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Centralized Risk Value Calculation Method in Qualitative Risk Analysis Phase

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Abstract- The risk analysis phase of the construction risk management process is subdivided into qualitative and quantitative risk analysis phases, in which qualitative risk analysis plays a major role and quantitative risk analysis plays a supportive role. However, the traditional risk value calculation method, which has been applied as a method of quantifying risk in the qualitative risk analysis phase, simply multiplies the probability of occurrence and the impact, and the resulting values show a biased distribution at low risk. As an alternative, a calculation method that is biased toward high risk is proposed, but if the risk distribution is biased toward low or high risk, it does not conform to the statistical general logic that most natural phenomena are close to the normal distribution. In this study, we propose a new risk value calculation method where the risk distribution is centralized. Through this, the risk distribution is expressed in a form similar to the normal distribution of natural phenomena so that the level corresponding to the risk can be reasonably selected from the medium risk without being inclined to high or low risk. It could also contribute to improve the flexibility and rationality of risk analysis phase by providing additional options for risk value calculation.

Keywords –Risk Management, Risk Analysis, Centralized Risk, Risk Value, Risk Contour

I. INTRODUCTION

Change is the essence of the construction business. Over the past few years, the construction industry has failed to meet its time, cost and quality goals and has been dishonored to be very vulnerable to coping with the adverse effects of change. A systematic approach is needed to successfully cope with change, which recognizes the source of the risk (risk identification phase), quantifies its effects (risk analysis phase), develops a response strategy (risk response phase), and finally determines the residual risk.(Smith, 1999)

The risk analysis phase of the construction risk management process is subdivided into qualitative and quantitative risk analysis phases, in which qualitative risk analysis plays a major role and quantitative risk analysis plays a supportive role. The traditional risk value calculation method applied to the qualitative risk analysis phase is the same as that for calculating the expected value from an economic point of view. That is, a formula that simply multiplies the probability that a particular event will occur and the profit or loss that can occur due to the event. Since this method has been recognized as the most common and rational across the industry so far, it has been accepted that it is natural and reasonable to calculate the magnitude of the risk as the product of the probability of occurrence of the risk and its impact in the risk analysis stage. However, when the magnitude of the risk is simply determined by the product of the probability of occurrence and the degree of impact, the distribution of the risk shows a phenomenon in which the high risk occupies a very small range, whereas the low risk is concentrated on the low risk, which occupies a large range. Such low-risk biases are likely to make passive responses to risks by assessing most risks at a low level.

As an alternative to the traditional risk value calculation method, a new risk value calculation method that deducts the product of the probability of occurrence and the degree of impact from the sum of the probability of occurrence and the degree of impact was proposed.(Dele Cooper et al., 2004) Unlike the traditional risk value calculation method, the distribution of risks calculated by the new method shows the phenomenon that high risks tend to occupy very large ranges, whereas low risks tend to bias high risks occupying very small ranges. Of course, Dele's proposal can be thought of as a non-logical or unreasonable method from the viewpoint of the traditional method of calculating expected values that is generally accepted. However, from the perspective of actively responding to risks, it can be evaluated as a new approach to risk assessment.

However, when the risk distribution is biased toward low or high risk, it does not conform to the statistical general logic that most natural phenomena are close to the normal distribution. Of course, there is no justification that the distribution of risk must be a normal distribution. Nevertheless, as an alternative to solving the distortion phenomenon in which the risk distribution is biased toward low risk or high risk, a new risk value calculation method that forms a normal distribution focused on the medium risk needs to be explored.

In this study, we propose a new risk value calculation method in which the distribution of risk is concentrated in the center. Through this, the risk distribution is expressed in a form similar to the normal distribution of natural phenomena so that the level corresponding to the risk can be reasonably selected from the medium risk without being inclined to high or low risk. Furthermore, it could contribute to improve the flexibility and rationality of risk analysis phase by providing additional options for risk value calculation method.

II. Research Scope and Methods

This study was conducted in the following method and order. First, the qualitative risk value calculation methods proposed so far are considered and their limitations are analyzed. Second, it presents the necessity for a risk value calculation method that represents a distribution format focusing on medium risk. Third, we propose the centralized risk value calculation method that concentrates on medium risk. Fourth, the existing risk value calculation methods and the centralized risk value calculation method are compared and verified through real cases. The scope of this study is limited to the method of calculating the risk in the qualitative risk analysis phase of the construction risk management process.

III. Review of Risk Analysis and Risk Value Calculation Mehtods

A. Risk Analysis Overview

The purpose of the risk analysis phase in the construction risk management process is to determine which risk factors should be responded. To do so, first, objectively assess the probabilities and impacts of each risk factor, secondly create a list of the shortest or most important risks that are likely to be responded, and finally decide whether or not to implement the response.(Mulcahy, 2003)

The risk analysis phase is to evaluate how the risk factors perceived in the risk identification phase will affect the project, and quantify the magnitude of the risk by analyzing the probability of occurrence of the perceived risk and the degree of impact from the risk. The techniques applied to quantify risk in the risk analysis phase are largely divided into qualitative and quantitative methods according to the acquisition of objective data for risk analysis and the repeatability of risk factors. The qualitative method is a method in which a risk assessment group measures the risk in terms of grades when the objective data for risk analysis is insufficient and the risk factor has non-repetitive characteristics. The quantitative method is a method to measure the risk through statistical probability analysis technique when objective data for risk analysis is sufficient and risk factors have repetitive characteristics. In general, construction projects, unlike manufacturing, have non-repetitive characteristics, so most risk analysis uses a qualitative method and a quantitative method in special cases.(Edwards 1995)

B. Risk Value Calculation Method

The purpose of the risk analysis phase in the construction risk management process is to determine which risk factors should be responded. To do so, first, objectively assess the probabilities and impacts of each risk factor, secondly create a list of the shortest or most important risks that are likely to be responded, and finally decide whether or not to implement the response.(Mulcahy, 2003)

The magnitude of the risk derived from the risk analysis phase is generally called the Risk Value (RV) which is traditionally defined as Eq. (1) as a function of the probability of risk occurrence (P) and the degree of the impact of the risk (C).

$$\mathrm{RV} = \mathrm{f}(\mathrm{P}, \mathrm{C}) \tag{1}$$

So far, two types of risk value calculation have been proposed as a method of calculating the risk value by applying Eq. (1). The first is the most common and widely applied method from the time when the risk management technique was first introduced to the present. It is a calculation method that calculates the risk value by simply multiplying the probability of occurrence and impact of the risk factor, and the calculated risk distribution shows the characteristic that the risk is biased toward low risk. The second is a calculation method that adds the probability of occurrence of risk factors and the degree of impact and then multiplies them, and the calculated risk distribution shows the characteristic that the risk is biased toward high risk as opposed to the first method.

C. Low Risk Biased Risk Value Calculation Method

This method is the most common method of calculating the risk value. It is the same as Eq. (2) for calculating the risk value (RV_i) by simply multiplying the probability of occurrence (P_i) and the impact (C_i) of the risk factor i.

$$RV_i = P_i \times C_i \quad (2)$$

In Eq. (2), the range of probability of occurrence and the impact is assumed to be the same scale from 0.0 to 1.0. Then, the risk probability is calculated by increasing the probability of occurrence and the impact by 0.1, respectively, and the risk values are displayed as contours on a two-dimensional square, as shown in Figure 1.

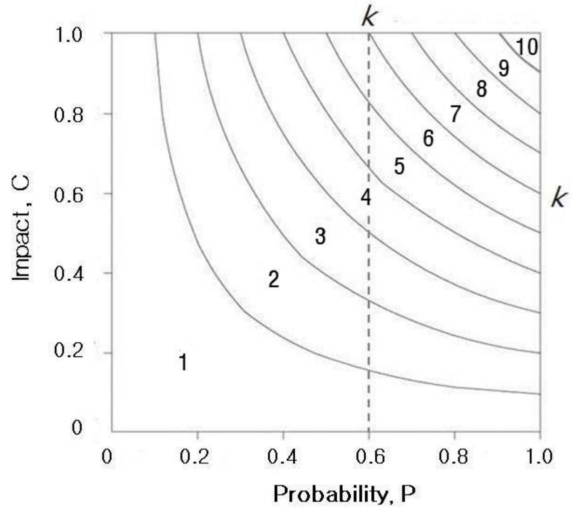

Figure 1. Contour of $RV_i = P_i \times C_i$

Figure 1 shows the contour of the top right corner with a probability of occurrence of 1.0 and an impact of 1.0, the highest risk level of 1.0, and the downward trend toward the bottom left, with the lowest risk level of 0.0 at the lower left corner of probability of occurrence of 0.0 and an impact of 0.0 to be. If a particular risk factor is assumed to have a high probability of occurrence of 0.8 and a very low impact of 0.2, the risk value is calculated as 0.16 from Eq. (2). This risk factor is located at level 2, which is the lowest grade in the contour line, divided from the lowest level 1 to the highest level 10 in Figure 1. Therefore, if the risk is estimated by Eq. (2), most of the risks are underestimated when the probability of occurrence or impact is not high. In order to accurately grasp these phenomena, it is necessary to calculate and compare the risk area for each contour line.

In order to calculate the area of risk value for each contour line, it can be defined as Eq. (3) assuming that k is an arbitrary contour line in Figure 1. Substituting this as an impact is the same as that of Eq. (4). The equation for integrating Eq. (4) from point k to point 1.0 in Figure 1 is shown in Eq. (5).

$$k = P \times C \quad (3)$$

$$C = \frac{k}{P} \quad (0 < k \leq 1) \quad (4)$$

$$\int_k^1 \frac{k}{P}\, dP = k[lnP]_{P=k}^{P=1} = -klnk \quad (5)$$

Since the rectangular area from the point k of Figure 1 to the point 1.0 is the same as Eq. (6), the area (S_k) based on the contour line k is summarized as in Eq. (7) in which Eq. (5) is subtracted from Eq. (6).

$$(1 - k) \times 1 \quad (6)$$

$$S_k = (1 - k) \times 1 - (-kink) = kink - k + 1 \quad (7)$$

In Eq. (7), after increasing the value by 0.1 and calculating the risk area for each contour line from the lowest level 1 to the highest level 10, subtracting the previously calculated areas from each area, the individual areas of risk for each contour line are calculated. When these are displayed in bar graph format, they are represented as in Figure 2.

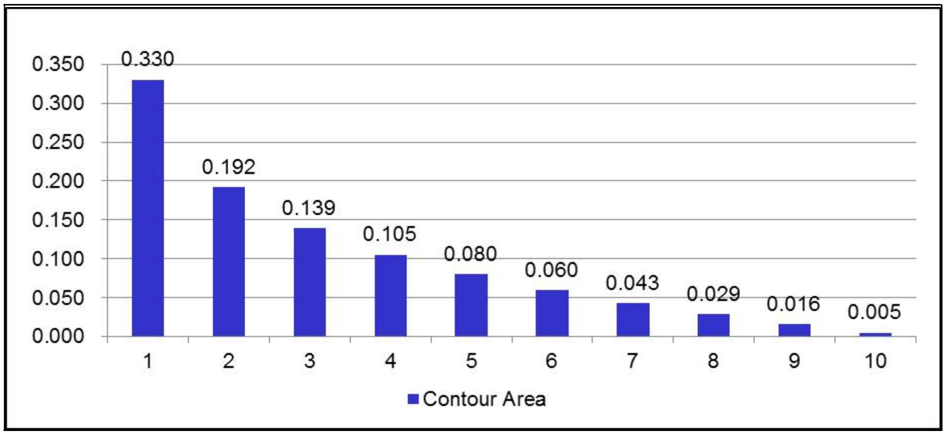

Figure 2. Contour Areas of $RV_i = P_i \times \ C_i$

Figure 2 shows that the contoured individual risk areas are gradually decreasing from the lowest level 1's 33% to the highest level 10's 0.5%. From these results, it can be confirmed that the risk value calculation Eq. (2) is a low-risk biased risk value calculation method that is concentrated at low risk.

D. High Risk Biased Risk Value Calculation Method

This method was proposed as in Eq. (8) to compensate for the low risk bias in Eq. (2).(Dele Cooper et al. 2004) Eq. (8) calculates the risk value (RV_i) by simply adding the probability of occurrence (P_i) and the impact (C_i) of the risk factor i and then subtracting the product of the probability of occurrence and impact.

$$RV_i = P_i + C_i - (P_i \times \ C_i) \tag{8}$$

In Eq. (8), the range of probability of occurrence and impact is assumed to be the same scale from 0.0 to 1.0. Then, the risk probability is calculated by increasing the probability of occurrence and the impact by 0.1, respectively, and the values are displayed as contours on a two-dimensional square, as shown in Figure 3.

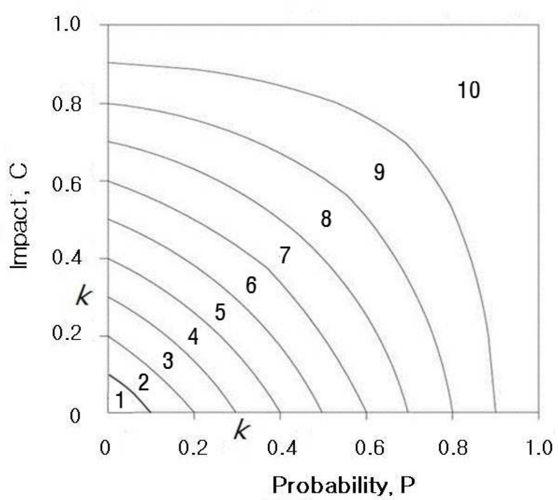

Figure 3. Contour of $RV_i = P_i + C_i - (P_i \times \ C_i)$

Figure 3 shows the contour of the top right corner with a probability of occurrence of 1.0 and an impact of 1.0, the highest risk level of 1.0, and the downward trend toward the bottom left, with the lowest risk level of 0.0 at the lower left corner of probability of occurrence of 0.0 and an impact of 0.0 to be. If a particular risk factor is assumed to have a high probability of occurrence of 0.8 and a very low impact of 0.2, the risk value is calculated as 0.84 from Eq. (8). This risk factor is located at level 9, which is the highest grade in the contour line, divided from the lowest level 1 to the highest level 10 in Figure 3. Therefore, when the risk is estimated by Eq. (8), even if only one of the probability of occurrence or impact is high, most of the risks are high risk bias. In order to accurately grasp these phenomena, it is necessary to calculate and compare the risk area for each contour line.

In order to calculate the area of risk value for each contour line, it can be defined as Eq. (9) assuming that k is an arbitrary contour line in Figure 3. Substituting this as an impact is the same as that of Eq. (10).

$$k = P + C - PC \quad (0 < k \leq 1) \tag{9}$$

$$C = \frac{k-P}{1-P} = 1 + \frac{k-1}{1-P} \quad (0 < k \leq 1) \tag{10}$$

Since the area (S_k) per contour line from point 0.0 to point k in Figure 3 can be integrated by Eq. (10), it can be expressed by the following Eq. (11).

$$\begin{aligned} S_k &= \int_0^k \left(1 + \frac{k-1}{1-P}\right) dP \\ &= [P - (k-1)ln(1-P)]_{P=0}^{P=k} \\ &= [P + (1-k)ln(1-P)]_{P=0}^{P=k} \\ &= k + (1-k)In(1-k) \end{aligned} \tag{11}$$

In Eq. (11), the contoured risk areas are calculated from the lowest level 1 to the highest level 10 by increasing the value by 0.1, and then subtract the previously calculated areas from each of them to calculate the contoured individual risk areas. If they are displayed in bar graph form, they are shown in Figure 4.

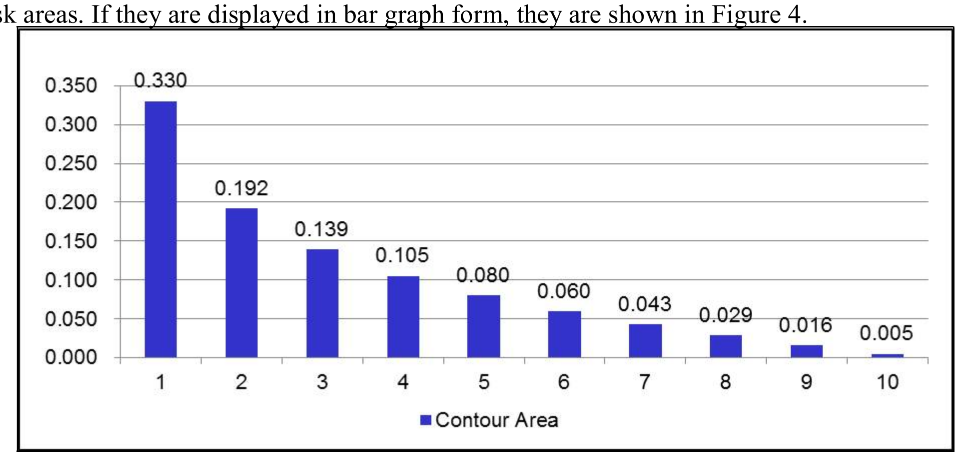

Figure 4. Contour Areas of $RV_i = P_i \times \ C_i - (P_i \times C_i)$

Figure 4 shows that the contoured individual risk areas are gradually increasing from the lowest level 1's 0.5% to the highest level 10's 33%. From these results, it can be confirmed that the risk value calculation Eq. (8) is a high-risk biased risk value calculation method that is concentrated at high risk as opposed to the risk value calculation Eq. (2).

IV. CENTRALIZED RISK VALUE CALCULATION MEHTOD

A. Need for a New Risk Value Calculation Method

The results of the existing risk value calculation methods are biased to low or high risk, which confirms that they are far from natural phenomena. In general, the distribution that most closely represents a natural phenomenon is called a normal distribution.(Walpole et al. 1985) That is, many of the world's phenomena follow a normal distribution because most of the management, economic, social, and natural phenomena have a normal distribution.(Park, 2003) Of course, all the phenomena in the world cannot be expressed only by the normal distribution, and there may be cases where the distribution is biased toward one side. Nevertheless, the results of the existing risk value calculation methods are so biased to one side that there is a lot of problems in securing the reliability of the risk analysis results. Therefore, in order to secure universal validity and reliability while being closest to the most natural phenomena, it is necessary to find a new risk value calculation method in which risk values have a normal distribution and are centrally distributed at medium level risk.

B. Centralized Risk Value Calculation Method ($0 < C \leq 1$)

In this study, when the estimated range of the impact for each risk is from 0.0 to 1.0, which is the same as the estimated range of the probability of occurrence, Eq. (12) is proposed as a risk value calculation method in which risk values tend to be centralized similarly to a normal distribution. Eq. (12) is to calculate the risk value (RV_i) by dividing the probability of occurrence of the risk event i by the probability (P_i) and the impact (C_i) by two.

$$RV_i = \frac{P_i + C_i}{2} \tag{12}$$

In Eq. (12), if the probability of occurrence and the impact are increased by 0.1 each from 0.0 to 1.0, the resulting risk values are represented by contour lines on a two-dimensional square as shown in Figure 5. Figure 5 shows the contour of the top right corner with a probability of occurrence of 1.0 and an impact of 1.0, the highest risk level of 1.0, and the downward trend toward the bottom left, with the lowest risk level of 0.0 at the lower left corner of probability of occurrence of 0.0 and an impact of 0.0 to be, as shown in Figure 1 and Figure 3.

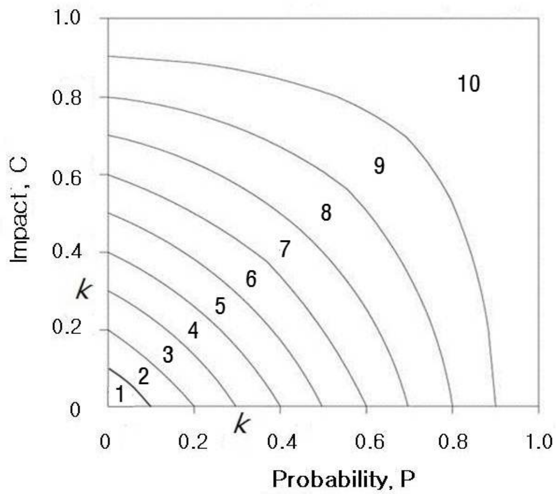

Figure 5. Contour of $RV_i = \frac{P_i + C_i}{2}$

If a particular risk factor is assumed to have a high probability of occurrence of 0.8 and a very low impact of 0.2, the risk value is calculated as 0.5 from Eq. (12). On the contrary, if the probability of occurrence is very low 0.2 and the impact is very high 0.8, the risk value is calculated from Eq. (12) as 0.5. These risk values are located at the middle level 5 in the contour line divided from the lowest level 1 to the highest level 10 in Figure 5. When the risk value is calculated by Eq. (12), the probability of occurrence or impact is balanced. In addition, it can be seen that there is a medium risk concentration phenomenon, in which the medium risk is high. . In order to accurately grasp these phenomena, it is necessary to calculate and compare the risk area for each contour line.

Assuming *k* is an arbitrary contour in Figure 5, the coordinates of (P, C) are defined differently in the lower part and the upper part based on the central contour line connecting (1.0, 0.0) and (0.0, 1.0). Therefore, the area of risk value for each contour line should be calculated differently.

First, based on the center contour, the contour of the lower part can be defined as Eq. (13). Substituting this as an impact, it is the same as Eq. (14).

$$k = P + C \quad (0 < k \leq 1) \tag{13}$$
$$C = k - P \quad (0 < k \leq 1) \tag{14}$$

Therefore, the triangle area at the lower part of the center contour in Figure 5 is expressed by Eq. (15), which integrates from point 0.0 to point k.

$$\begin{aligned} \int_0^k (k-P)\,dP &= \left[kP - \frac{P^2}{2}\right]_{P=0}^{P=k} \\ &= \frac{k^2}{2} \quad (0 < k \leq 1) \end{aligned} \tag{15}$$

Second, based on the center contour, the contour of the upper part can be defined as Eq. (16) by adding '1' to Equation (14). In Figure 5, the triangle area (S_k) at the upper part of the center contour in Figure 5 is expressed by Eq. (17), which integrates Eq. (16) from point k to point 1.0.

$$C = (1 + k) - P \quad (0 < k \leq 1) \tag{16}$$

$$\int_k^1 (1+k-P)\,dP = \left[(1+k)P - \frac{P^2}{2}\right]_{P=k}^{P=1}$$
$$= \frac{1-k^2}{2} \quad (0 < k \leq 1) \tag{17}$$

The rectangular area (S_r) from the point k in Figure 5 to the point 1.0 is shown in Eq. (18). Therefore, the triangular area (S_k) based on the center upper contour line k is summarized as Eq. (19) which subtracts Eq. (17) from Eq. (18).

$$S_r = (1-k) \times 1 \tag{18}$$
$$S_k = (1-k) \times 1 - \frac{1-k^2}{2} = \frac{(1-k)^2}{2} \tag{19}$$

After calculating by increasing the value from 0.0 to 1.0 by 0.2 in Eq. (15), subtracting the previously calculated areas from each area, the individual areas of risk from level 1 to level 5 are calculated. In addition, in Eq. (19), the value is increased by 0.2 from 0.0 to 1.0, and if the calculated areas are subtracted from each area, the individual areas of risk from levels 6 to 10 are calculated. The risk-specific individual areas calculated in this way are expressed in bar graph form as shown in Figure 6.

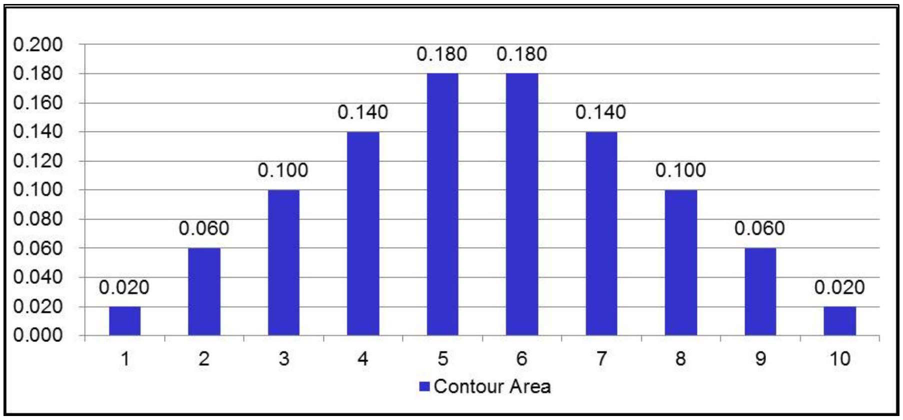

Figure 6. Contour Area of $RV_i = \frac{P_i + C_i}{2}$

Looking at the distribution of individual risk areas by level in Figure 6, it is the highest at 18% of the level 5 and 6, which is the center of the total distribution, and gradually decreases to 2% of the level 1 and 10, respectively. From these results, it can be confirmed that the risk value calculation Eq. (12) is a centralized risk value calculation method in which high risk is centrally distributed. In other words, the risk value of Eq. (12) is similar to the normal distribution close to natural phenomena, unlike the risk values of Eq. (2) and Eq. (8), which are biased toward low risk or high risk, indicating extreme distribution. It can be seen that it is intensively distributed in the middle risk.

C. Centralized Risk Value Calculation Method ($0 < C \leq C_{max}$)

Eq. (12) is a risk value calculation method that tends to be centered under limited conditions of 0.0 to 1.0 impact. However, even if the probability of occurrence is limited to a range of 0.0 to 1.0, the maximum limit of impact is often not limited to 1.0. For example, Edwards (1995) divides the financial impacts on organizations from 1 to 6 levels, and Muclcahy (2003) classified the excess of business budgets into 1 to 10 levels. Furthermore, there are many cases where the excess range of the budget is classified by amount or the excess range of duration is classified by the number of delay days. However, if the range of influence exceeds 1.0, the risk values calculated by applying Eq. (12) are expressed in a form similar to a uniform distribution, not a normal distribution. For example, if the range of probability is 0.0 to 1.0, but assuming that the range of influence is 0.0 to 10.0 and applying Eq. (12), the resulting risk values appear as a contour as shown in Figure 7.

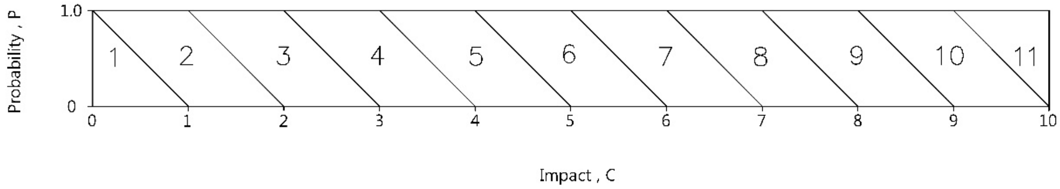

Figure 7. Contour of $RV_i = \frac{P_i+C_i}{2}$ $(0.0<C_i\leq 10.0)$

In the contour of Figure 7, the 1 and 11 levels are calculated by a simple triangle area, and the 2 through 10 levels are calculated by the parallelogram area. If the individual areas from level 1 to level 11 are displayed in bar graph format, it is expressed as in Figure 8.

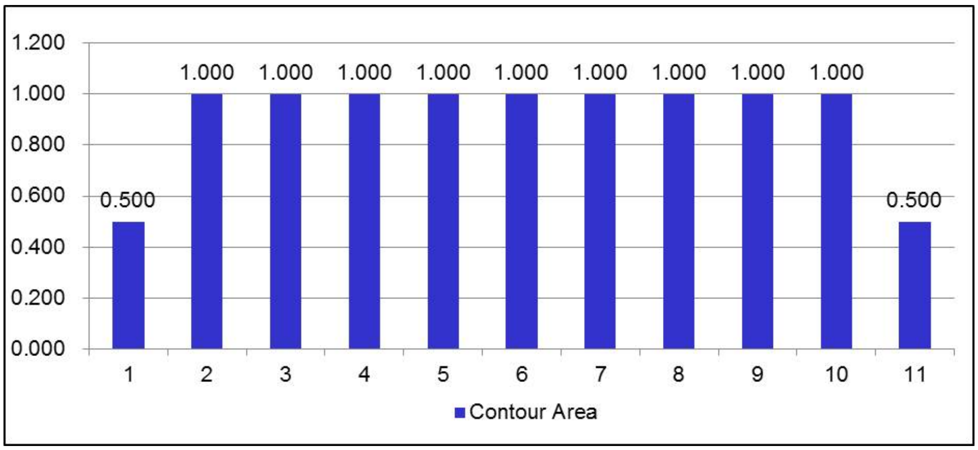

Figure 8. Contour Area of $RV_i = \frac{P_i+C_i}{2}$ $(0.0<C_i\leq 10.0)$

Looking at the individual area distribution of risk values in each level in Figure 8, the lowest and lowest rates of 5% in the 1st and 11th levels, which are the left and right sides of the total distribution, show the even distribution of 10% from the 2nd to 10th level in the middle. In this distribution, it can be seen that the risk values are more affected by the magnitude of the impact than the probability. In order to confirm that the risk value by Eq. (12) is affected by the magnitude of the impact, assuming that the range of the effect is increased by 10 times than in Figure 7, and assuming that 0.0 to 100.0, applying Eq. (12), the resulting risk values appear as contour lines as shown in Figure 9.

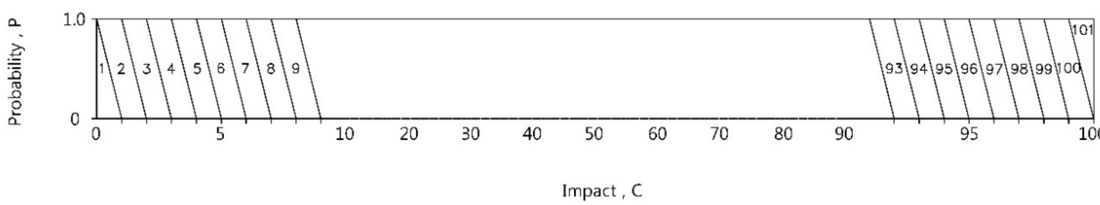

Figure 9. Contour of $RV_i = \frac{P_i+C_i}{2}$ $(0.0<C_i\leq 100.0)$

In Figure 9, the risk contours are represented almost vertically by level, which clearly shows that the risk values change proportionally with the magnitude of the impact. If the resulting risk value changes proportionally with the magnitude of the impact as shown in Figure 9, the new equation (12) does not meet the original proposed purpose to ensure that the risk distribution is expressed in a form similar to a normal distribution close to natural phenomena. Therefore, it is necessary to modify Eq. (12) so that even if the range of impact extends beyond 1.0, the risk distribution is similar to the normal distribution.

In this study, when the probability of occurrence of risk factors is limited from 0.0 to 1.0, and the impact range extends from 0.0 to the maximum value C_{max}, Eq. (20) is proposed as a risk value calculation method that the risk value tends to be centered similar to the normal distribution. In Eq. (20), the risk value (RVi) is calculated by multiplying the probability of occurrence of risk factor (Pi) by the maximum impact (C_{max}) and adding the impact (Ci), then dividing by two.

$$RV_i = \frac{P_i \times C_{max} + C_i}{2} \tag{20}$$

Eq. (20) extends the range of probability of occurrence equally to the range of impact so that the risk values are distributed in a square as shown in Figure 5. In Eq. (20), the probability of occurrence is increased from 0.0 to 1.0 and the impact is increased from 0.0 to C_{max}, and the risk values are represented by the contour lines on the square, as shown in Figure 10.

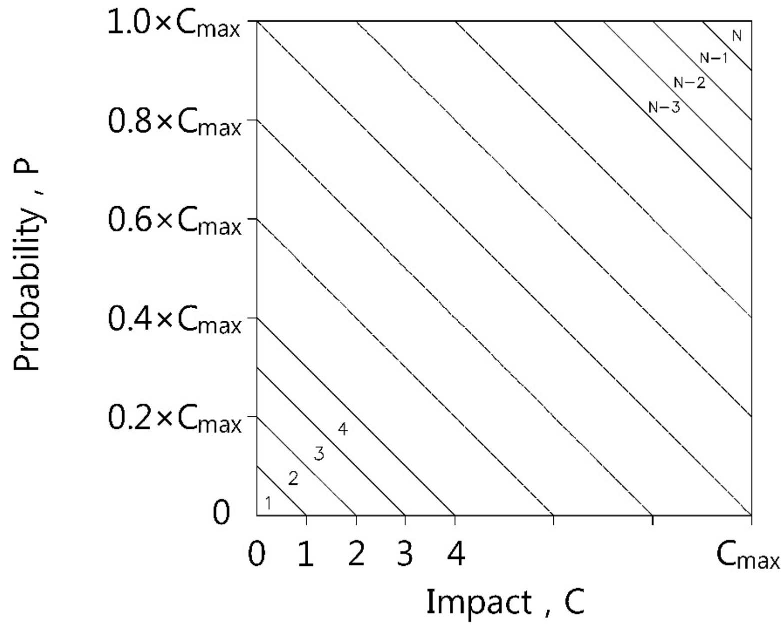

Figure 10. Contour of $RV_i = \frac{P_i + C_i}{2}$ ($0.0 < C_i \leq C_{max}$)

In Figure 10, the contour lines from level 1 to N are the same as in Figure 5, so the risk area distribution for each level based on Figure 10 shows the distribution centered on the medium risk as in Figure 6. As a result, while Eq. (12) is a basic equation for calculating the centralized risk under conditions that limit the probability of occurrence and the range of effects from 0.0 to 1.0, Eq. (20) confirms that even if the range of influence is expanded indefinitely, the centralized risk value calculation method focuses on the intermediate risk without changing the risk values.

V. Verification of Centralized Risk Value Calculation Mehtod

Eq. (2) and Eq. (8), which are traditionally applied, and Eq. (20) proposed in this study are applied to real cases and the results are compared with each other to verify centralized risk value calculation method. This study extracts three of the common risk factors in general construction work and applies two types of rating ranges to each. The first is the case where the probability of occurrence and the degree of impact are equally applied in the range of 0.0 to 1.0, and the results of calculating the risk values by Equations (2), (8) and (20) are shown in Table 1.

In Table 1, Risk Factor No. 1 ‘Design Change of Substructure’ is a higher risk with a probability of occurrence of 0.9 and an impact of 0.8. The risk value by Eq. (2) is 0.72, which corresponds to the contour level 8 in Figure 1, and the risk value by Eq. (8) is 0.98, which corresponds to the contour level 10 in Figure 3, and the risk value by Eq. (20) is 0.85, which corresponds to level 9 of the contour line in Figure 5. Risk Factor No. 2 'Procurement Delay of Curtain Walls' is a medium risk with a probability of occurrence of 0.4 and an impact of 0.6. The risk value by Eq. (2) is 0.24, which corresponds to the contour level 3 in Figure 1, and the risk value by Eq. (8) is 0.76, which corresponds to the contour level 8 in Figure 3, and the risk value by Eq. (20) is 0.50, which corresponds to level 5 of the contour line in Figure 5. Risk Factor No. 3 'Quality Deterioration of Cold Weather Concrete' is a lower risk with a probability of occurrence of 0.2 and an impact of 0.3. The risk value by Eq. (2) is 0.06, which corresponds to the contour level 1 in Figure 1, and the risk value by Eq. (8) is 0.44, which corresponds to the contour level 5 in Figure

3, and the risk value by Eq. (20) is 0.25, which corresponds to level 3 of the contour line in Figure 5. From these results, it can be confirmed that Eq. (2) represents a risk value that is biased toward low risk, Eq. (8) represents a risk value that is biased toward high risk, while Eq. (20) indicates a risk value that is focused on medium risk.

Table -1 Comparison of Risk Value Calculation Methods ($0.0<P_i\leq1.0$, $0.0<C_i\leq1.0$)

No	Risk Factor	Prob. (P_i)	Impact. (C_i)	Risk Value(RV_i)		
				Eq. (2)	Eq. (8)	Eq. (20)
1	Design Change of Substructure	0.9	0.8	0.72	0.98	0.85
2	Procurement Delay of Curtain Wall	0.4	0.6	0.24	0.76	0.50
3	Quality Deterioration of Cold Weather Concrete	0.2	0.3	0.06	0.44	0.25

The second is the case where the probability of occurrence is in the range of 0.0 to 1.0, but the degree of impact is extended to the range of 0.0 to 10.0, and the results of calculating the risk values by Equations (2), (8) and (20) are shown in Table 2. Increasing the rating range of impact by 10 times than the first case yields a maximum risk value of 10.0, and if the risk value is divided into 1.0 unit from 0.0 to 10.0, the risk level is divided into the lowest 1 and the highest 10 levels.

Table -2 Comparison of Risk Value Calculation Methods ($0.0<P_i\leq1.0$, $0.0<C_i\leq10$)

No	Risk Factor	Prob. (P_i)	Impact. (C_i)	Risk Value(RV_i)		
				Eq. (2)	Eq. (8)	Eq. (20)
1	Design Change of Substructure	0.9	8	7.2	1.7	8.5
2	Procurement Delay of Curtain Wall	0.4	6	2.4	4.0	5.0
3	Quality Deterioration of Cold Weather Concrete	0.2	3	0.6	2.6	2.5

In Table 2, in case of Risk Factor No. 1, the risk value by Eq. (2) is 7.2, which corresponds to the contour level 8, the risk value by Eq. (8) is 1.7, which corresponds to the contour level 2, and the risk value by Eq. (20) is 8.5, which corresponds to the contour level 9. In case of Risk Factor No. 2, the risk value by Eq. (2) is 2.4, which corresponds to the contour level 3, the risk value by Eq. (8) is 4.0, which corresponds to the contour level 4, and the risk value by Eq. (20) is 5.0, which corresponds to the contour level 5. In case of Risk Factor No. 3, the risk value by Eq. (2) is 0.6, which corresponds to the contour level 1, the risk value by Eq. (8) is 2.6, which corresponds to the contour level 3, and the risk value by Eq. (20) is 2.5, which corresponds to the contour level 3. From these results, Eq. (2) is biased to low risk as in the first case, and Eq. (8) distorts the risk value seriously when the range of impact exceeds 1.0. However, Eq. (20) shows that even if the range of impact exceeds 1.0, it shows the phenomenon of focusing on the medium risk as in the first case.

VI. CONCLUSION

In the overall risk management process, the risk analysis phase is a very important process of determining whether to respond to the risk by quantifying the size of perceived risk factors, and is divided into qualitative risk analysis and quantitative risk analysis. Among them, qualitative risk analysis is key, and quantitative risk analysis plays a role in supporting qualitative analysis. However, the risk value calculation method, which has been applied as a method of quantifying risk in the qualitative risk analysis phase, is an Eq. (2) that simply multiplies the probability of occurrence and the impact, and the resulting risk values show a biased distribution at low risk. As an alternative, Eq. (8) was proposed, and the result values showed a biased distribution at high risk as opposed to Eq. (2). These biased distributions are very likely to cause distortions where the risk distribution is biased towards low and high risk. However, these methods do not conform to the statistical general logic that most natural phenomena are close to the normal distribution. In this paper, a centralized risk estimation method, Eq. (20), representing the distribution of risk values close to natural phenomena is proposed and verified through real cases.

In the qualitative risk analysis phase, it is entirely up to the construction project team to select the risk value calculation method from the existing low-risk or high-risk biased method, or the centralized method proposed in this paper. However, since the resulting values for each risk value calculation method are different from each other, it is necessary to select carefully according to what goal the overall risk management process is to achieve. In particular, the risk value calculation method can have a significant impact on the risk response phase and risk monitoring and control phase after the risk analysis phase. Therefore, it is necessary to decide not only how to calculate the risk value at the stage of establishing a risk management plan, but also which risk value calculation method to choose for each type of risk.

This study focuses on proposing a risk value calculation method in which the risk values show a normal distribution close to natural phenomena. However, since the results of this study are not yet a complete normal distribution, further studies should be continued to find new risk value calculation methods that are more consistent with normal distributions.

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