Using FMEA Analysis for Assessing Air Conditioners Remanufacturing Processes

Bashir Salah
King Saud University, KSU, Industrial Engineering Department, College of Engineering, P.O. Box 800, Riyadh, 11421, Kingdom of Saudi Arabia
bsalah@ksu.edu.sa

Mohammed Alkahtani
King Saud University, KSU, Industrial Engineering Department, College of Engineering, P.O. Box 800, Riyadh, 11421, Kingdom of Saudi Arabia
moalkahtani@ksu.edu.sa

Aiman Ziout
Department of Mechanical Engineering, College of Engineering, UAE University, Al-Ain, United Arab Emirates
ziout@uaeu.ac.ae

Abstract
Air conditioner (A/C) is a device which used for cooling or heating. In this paper, we are working to enhance the re-manufacturing processes for the A/C window type unit by using the failure mode and effect analysis approach (FMEA) to estimate the values of risk priority number (RPN) by assigning the associated factors, the first factor is severity (S), the second factor is probability of occurrence (O), the third factor is detectability of the failure mode (D) and re-evaluate them by setting recommendations to reduce those factors as possible and estimates the new values of RPN. Those recommended actions would help the A/Cs window type manufacturer or local agents supply chain (SC) for their responsibilities to re-manufacturing processes by letting the decision-making process much easier by performing the role of the reverse supply chain (RSC). The idea behind the re-manufacturing is to activate the re-using of an older A/Cs unit to produce refurbished models that considered like a new product or better than new.

Keywords
Remanufactured air conditioners, Risk Priority Number, Failure Mode and Effects Analysis

1. Introduction
Air condition or as usually referred A/C, is one type of air cooling systems. It is widely used in hot countries due to its main role for cooling the room temperature. In the Kingdom of Saudi Arabia, the average temperature in the summer season around 45℃. Therefore, this leads to a higher need of using the A/Cs especially with the growing population of KSA [1]. The electricity consumption of the A/Cs in Saudi Arabia around 60% of total electric energy consumption [1]. According to the survey conducted in KSA by AMAD technical consulting and laboratories, the percentage of A/Cs window type is 75%, which is much more than others. To investigate the technological risks of A/C window type unit; Failure Mode Effect Analysis (FMEA) is applied.

The FMEA or Failure modes and effects analysis is a step-by-step engineering approach to identify all possible failures that may occur. Failures are prioritized regrinding the seriousness of their consequences, occurrence frequency and how easily they could be detected. The FMEA aims to take actions to eliminate or reduce failures, starting with the highest priority ones. FMEA should always be done whenever failures would mean potential risk to the product user.

Nowadays, reverse logistic systems have to be designed in such a way to be able to face continuous changes of their environment. Change is due to several factors, including the challenges of climate changing, increasing in waste generation, the high cost of energy, decreasing oil supply, increasing concentration of CO2 due to human activities, are some of the reasons that justify the need for remanufacturing. According to (Lund, 1984) remanufacturing is particularly applicable to complex electro-mechanical and mechanical products which have cores that, when recovered, will have value added to them which is high relative both to their market value and to their original cost.

Remanufacturing process is not likely recycling process. The recycling process is converting existing product or component that considered as waste into another product for reducing the natural recourses consumptions while the remanufacturing process is using components that working in a good condition for producing refurbished product. For a better understanding of the manufacturing processes sequences, and remanufacturing as well. See Figure 1 to simplify those two concepts.

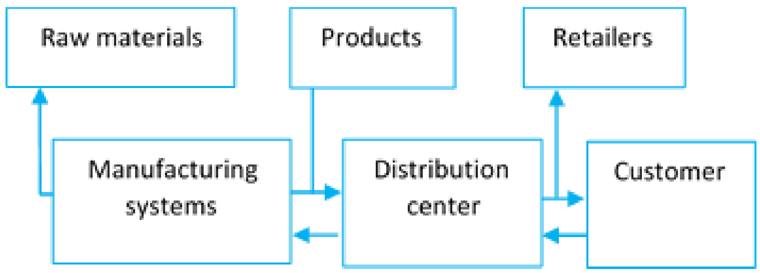

Figure 1. manufacturing processes in forward direction and remanufacturing processes in backward

The Failure mode and effect analysis usually refer as FMEA, is a step-by-step tool that detects possible defects from roots to eliminate them. The risk of a failure mode is lying on its effects [3]. FMEA tool has been proposed in the early of 1960s in the USA, they have used it for one of their biggest industries which were automotive industry, therefore they could find out the possible area of failures may occur at the designing stage [4].

The Advantages of FEMA include the simplicity of the tool, reliability of products and processes, reduced costs in terms of production and defective product, raising customer satisfaction, which reflects on market share, also creating process documentation and effectiveness of production [3].

The objective of the proposed study is to evaluate the potential risk of the product failure by determining RPN (risk priority number), however, the RPN could be calculated by a simple equation that has three parameters [5]:

$$RPN=O*S*D$$

where O is the risk factors, S is the occurrence and severity of a failure, and D is the ability to detect the failure before harm or damage. The customer in our case meant by the manufacturer or who stands in his place of responsibly.

The main objective of this paper to deliver a helpful FMEA tool in the A/Cs manufacturing industry, by designing this study for the remanufacturing processes to assist the manufacturer or agencies to improve the path to effective decision making in the manufacturing plant.

2. Methodology

The A/Cs system is cooling and heating integrated system. This system is widely known for its benefits. The system consists multiple components, to set an overview of the main components, figure 2 shows those major components of the A/C system. Additionally, Table 1 contains the main components of window A/C system which includes their parts name and functions description.

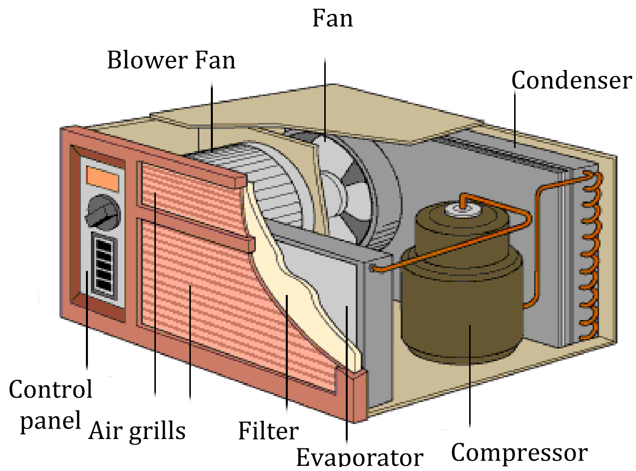

Figure 2. an overview of A/C system [6].

Table 1. Main components of window A/C system and their functions

Name	Function	Name	Function
Compressor	Compress the Freon gas	Outer case	Unit protection
Control panel	Controlling the temp., fan speed, turning on / off	Air filter	Filter the air from dust, small particle, etc.
Fan motor	Drive the fan	Fan	Generate air
evaporator	Cooling the air passing through	Rivets& nails	For tighten the parts together
Expansion valve	Regulates the liquid refrigerant going into the bottom of the evaporator.	Condenser coil	It used to condense a substance from its gaseous to its liquid state, by cooling it.
Blower Fan	Sends the air flow inside the room	Cord cable	Supply the unit with electricity

After getting familiar with the main system components. We established a team which contains expert in the A/Cs. The procedure which has been followed to create a successful tool with good results contains eight points as follows [7]:

1. Create a team including experts in the field of work area.
2. Make sure that the process is clear to each team member, so they could brainstorm the potential failure modes by listing them in appropriate way.
3. By listing those potential failure modes, it is a must to review each potential failure mode and listing the potential effects corresponding to.

4. Develop a rating criteria to each factor of the RPN, the factor are Severity (S), Occurrence (O), and Detection (D)
5. Assigning the factors to each failure mode based on a 10-point scale for those factor rating, starting from 1 which is the lowest rating to 10 the highest one.
6. Using the RPN equation the Risk Priority Number for Each Failure Mode should be calculated and point the importance of each failure mode using the highest to lowest RPN
7. Take Action to Eliminate or Reduce the High-Risk Failure Modes.
8. Start working on high risk failure modes to reduce it and then calculate the new RPN.

Table 2 include the evaluation criteria for the RPN equation, the factors are severity (S), the probability of occurrence (O) and Detectability (D) those are assigned by the responsible team for performing this analysis. Note that ppm meaning is a part per million. All those criteria have been assumed by 10-point scale to be more accurate in term of evaluation, this are set by the

3. FMEA ANALYSIS

Table 2: Evaluation criteria of RPN based on the team judgment.

Evaluation /criteria	Severity S	Occurrence O	Detection D
10	Hazardous without warning	500,000 ppm	Absolute Uncertainty
9	Hazardous with warning	200,000 ppm	Very Remote
8	Very High	100,000 ppm	Remote
7	High	50,000 ppm	Very Low
6	Moderate	10,000 ppm	Low
5	Low	5000 ppm	Moderate
4	Very Low	1000 ppm	Moderately High
3	Minor	500 ppm	High
2	Very Minor	100 ppm	Very High
1	None	1 ppm	Almost Certain

In the FMEA, we've considered five important components of A/C to perform the analysis. Firstly, the compressor is a vital component in the A/C unit. In this case the compressor is not going to work, the causes are low lubricant level or low gas pressure. The potential effect is A/C fails in producing cold air. Accordingly, the evaluated values are S = 8 very high, and the possibility of occurrence is not so high with O = 7, the possibility of detection D is moderately high. The multiplication of those values make the (RPN) = 224. In order to increase the detection of failure and decrees the severity, gas pressure sensor and lubricant level meter have to be applied which can give us a step ahead regarding the breakdown of the compressor. After a re-evaluation is done giving the severity of the failure S = 8, the possibility of occurrence O = 7, possibility of detection D = 1 and the new RPN=56.

Secondly, for the expansion valve the potential failure which is going to take place is the liquid regulating process is not performed properly, the causes are leakage or extensive usage of A/C at extreme weather conditions without taking care for the unit. The effect of this failure is the air current temperature is not controllable. The evaluated values for S, O, and D factors respectively are 6, 6, 5 which result in the RPN

= 180. The recommended action for enhancing the detectability and the risk factors is adding sensor for leaking issues, the re-evaluated factors are S = 5, O = 6, D = 3 and the new RPN = 18.

Thirdly, for the evaporator, the potential failure is the heat will not exchange to produce cold air, the possible causes are leakage or blocking in the coil itself. The potential effect that would happen is losing the cooling capacity. The evaluated factors for this element are S = 7, O = 5, and D = 5 the resulted RPN = 175. The recommended action is adding gage which could detect the amount of substance that enters the coil until leaving it, to check if there is a leakage or blocking. The re-evaluated factors are S = 4, O = 5, D = 3 and the new RPN = 90.

Fourthly, for the fan motor, the potential failure mode that may occur is breaking down of the motor itself, the potential effect is the fan could not generate air the causes are overheating or electrical problems. The evaluated factors are S = 8, O = 3, and D = 4 the resulted RPN = 96. The recommended action is to set temperature gauge for the motor to assist in the detection process. The re-evaluated factors are S = 8, O = 3, D = 1 and the new RPN = 60.

Finally, the blower fan potential failure might happen is decrease in amount of air flow, the causes are dents or fractures in fan blades or fan motor overheating, the potential effects is the air current is going to near somewhere near to the A/C unit that meet the air current could not reach the maximum distance to cover. The evaluated factors are S = 4, O = 3, and D = 4 the resulted RPN = 48. The recommended action is to add speed meter for the blower fan itself and temperature gauge on the motor to increase the detectability. The re-evaluated factors are S = 3, O = 3, D = 2 and the new RPN = 24.

4. FMEA Results

As shown in table 3 there are differences in terms of RPN values for each component. At The main component of the A/C system which is the compressor; there was a significant drop in the new RPN value by almost 75% from the original RPN value which indicates that the associated factors have decreased which leads to reducing the risks impact. In addition, for the rest of the components there were changes in the new RPN values they have decreased as well. The percentage of changes for the Blower fan, expansion valve, evaporator, fan motor are 62.5%, 50%, 65.7%, and 25% respectively. The new values of the RPN indicate that with minor changes to the product itself; it would increase the unit reliability and maintainability as consumer perceptive, on the remanufacturing perceptive it a bit easier to distinguish between the valuable and non-valuable products.

Table 3: FMEA results overview.

System element	**Failure**	**RPN**	**Solution**	**New RPN**
Compressor	Compressor breakdown	224	Gas pressure sensor and lubricant level meter	56
Blower Fan	Air flow decreased	48	Rational speed detector and motor temperature gauge	18
Expansion valve	Regulating is not work properly	180	Leakage sensor	90
Evaporator	Heat is not exchanging	175	Substance detector sensor	60
Fan motor	Motor breakdown	96	Motor temperature gauge	24

5. Conclusion

In this study, different recommendations have been stetted; by applying those recommendations it will leads to increase reliability and maintainability on one side, on the other side which is our concern in this paper; is providing help to decision on the returned products through retailers to select which is proper to send the A/Cs to manufacturer to perform the processes of remanufacturing or not. By reducing the resources and time spent on each returned unit to do tests.

6. References

1. Abdullah M. Alshaalan 2012. EER improvement for room air-conditioners in Saudi Arabia.439-446.
2. Lund R, (1984), Remanufacturing: The experience of the United States and implications for developing countries. UNDP Project Management Report No 2. World Bank Technical Paper No 31, pp 24-34
3. Artur Rękas, Magdalena Kurek, Tomasz Latos, Katarzyna Milczanowska 2015. Implementation of FMEA into mass production process to identify and eliminate causes of defects. 266 -278
4. Zhenyong Wu, X. G. Ming, Wenyan Song, Baoting Zhu, Zhitao Xu 2014. Nuclear product design knowledge system based on FMEA method in new product development. 39:2191–2203.
5. Nadia Belu, Nicoleta Rachieru, Emil Militaru and Daniel-Constantin Anghel. Application of FMEA method in product development stage.12-20.
6. Ammar Y. Alqahtani, Surenda M. Gupta, Kenichi Nakashima 2014. Performance analysis of advanced remanufacture-to-order, disassembly-to-order and refurbishment-to order system.140-149.
7. McDermott, R. E., & Mikulak, R. J., & Beauregard, M.R. (1996). The Basics of FMEA. Resource Engineering, Inc.

Biography

Dr. Bashir Salah is a graduate of The University of Duisburg Essen. He took technical training in mechatronics at the German Technical Cooperation Agency. Dr. Salah is currently an Assistant Professor in Industrial Engineering Department at King Saud University. He is also a member of accreditation committee in Industrial Engineering Department. Dr. Salah has collaborated on various Industrial and research projects. He has experience in teaching wide range of IE courses, is involved with several administrative duties, and has developed a network of industrial and academic collaborators across the world. Research areas and specialties: 1) Design and analysis of computer integrated manufacturing, logistics, and supply chain. 2) Industrial facilities planning. 3) Professional project management.

Dr. Mohammed Alkahtani is an Assistant Professor in Industrial Engineering Department at King Saud University. He is also the chairman of the Industrial Engineering Department and has recently been elected as chairman of the Industrial Engineering chapter of the Saudi Council of Engineers (SCE). Dr. Alkahtani has collaborated on various Industrial and research projects. He has experience in teaching wide range of IE courses, is involved with several administrative duties, and has developed a network of industrial and academic collaborators across the world. Research areas and specialties: 1) Design and analysis of manufacturing systems, logistics, and supply chain. 2) Lean/Agile based approaches for performance improvement of SMEs. 3) Application of simulation, operations research and optimization techniques to solve supply chain and logistics problems.

Dr. Aiman Ziout is an Assistant Professor in Mechanical Engineering Department at United Arab Emirates University. He is also the coordinator of M.Sc. program in Materials Science and Engineering (MTSE). Dr. Ziout runs various Industrial and research projects. He has secured almost one million dollars as research grants and in-kind funds. His research focus is sustainable product design and innovation, he has published many papers in reputable journals and presented his research findings in national and international conferences. Currently he researches active joining methods to facilitate sustainable end of life product recovery. He has experience in teaching wide range of design and manufacturing courses, such as CAD, CAM, and product design and innovation. He is involved with several administrative duties at the department and college level, he is a member of Canadian Engineering Education Association, a platform to share and communicate best practices in engineering education