

## A NEW APPROACH FOR RISK ASSESSMENT: THE CARTESIAN PRODUCT METHOD

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**Abstract:** In this study, a new risk scoring method, the Cartesian product method, is proposed. While existing risk scoring methods accept a single value for probability and severity parameters, the proposed method accepts a range for both probability and severity parameters for the risk related to the identified hazard source. The importance of the Cartesian product method is demonstrated by a real application study and compared with matrix and Fine-Kinney methods. Furthermore, a cloud software called CPMRisk is designed for easy understanding and application of the method.

**Keywords:** Fine-Kinney, Risk scoring, Hazard, Occupational health and safety.

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### 1. INTRODUCTION

Businesses have legal regulations to comply with in order to provide a safer working environment. Ensuring that production is carried out under safe conditions is the subject of occupational health and safety. According to the Occupational Health and Safety Law No. 6331 (Occupational Health and Safety Law, 2012), risk assessment has been made mandatory for employers to identify and eliminate hazards that exist in the workplace. In accordance with the relevant regulation, it is obligatory to periodically renew the risk assessment studies according to the hazard class of the workplace (Oturakçı and Dağsuyu, 2017). If the risk cannot be eliminated, it should be controlled.

Although there are many risk scoring methods, one of the most commonly used methods is the Fine-Kinney (FK) method (Oturakçı and Dagsuyu, 2017). The main three parameters used in risk scoring by FK method are probability, severity and frequency (Kinney and Wiruth, 1976). The determination of these parameters is entirely under the control of the expert performing the relevant risk scoring. The occupational health and safety expert does not have any tools and data sources to use when determining the relevant parameters. The expert tries to estimate the relevant parameters based on the observations. Therefore, the risk rating for the same hazard source varies from expert to expert. The main reason for the difference is the

lack of a standardized approach in determining the probability and severity parameters. Additionally, it is often not possible to accept a single point value for the risk scoring parameters.

Risk assessment involves examining the risks posed by identified hazards. Risk assessment is a two-stage process. In the first stage, a scoring is made with the appropriate method for the identified risk. In the second stage, control measures to be taken according to the degree of risk are determined.

Aker and Özçelik (2020) applied the matrix method and the FK methods for a company operating in the metal sector and showed that the risk analysis performed by FK method produces more reliable results than the matrix method. Erzurumluoğlu et al. (2015) carried out risk analysis for tower crane lifting activities according to FK method and made necessary recommendations to reduce the risks that may be caused by hazards to an acceptable level. Cündübeyoğlu and Kayabaşı (2022) conducted a risk assessment in a ceramic factory using the FK method and determined the necessary corrective/preventive actions to reduce high risks to acceptable levels. Durmuş et al. (2021) performed a risk assessment study for a tea factory with FMEA and FK methods. Yorulmaz and Sezen (2023) examined the risk assessment for the maritime field and stated that only the use of the FK method is insufficient, therefore it is appropriate to use it together with other methods.

More sophisticated methods have been introduced by the researchers. Kokangül et al. (2017) developed a hybrid risk assessment approach by combining the Analytic Hierarchy Process (AHP) with the FK method to provide a more systematic and reliable evaluation of occupational risks. Gul et al. (2018) introduced a comprehensive risk assessment framework that integrates the Fine-Kinney method with fuzzy AHP and fuzzy VIKOR to address uncertainty and improve decision-making in industrial safety management. Dagsuyu et al. (2020) presented an enhanced Fine-Kinney risk assessment method that incorporates a clustering approach to improve the prioritization of risks. Gul and Celik (2018) proposed a new approach by combining the FK and rule-based fuzzy system approach and demonstrated the importance of the model by applying the railway industry. The other hybrid approach that combines the ANFIS and FK approaches was proposed by Gökler et al. (2022). As can be seen, the use of the FK method in conjunction with fuzzy-based methods is quite common.

The other important method used in risk assessment is the matrix method. Bayraktar et al. (2019) used the L matrix method to analyse the non-structural risks of schools. Öztürk and Şimşek (2020) used the matrix risk assessment method in the risk assessment for roof works and provided recommendations for the measures to be taken against risks. Soykan (2018) carried out a risk assessment with L-type matrix method in industrial fishing vessels. Kabakulak (2019) used the matrix method for a textile company.

In the matrix method, only probability and severity parameters are included. The values of these parameters are determined by the occupational health and safety expert. However, it is not possible to determine the probability of an event occurring with a single point value. Also, the probability of an event occurring is related to its frequency. Therefore, as in the matrix method, it is possible to perform risk scoring using only probability and severity components. As in the FK method, the matrix method is limited in terms of flexibility as it uses a single estimation value for probability and severity values. In this study, a generalized version of the matrix method, the Cartesian product method, is introduced. The Cartesian product method is a method based on probability and severity parameters as in the matrix method. This method

is designed to be more flexible and inclusive than the existing matrix method. The Cartesian product method provides flexibility in determining the probability and severity parameters. In the Cartesian product method, the expert can determine the probability and severity parameters for the identified risk within a range rather than a fixed value. The Cartesian product method aims to eliminate the limitations of the matrix method. In addition, a web application is developed using the shiny package in R software to ensure the applicability of the Cartesian product method by the experts.

The other sections of the study are designed as follows. Section 2 includes risk scoring methods. In Section 3, risk scoring methods are compared on a real application. In Section 4, the developed tool for the proposed model, called as CPMRisk, is introduced. The results of the study are summarized in Section 5.

## 2. RISK SCORING METHODS

In this section, three different methods are summarized for risk scoring. These are matrix, FK and Cartesian product methods. Before moving on to risk scoring methods, the basic concepts that should be known are given. These are frequency, severity and probability.

**Frequency:** Repetition or duration of exposure to the hazard over time. It will be expressed numerically with probability in the criterion.

**Severity:** It is the estimated harm that the realization of the hazard will cause on human and workplace.

**Probability:** It is the expression of the occurrence of an event that has the potential to harm the employee, third party and / or workplace, taking into account the frequency.

After the hazards are identified, for each hazard, an assessment is made regarding the probability of the event that may occur due to this hazard. Probability refers to how often contact with the hazard is likely to occur or how long exposure occurs, and the following points are taken into account when making judgements about the probability of the event related to the hazard.

- Number of people exposed to the hazardous situation,
- The number of occurrences of the hazard in a given time interval (frequency),
- Duration of exposure to hazard,
- Environmental conditions,
- Residual risk,
- The proficiencies of the people involved in the situation in question,
- Attention/distractions,
- Human error, overtime and leave situations,
- Maintenance and repair weaknesses,
- Complexity of instructions,
- Difficulties in working in accordance with the determined flow,
- Failure to put control measures in place.

Furthermore, when calculating the probability of the risk associated with the hazard source, a list of unsafe behaviors needs to be established. Thus, the occupational health and safety

expert can reliably estimate the probability. The ratio of observed unsafe behaviors to total unsafe behaviors gives an estimate for the probability of the related risk. In the remaining part of this section, risk scoring methods are given.

### 2.1. Matrix Method

The risk value in matrix method is calculated by

$$R = P \times S \tag{1}$$

where P is the probability and S is the severity. Tables 1 and 2 show the probability and severity values according to the matrix method. Both parameters take discrete values in the range of 1-5.

Table 1. Probability Values and Corresponding Descriptions (Aker and Özçelik, 2020)

Probability	Description
Very low (1)	Occurs hardly ever
Low (2)	Occurs Once a year
Moderate (3)	Occurs a few times a year
High (4)	Occurs once a month
Very High (5)	Occurs very often

Table 2. Severity Values and Corresponding Descriptions (Aker and Özçelik, 2020)

Severity	Description
Very low (1)	Requires only first aid
Low (2)	Requires outpatient treatment and first aid
Medium (3)	Requires inpatient treatment
High (4)	Requires long-term treatment
Very high (5)	Death or permanent incapacity

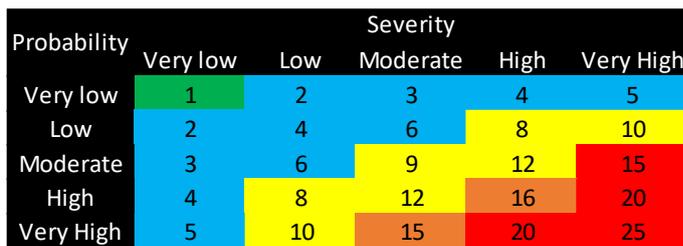


Figure 1. Risk scoring in matrix method (Çelikleş and Ünlü, 2018).

Figure 1 shows how to classify the risk values obtained by the matrix method. Here, a value of 25 represents unacceptable risk. The meanings of the values given in Figure 1 are as follows: 20-25 is unacceptable risk, 15-16 is significant risk, 8, 9, 10, 12 is moderate risk, 2, 3, 4, 5, 6 is acceptable risk and 1 is insignificant risk (Çelikleş and Ünlü, 2018).

### 2.2. FK Method

The FK method, introduced by Kinney and Wiruth (1976), is generally used by small-scale companies. The following equation is used to calculate the risk in FK method

$$R = P \times S \times F \quad (2)$$

where F is the frequency. In FK method, the risk value is obtained from the multiplication of these three parameters (Ilbahar et al., 2018). The values of these parameters and their definitions can be found in Kinney and Wiruth (1976). The risk score obtained by FK method is divided into 5 classes as acceptable risk, possible risk, substantial risk, high risk and very high risk (see, Figure 2).

Risk	Description
>400	Very high risk; consider
200 to 400	High risk; immediate correction
70 to 200	Substantial risk; correction
20 to 70	Possible risk; attention
<20	Risk; perhaps acceptable

Figure 2. Risk classification intervals for FK method (Kinney and Wiruth, 1976)

### 2.3. Cartesian Product Method

The Cartesian product method is a risk scoring method based on two parameters. These are probability and severity parameters. The probability and severity parameter ranges used in the matrix and the FK methods are difficult to interpret mathematically. Probability values should be defined in the range [0,1]. Defining inappropriate ranges for probability values leads to inaccurate expression of the relationship between probability and severity parameters. The relationship between probability and severity is  $Severity \leq Severity \times Probability$  and this relationship is not provided in matrix and FK methods. The product of  $Severity \times Probability$  is an upper bounded function with the severity parameter.

In both Matrix and FK method, probability and severity values are expressed with a single value. However, when determining the risk of an identified hazard, many possibilities are evaluated together. For example, the risks related to the hazard source can be expressed as a simple hand cut, loss of limb and death. In this case, the severity value for this risk should be expressed as a range covering all three risk values. Likewise, the probability value cannot be expressed by a single value. The probability of the risk depends on many parameters. For example, the risk of amputation or loss of limb of a worker may vary according to the experience, environmental conditions and working hours of the individuals operating the relevant machine. Depending on these parameters, the probability of the risk should be expressed as a range.

When making a judgement about the probability of the risk rising from the hazard in question, the intervals in Table 3 are used. When determining the probability intervals in the Table 3, it is taken into consideration that the probability of an event is only be a real number in the range (0,1].

Table 3. Probability Values of the Cartesian Product Method

Probability	Description	Probability Interval
Very low	Unlikely (once every 5 years)	(0-0.2]
Low	Likely (1 or 2 days per year)	(0.2-0.4]
Moderate	Possibly	(0.4-0.6]

High	(1 day every 6 months or 6 days a year) Very likely ( 2 days a month or 10-12 days a year)	(0.6-0.8]
Very high	Always near and within the reach of hazard	(0.8-1]

In order to ensure an accurate approach in determining the estimate of the severity of the hazard without control measures, it is essential to select any of the desired subintervals from the interval [0,100]. Table 4 is used to select these intervals.

Table 4. Severity Intervals

Severity	Description	Value
None	no incident	0
Very mild	No work hours lost (situations where first aid is adequate)	(0-20]
Mild	No working day loss (first aid and medical treatment required)	(20-40]
Moderate	Accident with loss of working day (treatment required )	(40-60]
Serious	Death, loss of limb, severe injury, occupational disease (long treatment )	(60-80]
Very serious	Multiple deaths	(80-100]

In the risk scoring process, the numbers which are the products of the arithmetic averages of the interval bound values selected separately for probability and severity are used as numerical symbols of the determined intersection clusters, i.e. risk areas. The intervals in Figure 3 are used to determine the degree of the risk. Note that if the severity score is between 60 and 80, the risk value is considered ‘high risk’ regardless of the probability value, and between 80 and 100 is considered as ‘very high risk’.

Risk	Description
R=0	No risk
0<R≤10 (Very low)	No need to take control measures
10<R≤30 (Low)	Personal protective equipment must be used
30<R≤60 (Moderate)	Administrative control
60<R≤80 (High)	Engineering control
80<R≤100 (Very high)	The work is completely stopped

Figure 3. Risk classification based on the Cartesian product method.

### 3. APPLICATION

In a tire manufacturing company, a risk assessment related to the bambury machine is performed and 7 hazard sources and risks related to these hazard sources are identified. Hazards and risks are given in Figure 4 and risk scoring is carried out according to 3 different methods. Based on the evaluation of risk scoring methods, it is observed that the matrix method has 4 moderate risks, 2 low risks, and 1 high risk. The FK method consists of 3

moderate risks, 2 low risks, 1 high risk, and 1 very low risk. Furthermore, the Cartesian product method includes 2 very high risks, 1 high risk, 2 moderate risks, 1 low risk, and 1 very low risk.

In the 1st and 2nd risk assessment, since the severity values are determined in the range of 80-85, these risk values are evaluated in the very high risk category according to the Cartesian product method. The agreement between these 3 methods is analyzed. The degree of agreement is calculated as the ratio of matching risk categories to the total category. Accordingly, the agreement between the matrix and Cartesian product method is 57.14% (4/7), and the agreement between FK and Cartesian product method is 71.43% (5/7).

Cartesian product and the FK methods produce different results for 2 cases. Matrix method and Cartesian product method give different results for 3 cases. The reason for this is that the Cartesian product method performs risk classification regardless of the probability parameter when the severity value is above the determined threshold level.

Matrix method and Cartesian product method give different results for 3 cases. In 2 of them, the severity value is above the determined threshold value. In the 7th risk assessment, while the matrix method gives a low risk classification, both FK and Cartesian product methods give a very low risk classification.

Order	Source of Hazard	Hazard	Risk	Matrix			FK				Cartesian				
				P	S	R	P	F	S	R	P		S		R
											a	b	a	b	
1	BAMBURY 5 UNIT	LAPPING PROCESS/ELECTRICITY	BURN, INJURY, DEATH AS A RESULT OF ELECTRIC SHOCK IN CASE OF ELECTRIC LEAKAGE WHILE WORKING IN THE MOULDING SECTION OF THE BAMBURY UNIT AND CONTACT OF THE EMPLOYEE	2	4	8	1	2	15	30	0.20	0.30	80	85	20.6
2	BAMBURY 5 UNIT	LAPPING PROCESS/ELECTRICITY	FAILURE TO TAKE ADEQUATE MEASURES RELATED TO ELECTRICAL PANELS (OPEN LIDS, CONTACT BY UNAUTHORISED AND UNINFORMED PERSONS, NOT USING INSULATED MATS, PRESENCE OF CONDUCTIVE LIQUIDS IN THE PANEL AREA, DIVERSION IN THE INSTALLATION, ETC.). IN CASE OF BURN, INJURY, DEATH DUE TO ELECTRIC SHOCK	3	4	12	3	3	15	135	0.40	0.50	80	85	37.1
3	BAMBURY 5 UNIT-SPINDLES	PRESENCE IN THE WORKPLACE / TEMPERATURE OF THE CYLINDER AND PRODUCT	IN CASE OF CONTACT WITH THE CYLINDER OR THE PRODUCT WITH A TEMPERATURE OF AROUND 150 DEGREES DURING THE PROCESS IN THE MOULDING AREA FOR REASONS SUCH AS MAKING ADJUSTMENTS IN THE AUTOMATIC WORKING MACHINE, MAKING THE FIRST OPERATIONS, INJURY AS A RESULT OF BURNING WITHOUT USING GLOVES	4	3	12	6	3	7	126	0.80	0.90	35	45	34.0
4	BAMBURY 5 UNIT-SPINDLES	PRESENCE AT WORK / SMOKE - ODOUR - VAPOUR FROM DOUGH	OCCUPATIONAL DISEASES THAT MAY OCCUR AS A RESULT OF CHEMICAL EXPOSURE FROM FUMES AND ODOURS EMITTED WHILE IN THE ENVIRONMENT FOR ANY REASON	5	2	10	10	6	3	180	0.80	0.90	35	45	34.0
5	BAMBURY 5 UNIT-SPINDLES	DOUGH CUTTING PROCESS / SPINDLE MOVEMENT	INJURY, SERIOUS INJURY, DEATH IN CASE OF CARELESS BEHAVIOUR OF THE EMPLOYEE WHILE WORKING BY HEATING THE METAL SHOVEL BY USING THE FLAME OF OXYGEN WELDING FLAME TO BREAK AND REMOVE THE DOUGH WHEN THE DOUGH IS STUCK AND COLLECTED UNDER THE SHAFT	3	5	15	6	1	40	240	0.40	0.50	50	65	25.9
6	BAMBURY 5 UNIT-TANK STAIRS	PRODUCT DELIVERY TO THE POOL TANK / HEIGHT OF TANK LADDERS	INJURY IF THE EMPLOYEE FALLS DUE TO ACCIDENT AND CARELESSNESS OR CORROSION (CORROSION) OF THE LADDER STEPS OVER TIME WHILE CLIMBING TO THE PLATFORM BUILT TO PUT PRODUCTS IN THE POOL TANK	2	2	4	1	3	7	21	0.20	0.30	40	45	10.6
7	BAMBURY 5 UNIT-POOL TANK	PRODUCT DELIVERY PROCESS TO THE POOL TANK / MOVEMENT OF TANK EQUIPMENTS	INJURY IF THE EMPLOYEES AND ESPECIALLY THE EMPLOYEE WHO PUTS PRODUCT INTO THE TANK PUTS HIS HAND INTO THE TANK WHILE THE TANK APARTS ARE MOVING FOR UNFORESEEN REASONS AND TOUCHES THE MOVING EQUIPMENT.	1	3	3	1	2	3	6	0.10	0.20	50	60	8.3

Figure 4. Comparison of the methods.

#### 4. CPMRISK

CPMRisk is designed in R software using the shiny package and can be accessed from <https://nusretefendioglu.shinyapps.io/CPMRisk/>.

CPMRisk is very easy to use. The user enters the lower and upper bound values for probability and severity parameters, the system automatically calculates the risk level and determines its position on the heat map. In addition, the system provides information about the measures to be taken according to the determined risk class (see, Figure 5).



Figure 5. CPMRisk web-tool.

#### 5. CONCLUSION AND FUTURE WORK

In this study, Cartesian product method is proposed. The Cartesian product method is a system based on the fact that probability and severity parameters cannot be expressed as a single value. With this method, all factors affecting the probability and severity parameter values are taken into consideration and lower and upper bound values are determined for these values. The effectiveness of the method is compared with matrix and FK method. In the application study carried out in a tire manufacturing company, it was observed that FK and Cartesian product methods gave similar results. The Cartesian product method provides the occupational health and safety expert with flexible thinking and application in the risk scoring process. In addition, a web application named CPMRisk was developed. Thanks to this application, the user can easily obtain the risk scoring for the probability and severity value determined by the user.

In the future work of the presented study, an artificial intelligence based recommendation system will be established. Depending on the identified hazard source and risk, it will inform the occupational health and safety expert about the measures to be taken according to the calculated risk score.

### **Ethics Committee Approval**

N/A

### **Peer-review**

Externally peer-reviewed.

### **Author Contributions**

Author have read and agreed to the published version of manuscript.

### **Conflict of Interest**

The authors have no conflicts of interest to declare.

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