CHAPTER IV
THE PROPOSED FMEA TECHNIQUE

In order to reduce energy and fuel cost, drying time and quantity of dried maize seeds rejected by QC, it is imperative to identify and eliminate the potential problems in the systematic way. The failure mode and effect analysis (FMEA) is an engineering technique used to define, identify and eliminate potential failures that impact to the maize drying process. In addition, the cause and effect diagram is also applied in the FMEA process as a supplement to identify root causes.

4.1 Problem analysis by means of the FMEA and the cause and effect diagram

4.1.1 The FMEA type selection

There are four types of FMEA: system, design, process, and service. The maize drying process in the studied factory uses only the process FMEA since it relates with analysis in manufacturing process. It focuses on failure modes caused by process deficiencies.

4.1.2 Team set up

Since the FMEA techniques is dependent on a proper team formation, not individual work, a team for solving the analysis of the maize drying process needs to be created first. The team needs to be formed by gathering members from multifunctional sections. An appropriate team also requires members having several different experience. In addition, it is important that the team members have to be committed to contribute to the project.

In this research, a team for the maize drying process in the studied factory consists of members with different education qualification and experience in maize drying process. Including the author the FMEA team in this project consists of 6 persons with multi-functional background as described in Table 4.1.

Table 4.1: Team members in this research

Team member	Qualification and experience
1. The author	
2. Process engineer	He has a Bachelor degree in Chemical Engineering and has been working with the company for 5 years. He has been trained about drying process and quality control techniques from many organisations in Thailand. He also had a contribution in designing and developing some of drying rooms used to dry maize sheaths. His main responsibility is process designing and production line troubleshooting.
3. Quality control chemist	He received a Bachelor's degree in Chemistry from a university in Thailand in 2003. He has been trained about drying technology and quality control technique from many organisations in Thailand. He has responsibility to control the quality of both raw material and finished products.
4. Production line supervisor	He received a Bachelor degree in Chemical Engineering and a Master degree in Production Engineering. He has been working with the company for 10 years and had some training experience abroad about risk analysis. At the moment he is part-time studying in production management. He has responsibility to supervise all production line of the factory.
5. Production foreman	He received the diploma from a Technical School in Electronic and Power Control in 1993. He has jointed with the company for more than 5 years. He has responsibility to assist the production supervisor and directly control workers in the production line.
6. Mechanical engineer	He has a Bachelor degree in Mechanical Engineering and has been working with the company for 3 years. He has been trained about drying process and quality control from some organisations in Thailand. His main responsibility is directly involved with controlling and solving problems occurring with machines and equipments used in the production line.

4.1.3 The process of conducting the FMEA

As previously mentioned, the scope of FMEA technique here covers only drying room and furnace workstation units. The process of conducting the FMEA in the studied factory is as following:

After the FMEA team had been set up, the team members were given the description and the flowchart of the maize drying process starting from loading unit to warehouse unit. As the chief of the team, the author explained to all members of the team about the concept of the FMEA tool and the objectives of the project in order to ensure that all members in the team understood the process in the same direction. Next step the team started to collect the data of failures and categorised them appropriately. The scope of the failures in this research covers only drying room and furnace workstation units. The failure in each unit is brainstormed by means of using the cause and effect diagram technique as shown in Appendix I. The information from this analysis will be used to fill in the columns of the FMEA form in relationship to the effects of failure, existing controls.

In the analysis of failure and effects, the score of severity, occurrence, and detection is developed and approved by the company's board of committee and then allow the FMEA team to use them as the guidelines and decision making for analysis, improvement and control in the FMEA technique. The criterion for severity (S), occurrence (O) and detection (D) of the process FMEA used in this study is shown in Table 4.2-4.4. According to Stamatis (1995), the score of 1 to 10 is mostly used since it provides ease of interpretation, accuracy, and precision in the quantification of the ranking.

Table 4.2: Severity (S) evaluation criteria

Effect	Criteria	Score
Hazardous effect	May endanger operators or machines or process without warning	10
Serious effect	May endanger operators or machines or process with warning	9
Extreme effect	Loss 100% of fuel due to 100% of product may have to	8

	be scrapped, drying process/furnace shutdown	
Major effect	Loss 80%-99% of fuel due to 80%-99% of product may have to be scrapped	7
Significant effect	Loss 50-79% of fuel due to 50-79% of product may have to be scrapped	6
Moderate effect	Loss less than 50% of fuel due to less than 50% of product may have to be scrapped but spend 100% fuel more due to the product may have to be re-dried	5
Minor effect	Spend 50-100% of fuel more due to 50-100% of product may have to be re-dried without scrap	4
Slightly effect	Spend 20-49% of fuel more due to 20-49% of product may have to be re-dried without scrap	3
Very slightly effect	Spend less than 20% of fuel more due to less than 20% of product may have to be re-dried without scrap	2
No effect	Slight inconvenience to operation or operator or no effect	1

Table 4.3: Detection (D) evaluation criteria

Effect	Criteria	Score
Almost impossible	No known controls available to detect the failure	10
Remote	Remote likelihood current work instruction and controls will detect the failure	9
Very slight	The current work instruction and controls are not applicable to detect the failure	8
Slight	The current work instruction and controls are applicable, but not effective to detect the failure. (Slight likelihood current controls will detect the failure)	7
Low	The current work instruction and controls are applicable and effective but lack of training to user. (Low likelihood current controls will detect the failure)	6
Medium	The current work instruction and controls are applicable and effective. They are trained to users, but they are not fully clear and understanding. (Medium likelihood	5

	current controls will detect the failure)	
Moderately high	The current work instruction and controls are applicable and effective. They are trained to users, but they might not follow instruction strictly. (Moderately high likelihood current controls will detect the failure)	4
High	The current work instruction and controls are applicable and effective. They are trained to users, but they perform with low skill. (Good likelihood current controls will detect the failure)	3
Very high	The current work instruction and controls are applicable and effective. They are generated in form of controlled document and are trained to users. The users understand and perform as the instruction with high skill. (Very high likelihood current controls will detect the failure)	2
Almost certain	The current work instruction and controls are applicable and effective. They are generated in form of controlled document and are trained to users. The users understand and perform as the instruction strictly. (Current controls almost always detect the failure. Reliable detection controls are known and used in similar processes)	1

Table 4.4: Occurrence (O) evaluation criteria

Effect	Failure rate (Higher than)	Criteria	Score
Almost certain	1 in 3 (33.3%)	Process inefficiencies almost certain to occur. History shows many process inefficiencies	10
Very high	1 in 5 (20%)	Very high number of process inefficiencies	9
High	1 in 10 (10%)	High number of process inefficiencies	8
Moderately high	1 in 20	Frequent process inefficiencies	7

	(5%)		
Medium	1 in 80 (1.25%)	Moderate number of process inefficiencies	6
Low	1 in 400 (0.25%)	Occasional number of process inefficiencies	5
Slight	1 in 2,000 (0.05%)	Few process inefficiencies	4
Very slight	1 in 4,000 (0.025%)	Very few process inefficiencies	3
Remote	1 in 10,000 (0.01%)	Remote number of process inefficiencies	2
Almost never	1 in 30,000 (0.003%)	Process inefficiency very unlikely	1

After the FMEA team quantify the severity, occurrence and detection in process FMEA, the priority of the failure is then articulated via the RPN (Risk Priority Number) which is the multiplication between severity (S), occurrence (O) and detection (D). The RPN is the value by itself that uses only for ranking and concerning in the process of maize drying in the studied factory. According to the definition of RPN and the defined scores of its components, its value will be between 1 and 1000. The result of quantification of severity, occurrence, detection, and RPN are summarised in Appendix II.

The FMEA team decides to solve the failures or problems based on 90 percent confidence or failures that have score higher than 100 out of 1000 by considering that these failures are critical and must be solved first. According to Stamatis (1995), the RPN score of 100 is acceptable. The total RPN score of 1000 is obtained by multiplication of 10 by 10 by 10 according to the evaluation of RPN from severity, occurrence, and detection scores. Therefore the detail examination of the failures having RPN scores equal to or higher than 100 is carried out further by the team.

However, only the severity (S) value is equal to or higher than 5 from the result of quantification of severity, occurrence, and detection in Appendix II will be used to take the action. This is because the severity value is below 5, will not be critical enough to take any actions for now. The team also mentions that severity score of 5 are given to nearly all failures and only one failure that has severity score of 6 is "Too hot in some areas of maize drying rooms". That made RPN can be set to any scores because the severity scores are equal 5 and 6 which do not have high effects as severity scores as 7 or higher. That was the reason why the team decided to set RPN scores equal to or higher than 100 is carried out further by the team followed the basis on 90 percent confidence.

To prioritise the failures having RPN scores not lower than 100, the failures with the highest score will be addressed first. In the case of failures having equal RPN scores, the failure having high severity score will be managed first, followed by that having high detection score and occurrence score respectively. This is because severity is the most important; it affects failure directly. Detection is more important than occurrence because the former is customer dependent and customers are now important for all business (Stamatis, 1995).

4.1.4 The way to quantify the severity, occurrence and detection of each process

The FMEA team has ranked the score of severity, detection and occurrence based on the criterion set up in Tables 4.2-4.4 respectively. Failure modes occurring in maize drying and furnace workstation units at the case study factory is summarised in Appendix II. There are 20 failure modes occurring in both drying room and furnace workstation units. However, only 19 failure modes that have RPN score higher than 100. Therefore these failures must be addressed to take the action. Explanation of how to rank the score of severity, detection and occurrence of all failure modes is discussed in the following section.

4.1.4.1 Drying process at drying room workstation unit

In the maize sheath drying process, there are several potential failure modes as shown in Appendix II.

One of the main critical failure modes is that the temperature in the drying room is not uniform. This will have a direct impact on the humidity of dried maize sheaths; their humidity is higher than required which, in the worst case, all maize sheaths have to be re-dried. This in turn will affect the drying time, energy cost, and quantity of maize rejected by QC. However it does not endanger operators or machines or process without warning. In addition, maize sheaths that do not pass the humidity specification can be recycled to the drying process and dried again (no product scraped). Therefore the severity score of 5 is assigned according to the criteria presented in Table 4.2. In terms of detection, the detection score of 8 is given since very slight likelihood current controls will detect the failure mode (only process engineer who understand the problem can investigate). In terms of occurrence, this failure mode happens very often; the failure was found in 151 batches out of 1415 batches of maize sheaths dried in year 2006 (10.7%). Therefore the occurrence score of 8 is given. Multiplying the severity score with detection score and occurrence score, the RPN score of 320 is obtained (5 x 8 x 8).

The reasons why the particular severity score is given to particular failure mode are shown in Table 4.5. Severity score of 5 is given to nearly all failures. Only one failure that has severity score of 6 is "Too hot in some areas of maize drying rooms" because this failure can cause less than 50% of the product to be thrown away.

For detection score, the reasons why the particular detection score is given to particular failure mode are shown in Table 4.6. Detection scores are varied between 5 and 8 in the drying process.

Occurrence score is based on the statistical data in terms of the frequency the failures occurred in year 2006. Total numbers of batches of maize sheaths that were dried in year 2006 were 1415 batches. Percentages of occurrence of failure were calculated by dividing the numbers of batches the particular failure occurred with the total numbers of batches of maize sheaths that were dried in year 2006 (1415 batches) and compared this percentage with the criterion shown in Table 4.4. The result of occurrence scores given to all failures in drying process is shown in Table 4.7.

Table 4.5: The way to give the severity score of potential failure modes at drying room workstation units

Potential failure modes	The worst effect of failure	Severity score
Inaccurate temperature in drying room	All maize sheaths have high humidity than required and need to be re-dried. This failure does not endanger operators or machines or process.	5
Non-uniform temperature in drying room	Some maize sheaths have high humidity than required but in practice it is difficult to separate high humidity maize sheaths from low humidity ones. Therefore all maize sheaths are re-dried. This failure does not endanger operators or machines or process	5
Humidity of maize sheaths varies batch by batch	Some batches have to be re-dried as a whole lot. This failure does not endanger operators or machines or process	5
High humidity of maize sheaths	When drying time is fixed, the maize sheaths have high humidity than required and need to be re-dried. This failure does not endanger operators or machines or process	5
Hot air blowing rate is not constant	Some maize sheaths have high humidity than required but in practice it is difficult to separate high humidity maize sheaths from low humidity ones. Therefore all maize sheaths are re-dried. This failure does not endanger operators or machines or process	5
Weak hot air blowing	All maize sheaths have high humidity than required and need to be re-dried. This failure does not endanger operators or machines or process.	5
Poor hot air distribution	Some maize sheaths have high humidity than required but in practice it is difficult to separate high humidity maize sheaths from low humidity ones. Therefore all maize sheaths are re-dried. This failure does not endanger operators or machines or process.	5

Table 4.5 (continued): The way to give the severity score of potential failure modes at drying room workstation units

Potential failure modes	The worst effect of failure	Severity score
Uncontrolled hot air direction	Some maize sheaths have high humidity than required but in practice it is difficult to separate high humidity maize sheaths from low humidity ones. Therefore all maize sheaths are re-dried. This failure does not endanger operators or machines or process.	5
Improper packing of maize sheaths	All maize sheaths have high humidity than required and need to be re-dried. This failure does not endanger operators or machines or process.	5
Packing of maize sheaths varies batch by batch	Some batches have to be re-dried as a whole lot. This failure does not endanger operators or machines or process	5
Too hot in some areas of maize drying rooms	Maize sheaths in those areas are too dried and off-spec. They need to be thrown away but typically the percentage of these too dried maize sheaths is less than 50%. This failure does not endanger operators or machines or process.	6
Contaminates/impurities in maize sheaths	Heat loss to contaminates/impurities. Some maize sheaths, particularly those next to contaminates/impurities have high humidity than required but in practice it is difficult to separate these high humidity maize sheaths from low humidity ones. Therefore all maize sheaths are re-dried. This failure does not endanger operators or machines or process.	5
Heat loss at drying rooms	Some maize sheaths have high humidity than required but in practice it is difficult to separate high humidity maize sheaths from low humidity ones. Therefore all maize sheaths are re-dried. This failure does not endanger operators or machines or process.	5

Table 4.6: The way to give the detection score of potential failure modes at drying room workstation units

Potential failure modes	Detection	Detection score
Inaccurate temperature in drying room	Random and manual checking the temperature indicators in drying rooms. This is applicable but it is not effective.	7
Nonuniform temperature in drying room	Visual observation only on temperature indicators in drying rooms by operators but this observation is not applicable to detect the failure. Only process engineer who understand the problem can investigate. There are controls available to detect this failure.	8
Humidity of maize sheaths varies batch by batch	Humidity of maize sheaths is regularly checked by QC but the results are not used by operators to vary the drying time according to the inlet humidity (lack of training to users)	6
High humidity of maize sheaths	High humidity of maize sheaths can be regularly detected by QC but the results are not used by operators to increase the drying time according to the inlet humidity (lack of training to users)	6
Hot air blowing rate is not constant	No work instruction and controls to detect the non-constant blowing rate. Only guaranteed by the supplier of blowers. Only process engineer who understand the problem can investigate. There are controls available to detect this failure.	8
Weak hot air blowing	No work instruction and controls to detect the weak blowing rate. Only guaranteed by the supplier of blowers. Only process engineer who understand the problem can investigate. There are controls available to detect this failure.	8

Table 4.6 (continued): The way to give the detection score of potential failure modes at drying room workstation units

Potential failure modes	Detection	Detection score
Poor hot air distribution	No work instruction and controls to detect poor hot air distribution in drying rooms but there are controls available to detect this failure. Only process engineer who understand the problem can investigate.	8
Uncontrolled hot air direction	No work instruction and controls to detect uncontrolled hot air direction in drying rooms. However there are controls available to detect this failure. Only process engineer who understand the problem can investigate.	8
Improper packing of maize sheaths	Detection of maize packing is carried on by shift engineers. This control is applicable and effectiveness. Packing of maize sheath is trained to operators but they are not fully clear and understanding.	5
Packing of maize sheaths varies batch by batch	Detection of maize packing is carried on by shift engineers. This control is applicable and effectiveness. Packing of maize sheath is trained to operators but they pack maize sheaths differently. This reflects that they are not fully clear and understanding.	5
Too hot in some areas of maize drying rooms	The temperature indicators in drying rooms can detect this failure. But usually the operators do not give importance to this failure. Lack of training to operators to realise the consequence of this failure.	6

Table 4.6 (continued): The way to give the detection score of potential failure modes at drying room workstation units

Potential failure modes	Detection	Detection score
Contaminates/impurities in maize sheaths	Detection is performed at loading and inspection workstation unit. The current work instruction and controls are applicable. But sometimes it still happens. This reflect that the ineffectiveness of the current work instruction and controls	7
Heat loss at drying rooms	No work instruction and controls to detect heat loss at drying rooms. However there are controls available to detect this failure. Only process engineer who understand the problem can investigate.	8

Table 4.7: The way to give the occurrence score of potential failure modes at drying room workstation units

Potential failure modes	Frequency of occurrence based on statistical data in year 2006	Occurrence score
Inaccurate temperature in drying room	This failure was found in 13 batches out of 1415 batches of maize sheaths dried in year 2006 (0.92%)	5
Nonuniform temperature in drying room	This failure was found in 151 batches out of 1415 batches of maize sheaths dried in year 2006 (10.7%)	8
Humidity of maize sheaths varies batch by batch	This failure was found in 186 batches out of 1415 batches of maize sheaths dried in year 2006 (13.1%)	8
High humidity of maize sheaths	This failure was found in 209 batches out of 1415 batches of maize sheaths dried in year 2006 (14.8%)	8
Hot air blowing rate is not constant	This failure was found in 82 batches out of 1415 batches of maize sheaths dried in year 2006 (5.8%)	7
Weak hot air blowing	This failure was found in 14 batches out of 1415 batches of maize sheaths dried in year 2006 (0.99%)	5
Poor hot air distribution	This failure was found in 215 batches out of 1415 batches of maize sheaths dried in year 2006 (15.2%)	8

Table 4.7 (continued): The way to give the occurrence score of potential failure modes at drying room workstation units

Potential failure modes	Frequency of occurrence based on statistical data in year 2006	Occurrence score
Uncontrolled hot air direction	This failure was found in 193 batches out of 1415 batches of maize sheaths dried in year 2006 (13.6%)	8
Improper packing of maize sheaths	This failure was found in 10 batches out of 1415 batches of maize sheaths dried in year 2006 (0.71%)	5
Packing of maize sheaths varies batch by batch	This failure was found in 88 batches out of 1415 batches of maize sheaths dried in year 2006 (6.2%)	7
Too hot in some areas of maize drying rooms	This failure was found in 224 batches out of 1415 batches of maize sheaths dried in year 2006 (15.8%)	8
Contaminates/impurities in maize sheaths	This failure was found in 376 batches out of 1415 batches of maize sheaths dried in year 2006 (26.6%)	9
Heat loss at drying rooms	This failure was estimated by the FMEA team to be highly occur (cannot actually measure)	8

4.1.4.2 Hot water generating process at furnace workstation unit

In the hot water generating process in which hot water is produced by burning fuel at the furnaces and pumped to drying rooms for maize drying process, there are also a variety of potential failure modes as shown in Appendix II. The way to rate severity, detection, and occurrence scores is similar to drying process and summarised in Table 4.8-4.10.

An example of the most important failure mode at furnace workstation unit is that the heating system is not optimize. This will have a direct impact on energy and fuel cost. It is estimated that when the heating system is not optimize, some amount of fuel is wasted. In other words, higher amount of fuel than it should be is required to give the same heat. This means that some amount of fuel may have to be scrapped but it is difficult to estimate this amount. In the worst case, when heating is not enough, the hot water to the drying rooms does not have sufficient temperature to heat up the maize sheaths in the drying rooms. This will have a direct impact on the humidity of dried maize sheaths; their humidity is higher than required and therefore all maize sheaths have to be re-dried. However this failure does not endanger operators or machines or process and maize sheaths that do not pass the humidity specification can be recycled to the drying process and dried again (no product scraped). Therefore the severity score of 5 is assigned according to the criteria presented in Table 4.2. The non-optimize heating system is almost certain since the first design of the heating system of the studied factory was not concerned with energy saving but concerned only the lowest fixed cost. Therefore the occurrence score of 10 is given. For detection score, there is no work instruction and controls to detect non-optimized heating system. Only process engineers who understand the problem and have working experience can investigate this. However there are known controls available to detect this failure. Based on the criteria in Table 4.4, therefore detection score of 8 is given. Multiplying the severity score with detection score and occurrence score, the RPN score of 400 is obtained (5 x 8 x 10).

Table 4.8: The way to give the severity score of potential failure modes at furnace workstation units

Potential failure modes	The worst effect of failure	Severity score
Inaccurate temperature at furnace	All maize sheaths have high humidity than required and need to be re-dried. This failure does not endanger operators or machines or process.	5
Insufficient supply of fuel	All maize sheaths have high humidity than required and need to be re-dried. This failure does not endanger operators or machines or process.	5
Insufficient heat generation (due to not good quality of fuel, variation of fuel)	All maize sheaths have high humidity than required and need to be re-dried. This failure does not endanger operators or machines or process.	5
Fouling inside hot water tubes	Some maize sheaths have high humidity than required but in practice it is difficult to separate high humidity maize sheaths from low humidity ones. Therefore all maize sheaths are re-dried. This failure does not endanger operators or machines or process.	5
Insufficient heat generation (due to fuel feed is not enough, feeding is inconsistent)	All maize sheaths have high humidity than required and need to be re-dried. This failure does not endanger operators or machines or process.	5
Heat loss at furnace	Some maize sheaths have high humidity than required but in practice it is difficult to separate high humidity maize sheaths from low humidity ones. Therefore all maize sheaths are re-dried. This failure does not endanger operators or machines or process.	5
Heating system is not optimize	Some maize sheaths have high humidity than required but in practice it is difficult to separate high humidity maize sheaths from low humidity ones. Therefore all maize sheaths are re-dried. This failure does not endanger operators or machines or process.	5

Table 4.9: The way to give the detection score of potential failure modes at furnace workstation units

Potential failure modes	Detection	Detection score
Inaccurate temperature at furnace	Random and manual checking the temperature indicators in drying rooms. This is applicable but it is not effective.	7
Insufficient supply of fuel	Detection is performed manually not systematically. When the fuel is short of supply, operators inform production engineers mostly by verbal. Therefore the current work instruction and controls are applicable but not completely effective.	7
Insufficient heat generation (due to not good quality of fuel, variation of fuel)	There is no current work instruction and controls to evaluate heat generation of different types of fuel. However there are controls available to evaluate heat generation by different types of fuel.	8
Fouling inside hot water tubes	There are current controls of quality of hot water fed to the boiler to prevent fouling such as addition of fouling preventing agents. Detection of fouling takes place every month and it is effective. Current controls are trained to users but they sometimes perform with low skills	3
Insufficient heat generation (due to fuel feed is not enough, feeding is inconsistent)	Detection is performed manually not systematically. Operators can indicate that heat generation is insufficient due to fuel feed is not enough based on their experience. Therefore the current work instruction and controls are applicable but not completely effective.	7

Table 4.9 (continued): The way to give the detection score of potential failure modes at furnace workstation units

Potential failure modes	Detection	Detection score
Heat loss at furnace	No work instruction and controls to detect heat loss at drying rooms. However there are controls available to detect this failure. Only process engineer who understand the problem can investigate.	8
Heating system is not optimize	No work instruction and controls to detect non-optimized heating system. Only process engineers who understand the problem and have working experience can investigate this. However there are controls available to detect this failure.	8

Table 4.10: The way to give the occurrence score of potential failure modes at furnace workstation units

Potential failure modes	Frequency of occurrence based on statistical data in year 2006	Occurrence score
Inaccurate temperature at furnace	This failure was found only 1 batches out of 1415 batches of maize sheaths dried in year 2006 (0.07%)	4
Insufficient supply of fuel	This failure was found 5 batches out of 1415 batches of maize sheaths dried in year 2006 (0.35%)	5
Insufficient heat generation (due to not good quality of fuel, variation of fuel)	This failure was found 11 batches out of 1415 batches of maize sheaths dried in year 2006 (0.78%)	5
Fouling inside hot water tubes	This failure is very slightly happen. Hot water tubes are clean in every 2 years and the fouling in 2 years time is very small	3
Insufficient heat generation (due to fuel feed is not enough, feeding is inconsistent)	This failure was found 2 batches out of 1415 batches of maize sheaths dried in year 2006 (0.78%)	4
Heat loss at furnace	This failure was estimated by the FMEA team to be highly occur (cannot actually measure)	8
Heating system is not optimize	This failure was almost certain since the first design of the heating system of the studied factory was not concerned with energy saving but concerned only the lowest fixed cost.	10

4.1.5 Results of conducting the process FMEA

The results of conducting the FMEA are shown in Appendix II. Moreover the cause and effect diagram is used to identify the root causes of each failure as shown in Appendix I. The outcome of identification and quantification of severity, occurrence, detection and RPN of each process are recorded in the process FMEA from. As stated before, the critical failure modes that have RPN scores higher than 100 (90% confidence) must be addressed to take the action. All of them are presented in Table 4.11.

Table 4.11: Summary the process FMEA that RPN is higher than 100 (90% confidence)

Item	Potential failure mode	Potential cause(s) of failure	RPN
1	Inaccurate temperature in drying rooms	Temperature indicator false/poor maintenance	175
2	Non-uniform temperature in drying rooms	Positions and efficiency of blowers	320
3	Humidity of maize sheaths varies batch by batch	Different sources of maize sheath/season of harvesting	240
4	High humidity of maize sheaths	Harvest maize in raining season/different sources of maize sheath	240
5	Hot air blowing rate is not constant	Old and low quality blowers/no maintenance plans for blowers	280
6	Weak hot air blowing	Old blowers that have low efficiency/no maintenance plans for blowers	200
7	Poor hot air distribution	Nonadjustable speed of blowers/no baffles in drying rooms	320
8	Uncontrolled hot air direction	Improper positions of blowers/no baffles in drying rooms	320

9	Improper packing of maize sheaths	Production operators do not follow manuals	125
10	Packing of maize sheaths varies batch by batch	Production operators do not follow manuals	175
11	Too hot in some areas of maize drying rooms	Non-worked blowers	288
12	Contaminates/impurities in maize sheaths	Inspection is not good enough/maize sheaths from various sources	315
13	Heat loss at drying rooms	Old, inefficient and improper insulation	320
14	Inaccurate temperature at furnaces	Temperature indicator false /Poor maintenance	140
15	Insufficient supply of fuel	Poor management and purchasing systems/operators do not follow work instruction	175
16	Insufficient heat generation	Not good quality of fuel, variation of fuel	200
17	Insufficient heat generation	Fuel feed in not enough or feeding is inconsistent	140
18	Heat loss at furnace	Ineffective insulation/old insulation	320
19	Heating system is not optimise	Non-optimise heating system (i.e. no recycle of used hot water, improper positions of blowers)	400

Based on analysis, it was found that there are 19 high-risk areas that must be addressed. The next step is that all of RPN are ranked from the highest to lowest to set up the priority of action. It is shown in Figure 4.1 and Table 4.12.

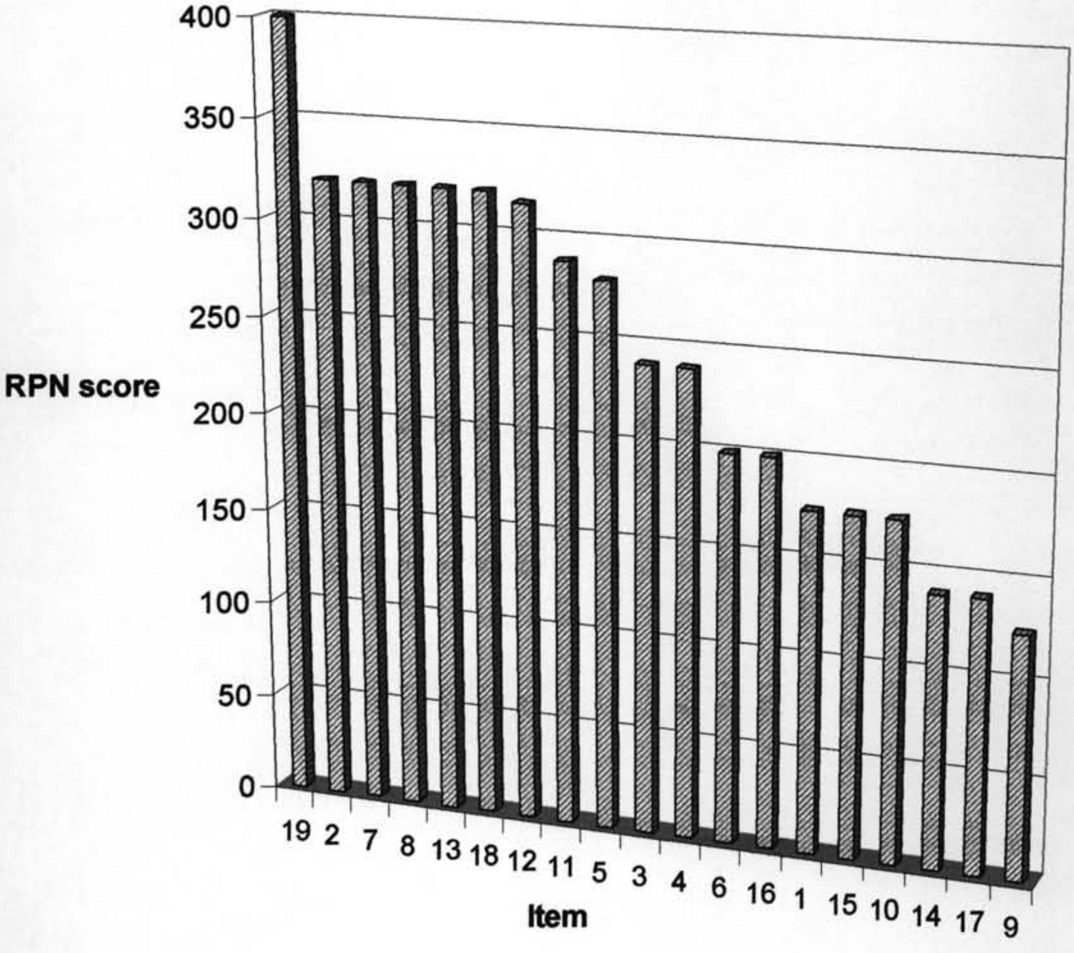

Figure 4.1: The RPN of the high-risk area ranked in order

Table 4.12: Process FMEA according to the RPN score from the highest to the lowest RPN score

Failure Mode and Effect Analysis (FMEA)

Workstation unit: Drying rooms
Process name: Drying process at drying rooms
Approved by: Factory Manager
Team members: Pachara L., Somsak T., Yupin K., Chainipat L., Manoch S., Noppadol K.

Documented by: Pachara L.
Approved date: 9/3/07

FMEA Date (Org.): 8/1/07
FMEA Date (Rev.):
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Process Function & Requirement	Potential Failure Mode	Potential Effect(s) of Failure	S	Potential Cause(s)/ Mechanism(s) of Failure	O	Current Process Controls	D	RPN	Recommended Actions(s)	Resonsibility & Target Completion Date	Action result			
											S	O	D	RPN
Furnace	Heating system is not optimize	High energy cost, long drying time, Some dried maize sheaths are off-spec	5	No recycle of used hot air, no maintenace plan for bloweres, improper positions of blowers	10	No control	8	400	Modifying heating system	Process Eng. (13/5/07)				
Maize drying	Non-uniform temp. in drying rooms	Some dried maize sheaths are off-spec	5	Position of blowers, efficiency of blowers	8	No control	8	320	Modify blowers set up preventive maintenance, install more temp. indicators	Process Eng. (13/5/07) Maintenance (10/5/07)				
Maize drying	Poor hot air distribution	Some dried maize sheaths are off-spec, long drying time, high energy cost	5	Non-adjustable speed and low efficiency of blowers, improper positions of blowers, no baffles in drying rooms	8	No control	8	320	Reposition blowers modify blowers and drying rooms i.e. add baffles	Process Eng. (13/5/07)				
Maize drying	Uncontrolled hot air direction	Some maize sheths have off-spec humidity	5	Improper positions of blowers, no baffles in drying rooms	8	No control	8	320	Modify blowers & drying room i.e. add baffles	Process Eng. (13/5/07)				
Maize drying	Heat loss at drying rooms	Some dried maize sheaths are off-spec, long drying time, high energy cost	5	Old, inefficient, improper insulation,	8	No control	8	320	Set up work instruction	Production (15/5/07)				

Failure Mode and Effect Analysis (FMEA)

Workstation unit: Drying rooms
Process name: Drying process at drying rooms — Documented by: Pachara L.
Approved by: Factory Manager — Approved date: 9/3/07
Team members: Pachara L., Somsak T., Yupin K., Chainipat L., Manoch S., Noppadol K.

FMEA Date (Org.): 8/1/07
FMEA Date (Rev.):
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Process Function & Requirement	Potential Failure Mode	Potential Effect(s) of Failure	S	Potential Cause(s)/ Mechanism(s) of Failure	O	Current Process Controls	D	RPN	Recommended Actions(s)	Resonsibility & Target Completion Date	Action result S	O	D	RPN
Furnace	Heat loss at furnace	Some dried maize sheaths are off-spec, long drying time, high energy cost	5	Old, inefficient insulation	8	No control	8	320	set up work instruction	Production (15/5/07)				
Maize drying	Contaminates/ impurities in maize sheaths	Some dried maize sheaths are off-spec, long drying time, high energy cost	5	maize sheaths from different sources, poor visual inspection	9	Visual check by operators	7	315	Internal training, set up work instruction	QC (18/5/07)				
Maize drying	Too hot in some areas of maize drying room	Some dried maize sheaths are off-spec	6	Non-worked blowers, poor visual inspection	8	Visual inspection by operators	6	288	Preventive maintenance, training	Maintenance (10/5/07)				
Maize drying	Hot air blowing rate is not constant	Some dried maize sheaths are off-spec	5	Old and low quality blowers, no maintenance plan for blowers	7	No inspection but it is guaranteed by the supplier	8	280	set up preventive maintenance	Maintenance (10/5/07)				
Maize drying	Humidity of maize sheaths varies batch by batch	High energy and fuel cost, long drying time Some dried maize sheaths are off-spec	5	Different sources of maize sheaths, season of harvesting, drying time unchnages with humidity of maize sheaths	8	No control for humidty of maize sheaths	6	240	set up work instruction to vary drying time according to inlet humidity, calibration drying time recorder	Process Eng. (13/5/07)				

Failure Mode and Effect Analysis (FMEA)

Workstation unit: Drying rooms
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Approved by: Factory Manager
Team members: Pachara L., Somsak T., Yupin K., Chainipat L., Manoch S., Noppadol K.

Documented by: Pachara L.
Approved date: 9/3/07

FMEA Date (Org.): 8/1/07
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Process Function & Requirement	Potential Failure Mode	Potential Effect(s) of Failure	S	Potential Cause(s)/ Mechanism(s) of Failure	O	Current Process Controls	D	RPN	Recommended Actions(s)	Resonsibility & Target Completion Date	Action result			
											S	O	D	RPN
Maize drying	High humidity of maize sheaths	High energy and fuel cost, long drying time Some dried maize sheaths are off-spec	5	Harvest maize in raining season, maize sheaths from different sources	8	No control for humidty of maize sheaths	6	240	set up work instruction i.e. sun drying	Production (15/5/07)				
Maize drying	Weak hot air blowing	Some dried maize sheaths are off-spec, long drying time, high energy cost	5	Old, low efficient blowers No maintenance plan for blowers	5	No control	8	200	set up preventive maintenance	Maintenance (10/5/07)				
Furnace	Insufficient heat generation	Some dried maize sheaths are off-spec, long drying time, high energy cost	5	Not good quality of fuel, variation of fuel	5	No control	8	200	develop methods to evaluate fuel quality	Process Eng. (13/5/07)				
Maize drying	Inaccurate temp. in drying rooms	Some dried maize sheaths are off-spec, long drying time, high energy cost	5	Temp. indicator false, poor maintenance	5	Random check of temp. indicator	7	175	set up work instruction for calibration	Maintenance (10/5/07)				
Furnace	Insufficient supply of fuel	Some dried maize sheaths are off-spec, long drying time	5	Poor management and purchasing systems, operators do not follow work instruction	5	Plan of fuel in advance	7	175	Set up work instruction	Inventory (11/5/07)				

Failure Mode and Effect Analysis (FMEA)

Workstation unit: Drying rooms
Process name: Drying process at drying rooms
Approved by: Factory Manager
Team members: Pachara L., Somsak T., Yupin K., Chainipat L., Manoch S., Noppadol K.

Documented by: Pachara L.
Approved date: 9/3/07

FMEA Date (Org.): 8/1/07
FMEA Date (Rev.):
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Process Function & Requirement	Potential Failure Mode	Potential Effect(s) of Failure	S	Potential Cause(s)/ Mechanism(s) of Failure	O	Current Process Controls	D	RPN	Recommended Actions(s)	Resonsibility & Target Completion Date	Action result			
											S	O	D	RPN
Maize drying	Packing of maize sheath varies batch by batch	Some dried maize sheaths are off-spec, long drying time, high energy cost	5	Production operators do not follow manuals, poor visual inspection	7	Visual inspection by shift engineers	5	175	Training operators, set up work instruction	Production (15/5/07)				
Furnace	Inaccurate temp. at furnace	Some dried maize sheaths are off-spec, long drying time, high energy cost	5	Temp. indicator false Poor maintenance	4	Temp. check every shift	7	140	set up work instruction for calibration	Maintenance (10/5/07)				
Furnace	Insufficient heat generation	Some dried maize sheaths are off-spec, long drying time	5	Fuel feed is not enough, feeding is inconsistent	4	manual feed of fuel	7	140	Set up work instruction, training	Production (15/5/07)				
Maize drying	Improper packing of maize sheath	Some dried maize sheaths are off-spec, long drying time, high energy cost	5	Production operators do not follow manuals, poor visual inspection	5	Visual inspection by shift engineers	5	125	Training operators, set up work instruction	Production (15/5/07)				

It was found that furnace workstation unit in terms of heating system is not optimize show the highest RPN score of 400. So it should be taken the action first because it directly impacts the energy and fuel cost.

The FMEA team has meeting to generate the recommendation and action plan to reduce each failure in the process FMEA. Departments who have responsibility for each action plan and the due dates to complete action plans also need to be specified in order to make the problem solving success. Responsible department, recommended actions and due date for the FMEA project of drying room and furnace workstation units are summarized in Table 4.13.

Table 4.13: Responsible department, recommended actions and due date to complete the FMEA project

Department	Action	D	Purposes	O	Due date
1. Production	*(1) Set up work instruction*				
	- Pre-drying procedure for maize sheaths that have very high humidity	4	To reduce some humidity in maize sheath before feeding to drying rooms and save energy	2	15/5/07
	- Standard procedure for packing maize sheath	4	To reduce deviation of packing and quantity of dried maize rejected by QC	2	15/5/07
	- Fuel feeding procedure	4	To ensure that heat generation is enough for drying rooms	2	15/5/07
	- Heat loss at drying rooms	4	To ensure that insulation are effective and replaced properly	4	15/5/07
	- Heat loss at furnaces	4	To ensure that insulation are effective and replaced properly	4	15/5/07
	(2) Training				
	- Packing of maize sheaths in more details	4	To reduce quantity of dried maize rejected by QC	2	15/5/07

	- Procedure for feeding fuel/fuel feeding schedule	4	To ensure that heat generation is enough for drying rooms	2	15/5/07
2. Process engineer	*(1) Set up work instruction*				
	- Drying time for raw materials that have different humidity	4	To reduce amount of off-spec dried maize sheaths and used energy	3	13/5/07
	(2) Design and development				
	- Modify blowers and positions of them in the drying room	4	To reduce quantity of dried maize rejected by QC due to non-uniform temperature in drying rooms	4	13/5/07
	- Modify drying rooms	3	To have a better hot air distribution and control of it and save more energy	7	13/5/07
	- Methods to evaluate quality of fuel	4	To reduce quantity of dried maize rejected by QC due to insufficient heat generation	2	13/5/07
3. Maintenance	*(1) Create preventive maintenance plan (PM plan)*				

	- Set up PM plan to prevent very hot spot in drying rooms	4	To reduce quantity of dried maize that has been thrown away	4	10/5/07
	- Set up PM plan for ventilation system in drying rooms	4	To reduce quantity of dried maize that has been thrown away	4	10/5/07
	- Set up PM plan to maintain constant blowing rate from blowers	4	To reduce quantity of dried maize sheaths rejected by QC due to low blowing rate	4	10/5/07
	- Set up PM plan to avoid a reduction in blowing rate at blowers	4	To reduce quantity of dried maize sheaths rejected by QC due to low blowing rate	4	10/5/07
	(2) Set up work instruction				
	- Calibration of temperature indicators	4	To reduce quantity of dried maize rejected by QC	2	10/5/07
4. QC	*(1) Set up work instruction*				
	- Procedure for removal of contaminates from raw material	4	To save energy spent on contaminates instead of maize sheaths	4	18/5/07
	(2) Training				
	- Removal of contaminates in raw materials	4	To increase the efficiency of workers on removal of	4	18/5/07

			contaminates from raw materials.		
5. Inventory	*(1) Set up work instruction*				
	- Control of fuel supply	4	To minimise short or over supply of fuel used at furnaces	2	11/5/07

After the action plan is performed, the FMEA team implements the process FMEA at drying room and furnace workstation units in May 2007. After implementation, data for the average energy and fuel cost, drying time, and quantity of maize seeds rejected by QC was collected and compared with before FMEA implementation.