fact the definition of probability by Laplace provides an approach to assign a probability when we have no information. Therefore, this definition can be complementary to the above definition for the subjective probability. In information theory, the state of minimum quantity of information is no more than the state where the probability is assigned based on Laplace's definition.

In case of the example of Figure 1 the frequency or likelihood is categorized into six groups from "Frequent" to "No Possibility." These expressions are subjective and are limited to only six groups. In addition, the expression "Frequent" may not have the same meaning to all people. Therefore, it is better to take the frequency or likelihood of the occurrence of the accident as the subjective probability. Once it is taken as the subjective probability the numerical expression for the probability of occurrence can also be obtained. That is, instead of using the word "Frequent," we can use, for example, a probability of 1/10.

The estimation of the probability values may be much more difficult than the estimation of the value of the loss. This may be because we are not accustomed to grasping very small probability values. In the same way that it is hard for us to recognize very large numbers, such as billion or trillion, without training. Fortunately, however, we need not know exact values of loss and probability for risk evaluation. It is sufficient to show the order of the values.

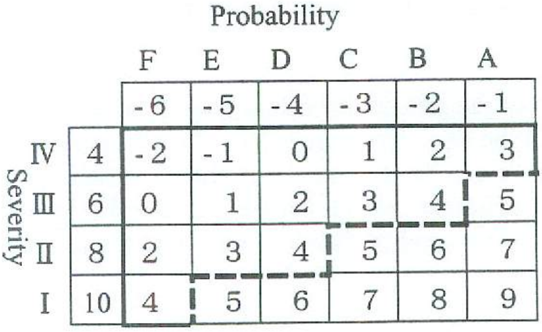
UNIT FOR RISK

The definition for risk mentioned above, implies that risk has the dimension of value. Probability has no dimension and severity can be measured as the amount of loss using unit of monetary value, such as yen or dollars. In this way risk can be measured using same units as severity by remembering that risk is defined as the expectation of loss. Therefore it is not necessary to create a new unit for measuring risk. Some conversion to monetary value would be necessary whenever we try to take an action to control the risk so monetary value will suffice. However, the Risk Index as defined in the next section can be considered a possible unit for risk evaluation. It might be more easily acceptable to people.

USEFUL RISK INDEX

According to the unit for risk mentioned above, we can assign the severity as the real amount of loss in terms of the chosen monetary unit. For example, catastrophic might mean more than a 10 billion dollar loss and so on, and we can assign a real number for the probability, for example, frequent means one tenth and so on. In this case we could enter the "real" value of risk in every entry of the matrix shown in Figure 1, instead of the risk index. The real values would be the products of the amount of loss and the probability value mentioned above. In this case we might accept a risk of less than or equal to ten thousand dollars.

It is convenient to use the common logarithm for the probability and loss, since we need to know only the order of magnitude. In this case the example of Figure 1 will change to Figure 2. The numbers are replaced with the products of scores of Figure 1 compose the revised risk index. We will then find the border of ALARP is different from the former one. This shows the reason why we should evaluate risk with risk itself. The number, –2, of risk index corresponds to 1 cent and therefore we should neglect such an item. The boundary line of Figure 2 is drawn so that we would accept a risk index of less than or equal to 4. The rows for severity can then be increased from only four, to 6,8, or 10, as we like. We may even say that the matrix itself is no longer needed.



Severity			F	E	D	C	B	A
			-6	-5	-4	-3	-2	-1
	IV	4	-2	-1	0	1	2	3
	III	6	0	1	2	3	4	5
	II	8	2	3	4	5	6	7
	I	10	4	5	6	7	8	9

Figure 2 Safety Evaluation with Revised Risk Index for Figure 1.

The matrix of Figure 1 can be taken as an ordering function for 24 (4x6=24) kinds of hazards. Giving the scores of 1 to 4 to the severity and giving 1 to 6 to the probability, the function defined as the product of these scores takes on 15 values. That is, Figure 1 is a mapping function from 24 states (two dimension) to 15 states (one dimension). Similarly, Figure 2 shows another mapping function from 24 states (two dimension) to 12 states (one dimension). However, there is an important difference. In the case of the latter function the risk is properly considered.

Figure 3 shows how the mapping function works on decision making for the acceptance of risk. There were 24 kinds of risky states in the Figure 1 example case. However always only two states are required to be considered at the time a decision must be made.

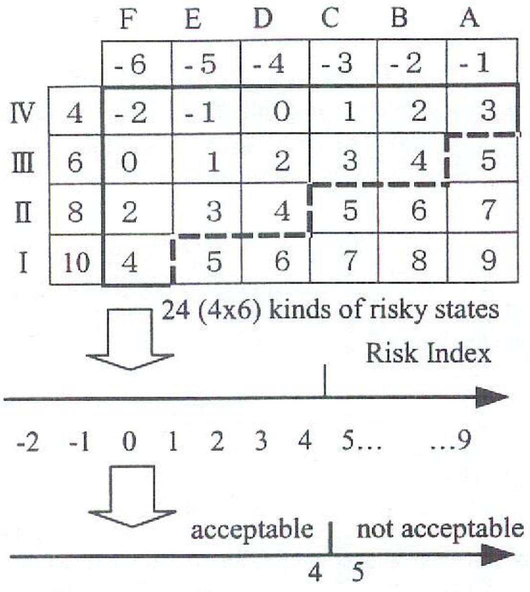


Figure 3 Mapping Function and Decision Making.

FMEA AND RISK PRIORITY NUMBER (RPN)

There are many analyses, such as environmental effect analyses or FMEAs, where risk is required to be evaluated. Recognizing that risk can be measured with monetary units implies that the main part of these analyses must be revised for proper risk evaluation. Failure Mode and Effect Analysis (FMEA) or Failure Mode, Effect and Criticality Analysis (FMECA) have been typically useful reliability analyses in the past and they may be used in the future also. However, it must be pointed out that the Risk Priority Number (RPN) developed in these analyses does not correspond to the risk itself.[10]

The RPN is introduced as an index number for expressing the importance of each item. The RPN of a component is determined by the multiplication of three score numbers. These are the severity of the consequence given the item fails, the possibility of defects in the component as the failure cause, and the possibility of detection of the defects. The range of the scores is arbitrarily, for example, from 1 to 5, or 1 to 10.

For components with large RPN values some countermeasures must be taken to avoid or mitigate the risk.

There are two important possibilities: The possibility of the defects being incorporated (Probability; Pi) and the possibility of overlooking the defects (Probability; Po). These, when combined, produce the possibility of the failure (Probability; Pf). Where, the possibility of overlooking of the defects, Po, is a conditional probability conditioned on the defects having been incorporated.

The total probability, is determined from the conditional probability by the relation, Pf = Pi x Po. This relation implies that the two possibilities should be multiplied in terms of their probabilities, Pi and Po above. Instead for the RPN in the current use, the score numbers of two possibilities are multiplied. It should be pointed out that in this current approach the RPN is no more than the product of three scores. The RPN does not correspond to risk defined as expectation of loss.

Table-1 Main Part of Revised FMEA

Item Name	Failure Mode	Loss SI	Probability PI=OI+DI	Occurrence OI	Detection DI	Risk Index CLR=SI+PI
Engine Chamber	Burn loss	10.0	–5.0	–3.0	–2.0	5.0

Where; (entities are an example)
SI : Severity Index (= common logarithm of Loss (dollar))
PI : Probability Index (= common logarithm of Failure Probability = OI+DI)
OI : Occurrence Index (= common logarithm of Failure Cause Existence Probability)
DI : Detection Index (= common logarithm of Overlooking Probability)

Table 1 shows the main part of a revised FMEA table with same idea of measuring risk, replacing RPN with CLR (Common Logarithm of Risk). If we take a digit after decimal point for CLR, a digit for absolute risk value is obtained. For example, CLR=4.3 corresponds to a 20,000 dollar risk.

CONCLUDING REMARKS

The most appropriate definition of risk is the expectation of loss. The unit of risk is then the same as a unit of value. We need not establish a new unit of value for risk beside the traditional monetary unit. In this case the risk should be measured in units of yen or dollars. As the risk index, it is useful to adopt common logarithm of risk measured with dollars. A risk matrix would be no longer necessary to show risk with the unit of value. However it is good practice to remember each of the two elements of risk, the amount of loss and the probability of occurrence.

Usually additional cost is required to reduce or to control risk. This additional cost should be paid only if the reduction of risk is much higher than the additional cost. It is quite natural that the upgrades program for the Space Shuttle is being conducted based on the QRA (Quantitative Risk Assessment).[11,12] However, as the foundation for the risk concept, the unit for risk measurement described in this paper must be clearly recognized.

Projects may proceed even if they are costly and also of high risk. However this should be allowed only when the mission value is high enough. That is mission value should be greater than the cost of the mission plus its expected risk measured in the same cost terms. This criterion should be a necessary condition to be satisfied prior to obtaining the ATP (Authorization To Proceed) for every project. To enable this evaluation risk must be measured in units of monetary value.

The concept of value was created by humans and therefore it depends on the variety of subjective perspectives across the human race. Similarly, the amount of loss also depends on the variety of subjective perspectives. Further, the concept of risk is a human concept and therefore it also depends on the varying perspectives. In addition, the probability to be assigned to the amount of loss is also subjective as has been discussed. Despite the fact that the components of the risk dichotomy, the value of loss and its associated probability, are both subjective, the subjective probability approach is not accepted as the primary approach taken for project risk management in the field of engineering. This is both curious and unfortunate.

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