The Assessment of the Risk of Fire at Woodworking Plants Via Failure Mode and Effect Analysis-Grey Relational Analysis Approaches

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Abstract

The aim of the study: Fire is amongst the primary dangers that woodworking plants encounter during their production process. In this study, it is aimed to display priority rankings of 14 basic fire risks that are seen at woodworking plants.

Method: In order to rank the risks in terms of priorities, Failure Mode and Effect Analysis (FMEA) – Grey Relational Analysis (GRA) approaches were utilized. Via Grey Relational Analysis, it was aimed to overcome the deficiencies of Failure Mode and Effect Analysis. The risks were evaluated by 10 risk experts on account of the probability, criticalness and determinability of a risk.

Findings: It was found out that the main risks for woodworking plants are the insufficient number of fire extinguishers, the lack of a lightning rod installment, the location or the lack of fire-escape stairs, the staff’s lack of fire training and the lack of a safety/security team, whereas the disorganization of general storage has the lowest rate of risk.

Discussion: It was found out that the risks caused by the lack of basic fire precautions have the highest priority. Woodworking enterprises have to consider the states of those risks, their effects and criticalness during their establishment process. The fires which are occasionally seen at woodworking plants can be avoided and the safety precautions of the enterprises can be positively contributed with the help of this study. Future studies can be made via integrated methods in which Fuzzy theory and other multi-criteria methods are included.

Keywords: Failure Mode and Effect Analysis, Grey Relational Analysis, risk, fire, wood.

1. Introduction

The flames that originate from a specific source and distribute by itself with no help are called fire (Güvel and Güvel, 2002:107). The risk of fire at woodworking enterprises is high. The burning rate of the raw materials and auxiliary materials that are used at plants is high. Therefore, it is quite important for the safety management of enterprises to assess the risks and to set a risk assessment matrix.

It is hard to assess the risks for fire safety at woodworking enterprises. The risks in this study were determined by risk experts. 10 risk experts assessed the 14 risks about fire which were encountered at woodworking plants.

In order to measure the priority numbers (RPN) of fire risks, FMEA was utilized. Since the probability, seriousness and determinability rate of risk depend on expert knowledge on account of RPN in FMEA, these data display subjectivity. To overcome those deficiencies of FMEA, the risk factors were solved via Grey Relational Analysis through setting up two different models which were determined by expert opinions. The fact that Grey Relational Analysis provides a safer and more flexible way, helps the sector develop strategies towards the future, ranks the risk, which is uncertain through risk priority numbers, and the fact that the enterprises take safety precautions against unacceptable risks are the contribution of the method that was utilized to the study.

When the studies which have been carried out via FMEA method recently are investigated, Li and Chen (2019) presented a new FMEA (GPRM) which integrates fuzzy and grey method to the conventional risk priority point calculations. They used GPRM to overcome the limitations in conventional FMEA and to make a wider assessment by integrating the criteria to the weights. Nie et. al. (2019) suggested Bayesian Fuzzy Assessment Number (BFAN) to get a further explanation to the various opinions of the experts and a new FMEA method by using extended grey relational analysis method like TOPSIS method. Lastly, they utilized the extended GRA-TOPSIS method to give priorities to failure modes. In order to confirm the effectiveness of the suggested approach and to display the advantages against the current FMEA methods, they presented a simulation study. Wang et. al. (2018) proposed an enhanced FMEA approach which depends on Dempster-Shafer Theory (DST) and TOPSIS in order to increase the efficiency of the conventional FMEA. They applied the new approach to a real-world problem, made comparisons and found out that the suggested method was more applicable. Wang et. al. (2018) proposed a new risk-based FMEA with HoR based rough VIKOR.
In order to manipulate the subjectivity and fuzziness, they used rough numbers. They displayed the efficiency and practicality of the suggested model by application the model to the transmission system of vertical processing center. Baynal et. al. (2018) determined the priorities of automotive production failures via GRA approach and minimized them via FMEA. The results showed that production process was improved with the help of the suggested method. Ayaz and Testik (2018) provided FMEA automatization for the computer users who utilize log data through grey relational analysis. They utilized grey relational analysis to automatize the process and to overcome the subjectivity. Hu et. al. (2018) presented a new approach that can overcome the disadvantages of FMEA method. Considering the fuzziness in the assessments in the failure modes in FMEA, They proposed two-dimensional fuzzy linguistic variables in order to define the reliability of the assessment result. They applied GRA-TOPSIS in order to determine the risk rankings of specified failure modes. Liu (2017) proposed a FMEA approach which integrates PROMETHEE with the cloud model in order to deal with the fuzziness and randomness. They displayed the efficiency of the model by applying the proposed approach in the risk analysis of health services. Zhao et. al. (2017) applied interval valued intuitionistic fuzzy (IVIF) entropy in order to weigh the risk factors and proposed FMEA-IVIF-MULTIMOORA method to determine the risk priority rank of failure modes. Alinezhad et. al. (2017) aimed to investigate the most significant risks in new product developing. For this aim, the risks were prioritized via COPRAS-G method.

It is aimed in this study to overcome the deficiencies on the subject in national literature. In this study, the grey modelling of failure mode and effect analysis which was developed by Chang et.al in 2001 was utilized in the prioritization of fire risks at woodworking plants.

2. Method

In this study, the valuation analysis report items of insurance companies and the potential risk modes which woodworking enterprises face were determined in accordance with the views of 10 fire experts. The experts graded each failure mode’s probability, criticalness and determinability according to the scale on Table 1. The average points that 10 experts determined for each mode were calculated.

The grey modelling of failure mode and effect analysis approach which was developed by Chang et.al in 2001 was utilized in the prioritization of fire risks at woodworking plants. In the final phase, the results of the failure mode and effect analysis and two grey models were compared.

2.1. Failure Mode and Effect Analysis

Failure mode and effect analysis (FMEA) is a proactive method which prevents risks, failures and faults which may occur in the system, production and enterprise. It is used as a planning instrument in developing the processes and services.

FMEA depends on three factors: the probability of the risk (O), the criticalness of the risk (S) and the risk of not being determinable (D). Risk priority number is calculated by multiplying the probability, criticalness and determinability of the risk. With this number used as risk priority number (RPN), the risks are ranked. The level of the probability, criticalness and determinability of the risk is graded by using a 10-point scale. The case that the point is high shows that the effects of parameters in the system are undesirable in the system. In order to solve the problems in the system, the risk modes which have the highest RPN are needed to be focused on (Zhang and Chu, 2011:208).

The scale on which each risk mode was assessed according to three risk factors is on Table 1.

Table 1. Qualitative Assessment Scale for FMEA

| Probability     | Score | Definition                  |
|-----------------|-------|-----------------------------|
| Almost no       | 1     | There is no certain probability |
| Little          | 2     | Rare failure                |
| Weak            | 3     | Very few failures           |
| Low             | 4     | A few failures              |
| Mid low         | 5     | Occasional failures         |
| Middle          | 6     | Medium range failure        |
| Mid high        | 7     | Medium range high failure   |
| High            | 8     | High failure                |
| Very high       | 9     | Very high failure           |
| Almost certain  | 10    | Almost certain failure      |
Different O, S, D combinations may give the same RPN value however the case that the risk modes which have the same RPN correspond to the different risk factors and do not take the indirect relations between the factors into account is one of the deficiencies of the method (Khasha et.al., 2013:18). It was aimed in the literature to review the deficiencies of failure mode and effect analysis through fuzzy or grey theory approaches and overcome them. In this study, the prioritization of fire risks at wood working enterprises with the help of grey FMEA modelling which Chang et. al. developed in 2001.

2.2. Failure Mode and Effect - Grey Relational Analysis

Grey system theory was developed by Deng Julong in 1982 in order to solve the problems in which fewer data is available and sampling distribution is unknown (Deng, 1982:288). The systems in which there is fuzziness or a lack of knowledge on system structure, system limitations, system behavior and parameters are called grey systems. Human body, agriculture and finance may be listed as examples of grey systems (Deng, 1989:1).

The purpose of grey system theory is to propose theory, technique, notions and ideas in order to solve fuzziness problems with deficient or incomplete knowledge. The basic content of grey system theory consists of grey relational analysis, grey forecasting, grey modelling, grey decision making, grey theory, grey mathematics and grey control (Deng, 1989:2).

Chang et. al. put forward in their study titled failure mode effects analysis using grey theory in 2001 that since the risk factors provide the characteristics of grey system theory which enables to analyze the relationship between the current, expandable, countable, independent intermittent quantitative and qualitative series, it is possible to apply grey theory to FMEA.

The aim of grey relational analysis is to determine the rate of the relationship between each factor and the factor which is taken as a reference for comparison. The grade of effect between the factors is called grey relational grade and the function which defines grey relational grade is supposed to provide normality, dual symmetry, wholeness and approachability axioms (Yıldırım, 2018:231).

The steps of grey relational analysis in the failure mode and effect analysis may be listed as below (Chang et. al., 2001:212-214).

Step 1. Comparative series are determined.

\[ X_i = \left( X_i(1), X_i(2), ..., X_i(K) \right) \in X \]

If n knowledge series is comparable, X matrix is defined as below.

\[
\begin{bmatrix}
X_1 \\
X_2 \\
\vdots \\
X_n \\
\end{bmatrix} = \begin{bmatrix}
X_1(1) & X_1(2) & ... & X_1(k) \\
\vdots & \vdots & \ddots & \vdots \\
X_n(1) & X_n(1) & ... & X_n(1) \\
\end{bmatrix}
\]

Step 2. Reference series are determined.

In failure mode and effect analysis, small point means small risk. Thus, reference series are ranked by taking the smallest values of all risk factors. Reference series are defined as

\[ X_0 = \{ X_0(1), X_0(2), ..., X_0(k) \} = \{ 1,1, ..., 1 \} \]

Step 3. Fuzzy relationship coefficient is determined by finding the difference between comparative series and reference series.

\[ \gamma(X_0(k), X_i(k)) = \frac{\Delta_{\text{min}} + \xi \Delta_{\text{max}}}{\Delta_{\text{0}(k)} + \xi \Delta_{\text{max}}} \]

Here \( j=1,2, ..., m \) and \( k=1,2, ..., n \)

\[ X_0(k): \text{reference series} \]

\[ X_i(k): \text{comparative series} \]

\[ \Delta_{\text{min}} = \min \forall j \in i \min \forall k \|X_0(k) - X_i(k)\| \]

\[ \Delta_{\text{max}} = \max \forall j \in i \max \forall k \|X_0(k) - X_i(k)\| \]

is a determinative coefficient between \( \xi \in (0,1) \). The studies express that \( \xi \) value does not affect the ranking which will be formed after grey relational grade. In order to decrease the effect of the maximum value to the relationship coefficient, \( \xi=0.5 \) is accepted (Sofyaloğlu,2011:160;Kurt,2008:3;Kuo et.al.,2008:82;Wu,2007:244).
Step 5. Grey relational grade is determined.

The degree of how comparative series is similar to reference series is defined as grey relational degree (Üstünışık, 2007:58)

\[ T(X_n, X_i) = \frac{1}{n} \sum_{k=1}^{n} Y \left( X_0(k), X_i(k) \right) \]  

(7)

On the condition that there are weigh values of the priority grades of criteria, grey relational grade can be found by multiplying the weigh value of the criterion and the grey relational coefficient.

\[ T(X_n, X_i) = \frac{1}{n} \sum_{k=1}^{n} Y \left( X_0(k), X_i(k) \right) * W_i(k) \]  

(8)

Step 6. Risk priorities are ranked.

In a decision making problem, the best decision alternative is the one which has the highest grey relational degree (Sofyaloğlu, 2011:161; Kuo et. al., 2008:83; Wu, 2002:212). The higher the relational grade is, the lower the effect of the failure source is.

3. Findings

10 fire risk experts graded each failure mode’s probability, criticalness and determinability according to the scale on Table 1. The average points that 10 experts determined for each mode were calculated. The results obtained by assessing the fire risks in woodworking business via FMEA are displayed on Table 2.

**Table 2. The Results of Failure Mode and Effect Analysis Application**

| Risk No | Potential Risk Mode | O | D | S | RPN | Rank No |
|---------|---------------------|---|---|---|-----|---------|
| 1       | Wood shavings left for piling up | 8 | 8 | 8 | 512 | 5       |
| 2       | Storing combustible material close to the heat sources of the plant (shaving burning stove) | 6 | 6 | 5 | 180 | 13      |
| 3       | Uncontrolled smoking | 7 | 9 | 6 | 378 | 8       |
| 4       | Improper using or storing inflammbale materials during painting process | 5 | 9 | 5 | 225 | 12      |
| 5       | Disrepair of electrical installation | 7 | 9 | 5 | 315 | 10      |
| 6       | Uncontrolled storage of wastes (fiber etc.) | 7 | 6 | 8 | 336 | 9       |
| 7       | Disorganizations seen in general storage | 3 | 9 | 4 | 108 | 14      |
| 8       | Problems caused by heating installation | 6 | 6 | 8 | 288 | 11      |
| 9       | Risks arising from the structural characteristics of the enterprise building such as building style, building date, construction materials | 7 | 7 | 8 | 392 | 7       |
| 10      | Insufficient number of fire extinguishers | 8 | 9 | 10 | 648 | 4       |
| 11      | Lack of a lightning rod installation | 6 | 9 | 9 | 486 | 6       |
| 12      | The location or the lack of fire-escape stairs | 8 | 10 | 9 | 720 | 3       |
| 13      | Staff’s lack of fire training. | 9 | 9 | 9 | 729 | 2       |
| 14      | The lack of fire/safety team | 9 | 10 | 9 | 810 | 1       |

The information series matrix about the risk factor points on Table 2 is displayed on (9).

\[
\begin{bmatrix}
X_1(1) & X_1(2) & X_1(3) \\
X_2(1) & X_2(2) & X_2(3) \\
X_3(1) & X_3(2) & X_3(3) \\
X_4(1) & X_4(2) & X_4(3) \\
X_5(1) & X_5(2) & X_5(3) \\
X_6(1) & X_6(2) & X_6(3) \\
X_7(1) & X_7(2) & X_7(3) \\
X_8(1) & X_8(2) & X_8(3) \\
X_9(1) & X_9(2) & X_9(3) \\
X_{10}(1) & X_{10}(2) & X_{10}(3) \\
X_{11}(1) & X_{11}(2) & X_{11}(3) \\
X_{12}(1) & X_{12}(2) & X_{12}(3) \\
X_{13}(1) & X_{13}(2) & X_{13}(3) \\
X_{14}(1) & X_{14}(2) & X_{14}(3)
\end{bmatrix}
\]

\[
\begin{bmatrix}
8 & 8 & 8 \\
6 & 6 & 5 \\
7 & 9 & 6 \\
5 & 9 & 5 \\
7 & 9 & 5 \\
7 & 6 & 8 \\
3 & 9 & 4 \\
6 & 6 & 8 \\
7 & 7 & 8 \\
8 & 9 & 10 \\
6 & 9 & 9 \\
8 & 10 & 9 \\
9 & 9 & 9 \\
9 & 10 & 9 
\end{bmatrix}
\]

(9)
The differences matrix is on (10).

\[
\begin{bmatrix}
\Delta_{01}(1) & \Delta_{01}(2) & \Delta_{01}(3) \\
\Delta_{02}(1) & \Delta_{02}(2) & \Delta_{02}(3) \\
\Delta_{03}(1) & \Delta_{03}(2) & \Delta_{03}(3) \\
\Delta_{04}(1) & \Delta_{04}(2) & \Delta_{04}(3) \\
\Delta_{05}(1) & \Delta_{05}(2) & \Delta_{05}(3) \\
\Delta_{06}(1) & \Delta_{06}(2) & \Delta_{06}(3) \\
\Delta_{07}(1) & \Delta_{07}(2) & \Delta_{07}(3) \\
\Delta_{08}(1) & \Delta_{08}(2) & \Delta_{08}(3) \\
\Delta_{09}(1) & \Delta_{09}(2) & \Delta_{09}(3) \\
\Delta_{10}(1) & \Delta_{10}(2) & \Delta_{10}(3) \\
\Delta_{11}(1) & \Delta_{11}(2) & \Delta_{11}(3) \\
\Delta_{12}(1) & \Delta_{12}(2) & \Delta_{12}(3) \\
\Delta_{13}(1) & \Delta_{13}(2) & \Delta_{13}(3) \\
\Delta_{14}(1) & \Delta_{14}(2) & \Delta_{14}(3) \\
\end{bmatrix} = \begin{bmatrix}
7 & 7 & 7 \\
5 & 5 & 4 \\
6 & 8 & 5 \\
4 & 8 & 4 \\
6 & 8 & 4 \\
6 & 5 & 7 \\
2 & 8 & 3 \\
5 & 5 & 7 \\
6 & 6 & 7 \\
7 & 8 & 9 \\
5 & 8 & 8 \\
7 & 9 & 8 \\
8 & 8 & 8 \\
8 & 9 & 8 \\
\end{bmatrix}
\]  

(10)

Grey relational coefficients are calculated with the help of differences matrix values and decisiveness coefficient. Grey relational coefficients calculated by using \(\Delta_{\text{min}} = 2, \Delta_{\text{max}} = 9\) and \(\zeta=0.5\) values are displayed on (11).

\[
\begin{bmatrix}
Y_{01}(1) & Y_{01}(2) & Y_{01}(3) \\
Y_{02}(1) & Y_{02}(2) & Y_{02}(3) \\
Y_{03}(1) & Y_{03}(2) & Y_{03}(3) \\
Y_{04}(1) & Y_{04}(2) & Y_{04}(3) \\
Y_{05}(1) & Y_{05}(2) & Y_{05}(3) \\
Y_{06}(1) & Y_{06}(2) & Y_{06}(3) \\
Y_{07}(1) & Y_{07}(2) & Y_{07}(3) \\
Y_{08}(1) & Y_{08}(2) & Y_{08}(3) \\
Y_{09}(1) & Y_{09}(2) & Y_{09}(3) \\
Y_{10}(1) & Y_{10}(2) & Y_{10}(3) \\
Y_{11}(1) & Y_{11}(2) & Y_{11}(3) \\
Y_{12}(1) & Y_{12}(2) & Y_{12}(3) \\
Y_{13}(1) & Y_{13}(2) & Y_{13}(3) \\
Y_{14}(1) & Y_{14}(2) & Y_{14}(3) \\
\end{bmatrix} = \begin{bmatrix}
0.545455 & 0.545455 & 0.545455 \\
0.666667 & 0.666667 & 0.750000 \\
0.600000 & 0.500000 & 0.666667 \\
0.750000 & 0.500000 & 0.750000 \\
0.600000 & 0.500000 & 0.750000 \\
0.545455 & 0.666667 & 0.545455 \\
1.000000 & 0.500000 & 0.857145 \\
0.666667 & 0.666667 & 0.545455 \\
0.600000 & 0.600000 & 0.545455 \\
0.545455 & 0.500000 & 0.461538 \\
0.666667 & 0.500000 & 0.500000 \\
0.545455 & 0.461538 & 0.500000 \\
0.500000 & 0.500000 & 0.500000 \\
0.500000 & 0.461538 & 0.500000 \\
\end{bmatrix}
\]  

(11)

Two grey models were set. In the first model, risk factors were accepted as equally weighted and the grey relational degree of each risk was calculated as on the equation (7). In the second model, fire risk experts of insurance firm weighted the priority levels of risk factors. The weight coefficients were determined as \(W_{P}=0.3\) , \(W_{D}=0.3\) , \(W_{S}=0.4\) according to this. With the help of the equation (8), grey relational grade on the condition that risk factors had different weights was recalculated.

The failure mode and effect analysis of the potential risks which enterprises in woodworking business may encounter, equally weighted risk factor models, different weighted risk factors model and priority ranking were displayed on Table 3.
Table 3. The comparison of FMEA, Equally weighted GREY and Different Weighted GREY Models

| Risk No | Rank No | HMEA Rank No | Risk Factors Equally Weighted Grey RPN | Rank No | Risk Factors Different Weighted Grey RPN |
|---------|---------|--------------|---------------------------------------|---------|------------------------------------------|
| 1       | 5       | 512          | 5 0,545454545                         | 5       | 0,545454545                              |
| 2       | 13      | 180          | 13 0,694444444                        | 13      | 0,7                                      |
| 3       | 8       | 378          | 8 0,588888889                        | 8       | 0,596666667                              |
| 4       | 12      | 225          | 12 0,666666667                        | 12      | 0,675                                    |
| 5       | 10      | 315          | 10 0,616666667                        | 11      | 0,63                                     |
| 6       | 9       | 336          | 9 0,604040404                         | 9       | 0,598181818                              |
| 7       | 14      | 108          | 14 0,785714286                        | 14      | 0,792857143                              |
| 8       | 11      | 288          | 11 0,626262626                        | 10      | 0,618181818                              |
| 9       | 7       | 392          | 7 0,581818182                        | 7       | 0,578181818                              |
| 10      | 4       | 648          | 3 0,502331002                        | 2       | 0,498251748                              |
| 11      | 6       | 486          | 6 0,555555556                        | 6       | 0,55                                     |
| 12      | 3       | 720          | 4 0,502331002                        | 4       | 0,502097902                              |
| 13      | 2       | 729          | 2 0,5                                  | 3       | 0,5                                      |
| 14      | 1       | 810          | 1 0,487179487                        | 1       | 0,488461538                              |

When Table 3 is viewed, the risks of wood shavings left for piling up, storing combustible material close to the heat sources of the plant (shaving burning stove), uncontrolled smoking, improper using or storing inflammable materials during painting process, uncontrolled storage of wastes (fiber etc.), disorganizations seen in general storage, lack of a lightning rod installation, the lack of fire/safety team displayed the same results for three applications. However, there were slight differences in the ranking of risks of disrepair of electrical installation, problems caused by heating installation, insufficient number of fire extinguishers, staff’s lack of fire training. It was found out that the highest risks for the enterprises in woodworking business were insufficient number of fire extinguishers, lack of a lightning rod installation, the location or the lack of fire-escape stairs, staff’s lack of fire training and the lack of fire/safety team risks which were the ones about the inadequacy of fire precautions of the enterprises. Disorganization seen in general storage had the lowest risk.

**Conclusion**

There are numerous risks and risky areas which may cause a fire at woodworking plants. It is aimed in this study to prioritize the fire risks at woodworking enterprises. Failure mode and effect analysis and grey theory approaches were utilized in the process of prioritizing the risks.

In this study, 14 possible risks for woodworking plants were determined by 10 risk experts. After all the risks subjected to this study were assessed by the experts according to their probability, criticalness and determinability, the findings of failure mode and effect analysis weighted and unweighted grey relational analysis were compared at the end of the study. According to the results obtained, woodworking enterprises are supposed to take primary precautions against the risks of insufficient number of fire extinguishers, lack of a lightning rod installation, the location or the lack of fire-escape stairs, staff’s lack of fire training and the lack of fire/safety team risks. In this study, the applicability of grey relational analysis which was proposed in literature in order to overcome the deficiencies of failure mode and effect analysis was also tried. In the methods utilized, the case that the experts make different weighting changes the ranking of risk priority numbers. Therefore, the knowledge and experience of the experts are of the essence.

Through this application on woodworking enterprises, possible risks of fire, the effects and the priorities of these risks were determined. The risks about fire are not supposed to be neglected. Enterprises may review their safety management and use their limited resources more efficiently with the help of this study.
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