Risk and Safety Assessment on the Production of Firecrackers in Bulacan, Philippines

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Abstract

Manufacturing firecracker is one of the most hazardous field in manufacturing yet, in Philippines, prevention and mitigation programs provided for manufacturing firecrackers are limited and outdated. Hence, this study focused on the welfare of the factory workers. The study also provided general prevention and mitigation programs for manufacturing firecrackers. These prevention and mitigation programs resulted to a 56.15% RPN reduction. The reduction was achieved through the Identify, Analyze, Assess, Prevention and Mitigation phases. In the results, management, physical, and operation needed to be prioritized. And under these major risk factors were sub factors that lacks in most of the company. For management, these are provision of personal protective equipment, provision of safety training, proper labeling of equipment, provision of orientation before start of work, and safety officer in the factory. For physical, floor and wall condition (good), appropriate lighting, and proper ventilations. For operation, appropriate distance between processes, correct drying time, and lastly appropriate chairs and tables. The four general risks were assessed and given different risk responses. For accidents, control. For explosion or fire, mitigate. For both health issue and environmental issue, accept. And to prevent and mitigate the risks, different hazard controls were used, such as engineering controls, work practices, administrative controls, and personal protective equipment.

Keywords
firecrackers, manufacturing, risk and safety assessment, risk matrix, risk responses

1. Introduction

Fireworks industry is one of the most hazardous industries. As the said industry involves a lot risks in using and making fireworks. These risks can be avoided through appropriate safety measures. However, most safety measures used in most companies in Bulacan are quite limited and outdated. A good number of these safety measures are considered reactive, instead of proactive. Reactive measures are used after an incident or accident has happened, while the proactive measures are used before an incident or accident happen. A reactive measure is one of the evidence that workers' welfare is being ignored. Hence, this study focused on worker's welfare.

The conceptual framework used in this study was to determine the significant factors that affect worker's welfare and to determine the relationship of these factors to work environment, safety, and health. To properly develop risk management plan, the researcher identified risk factors associated to work environment, safety, and health. The main risk factors are physical factors, management-related factors, workers-related factors, and operational-related factors. Physical factors are considered environmental factors such as temperature, lighting, etc. Management-related factors are the factors that fall under the responsibility of the management, such as the maintenance of the building, implementation of policies, etc. Worker-related factors are factors that can be confused with management-related factors. But worker-related factors are the factors that affect knowledge and capabilities of workers. For example, there are policies in the company. But the policies are not known to everyone. In that case, it can be confused with worker and management-related factors because it is both the responsibility of the management and worker to implement policies and know the policies. Implementing would be under management-related factor, and knowing would be under worker-related factor. Lastly, the operation-related factor is the factors that are found mainly in production area. Under these main factors, there are several sub factors. An ISO 31000 based framework used as guide to properly develop risk management plan.

To determine the factors and risks, the current situation was assessed to know whether the companies are complying with the rules or whether the rules are still appropriate to use. These factors were analyzed to determine which of these significantly affect the work environment, safety, and health of the workers. In addition, the risks were assessed for its likelihood and severity. These became the basis in constructing risk management plans.

2. Methods

2.1 Data Collection

Descriptive research method was utilized in this study. Observation, interviews, and survey questionnaire was used to describe, analyze, and assess the current situation of the firecracker industry in Bulacan, Philippines. The respondents of the study included direct workers and owners from firecrackers industry in Bulacan, Philippines. Only 75 sample size was achieved in this study. The research study was conducted in Bulacan as the majority of firecrackers factory are located in the said province. The survey questionnaires were distributed in different places in Bulacan, near firecrackers factory. Observations of different factories were also conducted in Bulacan. From the results of the survey, several risk assessment tools were used in this study such as risk list, risk matrix, and failure mode and effect analysis.

2.2 Statistical Analyses

In this study, one-way analysis of variance was used to determine if there is a significant difference between the means of the main factors. Also, odds ratio of the logistics regression was also used to determine which sub factors greatly affects the perception of the safety of the workers to the factory.

3. Results

The demographics of the sample is demonstrated in the table 1. Based from the results, 22.67% of the workers are female, while 77.33% are male. There are no minor workers. 5% of the respondents are 18 to 25 years old, while 38% are 26 to 35 years old. The majority of the respondents aged from 36 to 50 years old. Interestingly, 11% of the workers are 50 years old above. This just shows that number of old workers in firecracker industry is quite high. 36% of the survey respondents have a more than seven years of work experience in making firecrackers, 43% have four to seven years, 16% have one to three years, and 5% have less than a year. Most of the respondents surveyed are workers. Only 3% of the survey respondents are owner, the rest of the respondents are worker.

Table 1. Demographics of the Sample

	Variables	Frequency	Percentage
Gender	Female	17	22.67%
	Male	58	77.33%
Age	< 18 years old	0	0.00%
	18-25 years old	4	5.33%
	26-35 years old	29	38.67%
	36-50 years old	34	45.33%
	> 50 years old	8	10.67%
Years in Work Experience	< 1 year	4	5.33%
	1-3 years	12	16.00%
	4-7 years	32	42.67%
	> 7 years	27	36.00%
Position in the Company	Worker	73	97.33%
	Owner	2	2.67%

In management related factor, the variables that yielded a value of more than 1 in odds ratio are A1, A2, A5, A7, and A9. These variables are considered as significant, as it affects the perception of the workers to the safety greatly. This means that if A1, A2, A5, A7, and A9 variable is present in a factory setting, then the odds of the workers seeing the factory as safe increases multiplicatively by 2.23, 1.87, 1.16, 3.06, and 1.56, respectively.

In physical related factor, three out of the four variables yielded a value of more than one in odd ratio. The variables were B1, B3, and B4. Having B1, B3, and B4 variables present in the factory increases multiplicatively the chance of having a factory safe by 1.46, 1.02, and 1.18, respectively.

In worker related factor, none of the variables yielded a value of more than 1 in odds ratio. It shows that these factors do not affect the perceptions of the workers to the safety of the factory, because apparently, most of the workers are considered seasoned. Most of the workers in this industry have worked for more than five years. Workers are already knowledgeable in their work. But still, human errors cannot be ignored. Among the variables, C1 and C4 yielded the highest value in odds ratio.

In operational related factor, four out of six are considered significant. The variables are D2, D4, D5, and D6. Having D2, D4, D5, and D6 variables present in the factory increases multiplicatively the odds of having a factory safe by 1.05, 1.05, 1.05, and 1.38, respectively.

Table 2. Odds Ratio of each Sub Factors

Main Factor	Variable	Description	Odds Ratio
Management	A1	Every worker is provided with Personal Protective Equipment	2.23
	A2	There is proper garbage can for wastes produced	1.87
	A3	Tools used for making firecrackers are safe	0.43
	A4	Hazardous processes are isolated	0.91
	A5	Management provides equipment against fire	1.16
	A6	Management provides safety training (monthly or yearly)	0.53
	A7	Proper labeling of equipment	3.06
	A8	Management provides an orientation or explanation before officially working in the company	0.23
	A9	There is a safety officer in the factory	1.56
	A10	Rules and regulation are strictly implemented	0.53
Physical	B1	The factory is considered safe	1.46
	B2	Floor, walls, way are in good condition	0.94
	B3	The lighting in the factory is appropriate	1.02
	B4	There is a proper ventilation in the factory	1.18
Worker	C1	Workers are knowledgeable about the chemicals they handle and use	0.82
	C2	Workers have the knowledge about the risks present inside the factory	0.62
	C3	Workers know the rules and regulation inside the factory well	0.24
	C4	Workers follow rules and regulation	0.77
Operation	D1	The distance between processes are appropriate	0.76
	D2	Drying time of explosives is correct	1.05
	D3	Workers rarely feel numbness or any abnormal sensation when seating or standing	0.95
	D4	Chemicals used in making firecrackers are not hazardous	1.05
	D5	The process in making firecracker is not complicated	1.08
	D6	Only few steps are needed to be memorized in making firecrackers	1.38

4. Discussion

After identifying the risks present in the factory, these risks were assessed to determine the appropriate risk responses. The risks were assessed through risk scores and risk matrix.

Explosion or fire has the highest risk score of 12, and it is classified as severe risk. Next to it is accident which yielded a score of 8, and is classified as significant risk. Both health issue and environment issue yielded a score of 1, which is classified as acceptable risk. The prioritized risks are explosion or fire and accident.

Table 3. Risk and its Risk Score and Risk Level

	Likelihood		Severity	Risk Score	Risk Level
Accident	4	X	2	8	Significant Risk
Explosion or Fire	4	X	3	12	Severe Risk
Health Issue	1	X	1	1	Acceptable Risk
Environmental Issue	1	X	1	1	Acceptable Risk

The figure below shows what responses are appropriate for the risks. For health issue and environmental issue having a low risk, the response is to accept the risk. For accident having a medium risk (higher likelihood), the response is to control the risk. And lastly, for explosion or fire, since it has both high severity and high likelihood, the response is to mitigate the risks.

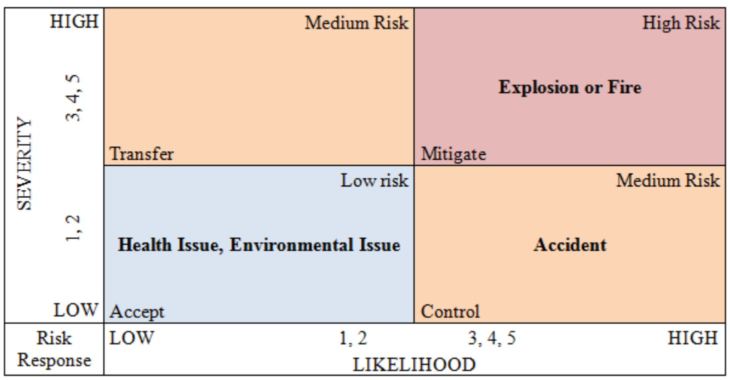

Fig. 1 Risk Response Chart

Failure modes were ranked to determine which failure modes were needed to be prioritized. From the results the top failure mode was from the grinding, and mixing process which both yielded an RPN of 500. These failure modes were the sudden ignition of explosive powders, and wrong combination of chemicals used. Recommended actions for the failure mode from grinding process were to provide appropriate and safer tools, such as alternative for metal tools, and to regularly inspect the tools. And the recommended actions for the failure mode from the mixing process were to provide labels for the chemicals, and to educate the workers more about the chemicals used in the manufacturing of firecrackers.

Based on occurrence, 5 out of 10 of the failure modes needed to be prioritized. These failure modes were sudden ignition of explosive powders (grinding and loading), excess drying time (drying), wrong combination of explosive powders (mixing), and wrong cut (fuse making).

Based on severity, 4 out of 10 of the failure modes needed to be prioritized. These failure modes were sudden ignition of explosive powders (grinding and loading), excess drying time (drying), and wrong combination of chemicals mixed (mixing).

Table 4. Ranking of Failure Mode Based on Occurrence

Process	Failure Mode	Occurrence
Grinding	Sudden ignition of explosive powders	5
Drying	Excess drying time	5
Mixing	Wrong combination of chemicals mixed	5
Loading	Sudden ignition of explosive powders	5
Fuse making	Wrong cut	5
Grinding	Inhalation of hazardous chemicals	1

Grinding	Chemicals leaking on the ground	1
Mixing	Inhalation of hazardous chemicals	1
Mixing	Direct contact of explosive powder on the worker's body parts	1
Packaging	Wrong posture	1

Table 5. Ranking of Failure Mode Based on Severity

Process	Failure Mode	Severity
Grinding	Sudden ignition of explosive powders	10
Drying	Excess drying time	10
Mixing	Wrong combination of chemicals mixed	10
Loading	Sudden ignition of explosive powders	10
Packaging	Wrong posture	8
Grinding	Inhalation of hazardous chemicals	6
Mixing	Inhalation of hazardous chemicals	6
Mixing	Direct contact of explosive powder on the worker's body parts	6
Fuse making	Wrong cut	6
Grinding	Chemicals leaking on the ground	4

Table 6. Ranking of Failure Mode Based on RPN

Process	Failure Mode	RPN
Grinding	Sudden ignition of explosive powders	500
Mixing	Wrong combination of chemicals mixed	500
Drying	Excess drying time	350
Fuse making	Wrong cut	300
Loading	Sudden ignition of explosive powders	250
Packaging	Wrong posture	80
Grinding	Inhalation of hazardous chemicals	48
Grinding	Chemicals leaking on the ground	40
Mixing	Inhalation of hazardous chemicals	30
Mixing	Direct contact of explosive powder on the worker's body parts	30

After recommending actions appropriate to the failure mode, the occurrence, severity, and detection decreased accordingly. Tables below show the recalculated RPN, and the % RPN reduction.

Table 7. Percent RPN Reduction

Process	Failure Mode	Present RPN	RPN (New)	% RPN Reduction
Grinding	Inhalation of hazardous chemicals	48	4	91.67%
	Sudden ignition of explosive powders	500	40	92.00%
	Chemicals leaking on the ground	40	5	87.50%
Drying	Excess drying time	350	36	89.71%
Mixing	Wrong combination of chemicals mixed	500	12	97.60%
	Inhalation of hazardous chemicals	30	4	86.67%
	Direct contact of explosive powder on the worker's body parts	30	4	86.67%
Loading	Sudden ignition of explosive powders	250	48	80.80%
Fuse making	Wrong cut	300	24	92.00%
Packaging	Wrong posture	80	10	87.50%
Average % RPN Reduction				89.21%

5. Conclusion

There were four factors used in this study, the management, physical, worker, and operation. However, only three out of the four factors were considered as a factor that helps in making the factory safe. The only factor that did not really need to be given attention was the worker factor. Because according to the workers and owners, most of the workers were knowledgeable enough. The workers knew the roundabout in making firecrackers, being knowledgeable enough reduces risks in the factory.

Not all risk scores with same value have the same risk responses. Likelihood and severity must be taken into account. There are cases that same risk scores, but different risk responses. Risk responses must be given carefully, to optimize and to avoid unnecessary expenses. Application of the mitigation and prevention programs would give a reduction of 89.21% in RPN.

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Biographies

Marvin I. Noroña is an Industrial Engineering and Engineering Management Professor at the Mapúa University in Manila, Philippines. He holds a Bachelor of Science degree in Industrial Engineering and a Master degree in Business Administration from the University of the Philippines. He is also a candidate to earn a Doctor degree in Business Administration at the De La Salle University in Manila, Philippines finishing his thesis entitled "Lean and Green in the Philippine Automotive Industry." He is a Professional Industrial Engineer certified by the Philippine Institute of Industrial Engineers and was a member of the Board of the Production & Operations Management Association of the Philippines. With 30 years of industry experience working for leading business firms in the packaging, food & beverage and engineering services industries, he is a recognized professional management consultant in the areas of manufacturing, operations and quality improvement, strategic management, lean systems and logistics & supply chain management. In addition this areas, he handles the courses in entrepreneurial engineering, product design & development and project management. His research interests include service quality, operations & supply management, technopreneurship and sustainability.

Cherry Jean D. Bondal is a graduate of Bachelor of Science in Industrial Engineering in Mapua University. She currently works as an Analytics Consultant in an Information Technology and Services company. Her current work is about data analysis, modeling and visualization. In her past occupations and on-the-job training, she successfully spearheaded business process improvement projects presented to top managements to solve for inefficiency and unproductivity problems. She took an interest in Data Science to further her domain and technical knowledge in process improvement, optimization and analytics. She recently finished Data Science Immersion Program from FTW Foundation as a scholar. As part of the program, she, with her groupmates, analyzed social media posts using different Machine Learning Algorithms (e.g. Naïve Bayes, Support Vector Machine, Random Forest, etc.) and Natural Language Processing (e.g. Topic Modeling using Latent Dirichlet Allocation, Sentiment Analysis, etc.) to help improve information dissemination and customer experience. Her ambition is to incorporate business process improvement with Data Science.