QATAR UNIVERSITY

COLLEGE OF ENGINEERING

APPLICATION OF MANAGEMENT SCIENCE TOOLS TO EFFECTIVE DECISION MAKING:

A CASE STUDY OF SMART HVAC PRODUCTS IN QATAR

BY

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ABSTRACT

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Title: Application of Management Science Tools to Effective Decision Making: A Case Study of Smart HVAC Products in Qatar

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Qatar is a fast-developing country, and this rapid growth increases the need for the introduction of new product ideas to the market aiming to satisfy customer's needs. However, not all product ideas are equally attractive and not products are applicable since some product ideas require high investments and tend to have a high risk. Moreover, recent studies have shown that the process of applying new product screening techniques is very crucial to the company's managers, where the process of investigating the products successfulness saves significant investments and opportunity costs, without killing the newly generated product ideas. Unfortunately, some managers still take decisions regarding new product ideas informally and in an unsystematic way although there is always room for improvements in the area of decision making.

In this project, an actual application of management science tools including the Monte-Carlo Simulation and the Analytic Hierarchy Process (AHP) are illustrated as decision support tools to aid the CEO of Company X in Qatar to select the best product idea to pursue. The project aims to show the CEO of Company X how such tools are useful in decision making when conflicting objectives and complex situations arise, and the final decision to be made becomes ambitious.

DEDICATION

I would like to dedicate this work to my family, especially my mother and father for their patience, love, and support throughout this journey. This work is also dedicated to my husband who kept on encouraging me and believed in my ability to achieve my academic goals and overcome all the challenges I have faced.

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I would like to take this chance to thank Dr. Mohamed Haouari for being my project supervisor and guiding me throughout the project phases. Although he had other responsibilities and workload, he always met me with a smile and encouraged me to accomplish this work.

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A special thanks to my family, especially Engineer Dhuha Alhorr , she was not only a sister but a true friend who helped me achieve my goals and have always supported me with useful ideas , thoughts and resources. Without the continuous support of my family, this project would not have been possible.

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CHAPTER 1 INTRODUCTION

After Qatar's Blockade in June 2017, different products were banned to be distributed in the market, and many companies have realized the need for the development of new product ideas and the introduction of them to the market to satisfy customers growing needs. As his Highness Sheikh Tamim bin Hamad Althani stated ‘’ In today's competitive environment, it is important to achieve sustainable development in Qatar and diversify sources of income through the development of new products’’.

1.1 New product ideas

Not all new product ideas are equally viable and are guaranteed to be successful in the market due to many factors including, the acceleration of the technological development rate, more intense competition and the increased costs of research and development. Furthermore, taking a decision to manufacture a poor new product idea can lead to negative results and can cause major losses of opportunity costs to the company.

Therefore, the process of new product screening is of vital importance for managers in different fields nowadays to know the probability of success of the new product ideas. In fact, the screening of new product ideas is the most critical activity in new product development projects, yet it is not frequently adopted by managers although its importance was realized in past research (Battiston et al., 2013). Also, when successful product ideas are implemented, then this will result in profit gain for the companies and lead to being successful in the market. The profitable gain can be translated into a positive competitive advantage for the managers of the company.

In addition, different management science tools are widely available nowadays for the aid of managers in the area of new product ideas decision making. The Monte-Carlo simulation and the Analytic Hierarchy Process (AHP) technique are some of the powerful tools in the area of new product screening.

The Monte-Carlo simulation is useful in aiding managers generate repeated values of data based on probability distributions and help account for risk measures. The probability of how successful a new product will tend to be in the market is a common area of the Monte-Carlo Simulation applications.

The Analytic Hierarchy Process (AHP) technique enables managers to make effective decisions by evaluating the attractiveness of each product type depending on qualitative and quantitative set of criteria. The set of criteria revolves around many factors, such as the innovativeness of the product, the profit level, the skills needed to manufacture the product and the technical fit of the product.

1.2 Q-COOL HVAC system in Company X

Company x has introduced the first Qatari patented HVAC system 'Q-COOL' in Qatar, the products of 'Q-COOL' are highly innovative, sustainable and save energy, yet contain a high risk and investment to manufacture. The company aims to launch the smart products that have the potential to reduce carbon footprint of the country by introducing energy efficient solutions in cooling systems and the next section provides a brief overview of 'Q-COOL' products.

1.2.1 Project Concept

QCOOL, an innovative smart patented air conditioning system by Company X is a fully integrated and controlled ventilating and air conditioning system that provides efficient and sustainable fresh air cooling for open or enclosed spaces in moderate, hot or humid climates.

The table below shows the difference between Q-COOL chiller system types and the typical chiller system type :

Table 1.Comparsion between Q-COOL chiller and a typical chiller

	Typical chiller	Q-COOL chiller
System type	Vapour Compression (Typical System)	Desiccant cooling (QCOOL System)
Indoor air quality	Comparatively lower	High due to air circulation
Moisture removal capacity	Average due to low water absorption capability	High due to absorption of water from vicinity
Energy storage capacity	Low because of conventional technology	High due to the use of desiccant technology
Effect on environment	Generally harmful	Comparatively eco-friendly
Energy Consumption	Higher energy consumption.	50%-62% reduction in energy consumption compared to conventional systems

1.2.2 Products technical description

Centralized chiller (packaged air conditioners with air cooled condensers) is a type of central air conditioner in which the atmospheric air cools the condenser of the refrigeration system. There is an outdoor unit that comprises of the important components like the compressor, condenser and in some cases the expansion valve. Moreover, the outdoor unit can be kept on the terrace or any other open place where the free flow of the atmospheric air is available. The fan located inside this unit sucks the outside air and blows it over the condenser coil cooling it in the process. The condenser coil is made up of several turns of the copper tubing and it is finned externally.

The final products of the company comprise of small & large centralized chillers. Q-COOL products can add value to consumers by offering energy efficient cooling system that can reduce carbon emissions in a cost-effective manner. Furthermore, Q-COOL products has advantages over the conventional system that is supplied in the Qatar market in terms of coil load reduction, cost effectiveness and efficiency. Q-COOL envisages to take advantage of the rising demand for cost effective air conditioners in Qatar.

The table below gives an overview for the small chillers and large chillers:

Table 2. Comparison between small and large chiller

	Small chillers	Large chillers
Technology	Centralized chillers	Centralized chillers
Area cooled	Small-to-medium	Medium-to-large
Type of buildings	Low rise buildings	High rise buildings
Applications	Residential Villa Education Healthcare Retail	Leisure Public Hospitality Outdoor spaces

1.3 Project aim and objectives

The project aims to investigate through the use of different science management decision making tools a real-life problem scenario in the area of new product screening in Company X

The project goals are as follows:

1) State the importance of using management science tools to aid managers in the process of multi-objectives decision making under uncertainty.
2) Apply the Monte-Carlo Simulation at a case study for Company X to investigate about the probability of success of two new innovative product ideas which are small and large chillers of Q-COOL HVAC system.
3) Apply the Analytic Hierarchy Process (AHP) at Company X to investigate which type of chiller will tend to be more successful when introduced to Qatar's market.

1.4 Outline of the project

Chapter 1: The first chapter provides an introduction to the topic and illustrates an overview of the product screening issues managers face nowadays and in the past in decision making. Furthermore, the types of chillers to manufacture are briefly introduced, where a comprehensive analysis of the two types of chillers will be provided in the following chapters.

Chapter 2: the second chapter demonstrates how past researchers have used several decision-making tools in the area of product screening. Also, it suggests several frameworks and methods to overcome the issues of uncertainty in new product screening.

Chapter 3: the third chapter presents the methodological steps followed in this project, including the quantitative and qualitative data collection steps and how the Analytic Hierarchy Process (AHP) can be combined with the Monte-Carlo Simulation as a method for aiding the managers of Company X to know which type of chiller will tend to be more successful in Qatar's market.

Chapter 4: the fourth chapter illustrates the analysis of the gathered data where the first section demonstrates the use of Monte-Carlo Simulation as an account for risk of each type of chiller, and the second section illustrates how the Analytic Hierarchy Process (AHP) tool can be combined with the results of the Monte-Carlo Simulation.

Chapter 5: the fifth chapter of the project presents a discussion of the results gained from the analysis part of the project for each tool used and shows how the sensitivity analysis is important to conduct in such situations.

Chapter 6: the last chapter presents the conclusions of the project work along with suggesting a few recommendations for future work.

CHAPTER 2 LITERATURE REVIEW

In this chapter, different literature reviews are analyzed in order to show how previous research papers have addressed different decision-making scenarios in real life through applying management science tools.

2.1 Challenges faced in new product development

Past researches have emphasized that companies responsible for manufacturing products believe that the principle driver of future growth is by developing new products and introducing them into the market (Battistoni et al., 2013). Due to the acceleration in the technological development rate and the intense competition managers face nowadays, the process of developing new products must be done as fast as possible (Chiu et al., 2006). However, not all products are guaranteed to be successful in the market, even though the idea tends to have a high level of innovation (Battistoni et al., 2013).

Furthermore, past researchers have noted that it is often easier to come up with many product ideas in a short time, however it can be very costly and risky to develop those product ideas and introduce them into the market since not all product or project ideas are feasible or can be implemented. Additionally, product ideas differ from one another according to different issues including fitting the organization's objectives, the innovation level, developing costs, probability of success or failure, and whether they are profitable or not (Calantone et al., 1999).

2.2 Decision support tools

Managers nowadays tend to make advantage of intelligent and advanced tools to overcome the issues faced in the process of new product development. Since new product development requires a mixture of quantitative and qualitative criteria such as market demand, profit, fit with organizational objectives, the process becomes a challenge for decision makers. Additionally, companies have focused on eliminating product ideas with a high failure rate at early stages, to save opportunity costs and increase the growth of the company (Chin et al. 2008).

Also, managers have been considering measuring tangibles and intangibles in the decision-making process for selecting the best products to develop according to certain criteria. The Analytic Hierarchy Process (AHP) was introduced in the 1980, to assist managers working in different sectors in decision-making, it is a simple yet very powerful tool in structuring complex decisions with multiple criteria and reflects relative preferences depending on pairwise comparisons between both tangibles and intangible measurements (Saaty,1987).

Furthermore, the Analytic Hierarchy Process (AHP) have been used as a decision supporting tool which depends on managerial inputs for scoring alternatives based on different criteria that fits each application. For example, the process of prioritizing a range of product ideas for the final selection of the best product to proceed with could include the profit of each product and the market demand (Saaty,1987).

In addition, the managerial judgments will have a percentage of inconsistency which can easily be calculated through different decision supporting software like 'Expert Choice Software 'and 'Super Decisions Software 'which readily available online. As emphasized by Calantone et al., (1999), although tools such as the Analytic Hierarchy Process (AHP) exists for more than a decade, managers still do not widely adopt such approaches.

Moreover, previous papers have noted that some firms have killed interesting ideas and projects due to the conflicting objectives and the high risk of failure, without considering that the problem picture can be addressed through the use of decision support tools such as the Monte-Carlo Simulation and the Analytic Hierarchy Process (AHP) which are very useful tools in solving such conflicts (Calantone et al., 1999). In addition, authors share that the Analytic Hierarchy Process (AHP) is an important management science tool in the area of product screening, it works as a foundation for decision makers and managers in order to reach the final decision (Chin et al. 2008). Therefore, managers should use approaches and different decision-making tools which will support the managers final decision and keep him/her on the right track (Saaty,1987).

2.3 The Analytic Hierarchy Process (AHP) technique

The Analytic Hierarchy Process (AHP) decision supporting technique works as follows:

- **Problem definition:** to define the problem to be addressed, or the complex decision to be made with a clearly defined goal along with the necessary assumptions (Russo & Camanho ,2015).
- **The development of the hierarchy structure:** which is structuring the decision hierarchy through asking the main person responsible for the decision what is his/her goal. The goal will take place at the highest level of the hierarchy. The level at the middle includes the main criteria in considering the alternatives at the lowest level of the hierarchy. At this stage managers must consider the criteria which will affect the final decision and eliminate any alternative that does not meet the developed criteria. For example, in investigating product screening scenarios, the criterion could include the probability of success, the fit with organizational objectives, and the minimum risk, while the alternatives could be a set of generated product ideas not equally meeting all the criteria (Russo & Camanho ,2015).
- **Pairwise comparisons at all hierarchy levels:** comparing the criteria and sub-criteria with respect to the goal according to their importance, since some criteria are considered much more important than other criteria, while the rest could be equally likely. The same comparison is done with alternatives according to their preference on each criterion/sub-criterion (Russo & Camanho ,2015).
- **Weight recording:** translating the comparison or judgmental data into weights on different scales to calculate the priorities of each element as well as the inconsistency level at each matrix. This can be obtained by Analytic Hierarchy Process (AHP) software such as 'Super Decisions'. (Russo & Camanho ,2015).

- **Checking/validating the decision:** the ranking of alternatives will be provided by combining all the information provided in the earlier steps to give the manager which alternative is the most favourable depending on the criteria and the pairwise comparisons. However, the manager must revise this step by checking whether the Analytic Hierarchy Process (AHP) technique result is consistent and meets expectations. If the provided result is far from reality, the steps of the technique must be revised, and the judgments must be adjusted (Russo & Camanho ,2015)..

In addition, different researchers have noted that using the Analytic Hierarchy Process (AHP) method can generate some inconsistency, however this inconsistency can be tolerated if the percentage is 10% or less for a scale of 0-1. It was also noted that the number of compared elements should be not very high, because many compared elements would result in reducing the relative priorities and therefore cause high sensitivity on each node (Saaty,1987).

2.4 Applications of the Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is applied in different fields, however the most commonly used fields are the multi-criteria decision making. For instance, some practical problems which were solved by the Analytic Hierarchy Process (AHP) include combining the Analytic Hierarchy Process (AHP) along with Geographic Information System (GIS) to investigate in sustainable development based on the economic, social and physical improvements.

Furthermore, other papers have combined the Analytic Hierarchy Process (AHP) with SWOT (strength , weakness , opportunities , threats) technique to find the most important strategic factors which affect a manufacturing firm based on pairwise comparisons at each element group, the results of the study showed that the significant factors belong to the ‘ opportunities’ group (Gorener et al., 2012). Furthermore, other prior studies have combined the Analytic Hierarchy Process (AHP) with Quality Function Deployment (QFD), for the purpose of translating quality requirements into technical requirements based on surveys and interviews (Tu et al., 2011).

The other main applications of the Analytic Hierarchy Process (AHP) include:

- Marketing planning
- Economics planning
- Transportation and logistics
- Tourism planning
- Business planning

2.5 AHP applications in new product screening

Although the Analytic Hierarchy Process (AHP) has been applied in different applications as discussed earlier, it is still not extensively applied in the area of product screening although other researches have claimed its importance and usefulness in such contexts. Calantone et al., (1999) presents an application of the Analytic Hierarchy Process (AHP) in new product screening. In the research, different criteria where provided by the managers which are of vital importance, including fitting the firms marketing competencies, fitting with firms technological competencies, total dollar risk profile of the project and overall management uncertainties about the project outcomes as shown in the figure below. Each criterion had sub-criterion which consists of the main issues regarding new product idea, since not all projects are feasible. Additionally, the decision was made through the use of Analytic Hierarchy Process (AHP) software ‘Expert Choice ‘ to rank the four product ideas alternatives according to the provided weights and criteria at each level, and the software provided a sensitivity analysis report to conduct a ‘ what if ‘ analysis and show the alternatives behaviour according to each criterion with respect to the goal .

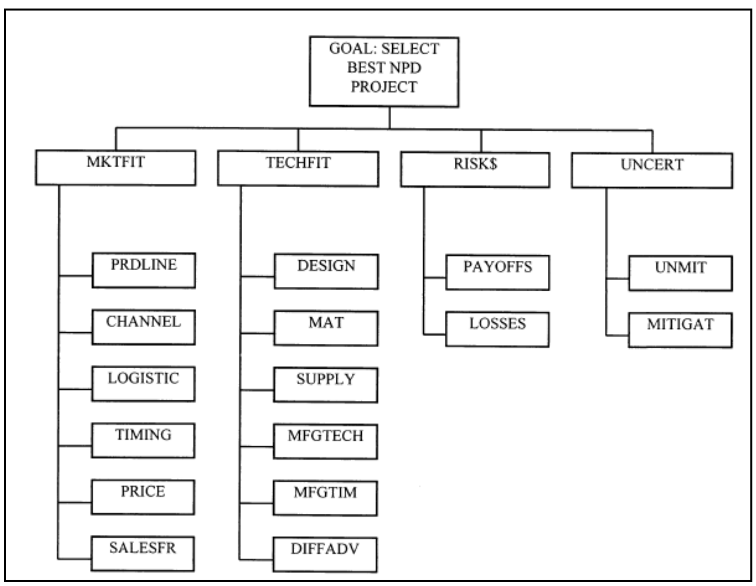

Figure 1. Selecting the best new product development project, (Calantone et al., 1999)

Furthermore, as Chiu et al., (2006) emphasized in the area of new product launch strategy, the managers of a company may combine the strategic qualitative objectives along with forecasted and estimated values in order in have a close indication of what might be the best product to introduce in the market, through combining the use of the Analytic Hierarchy Process (AHP) and management science tools. The paper focused on ensuring that all the firms strategic objectives are included in the tree structure and the final decision to be made became clearer, and consistent with the originally defined pair-wise comparisons in terms of different product alternatives.

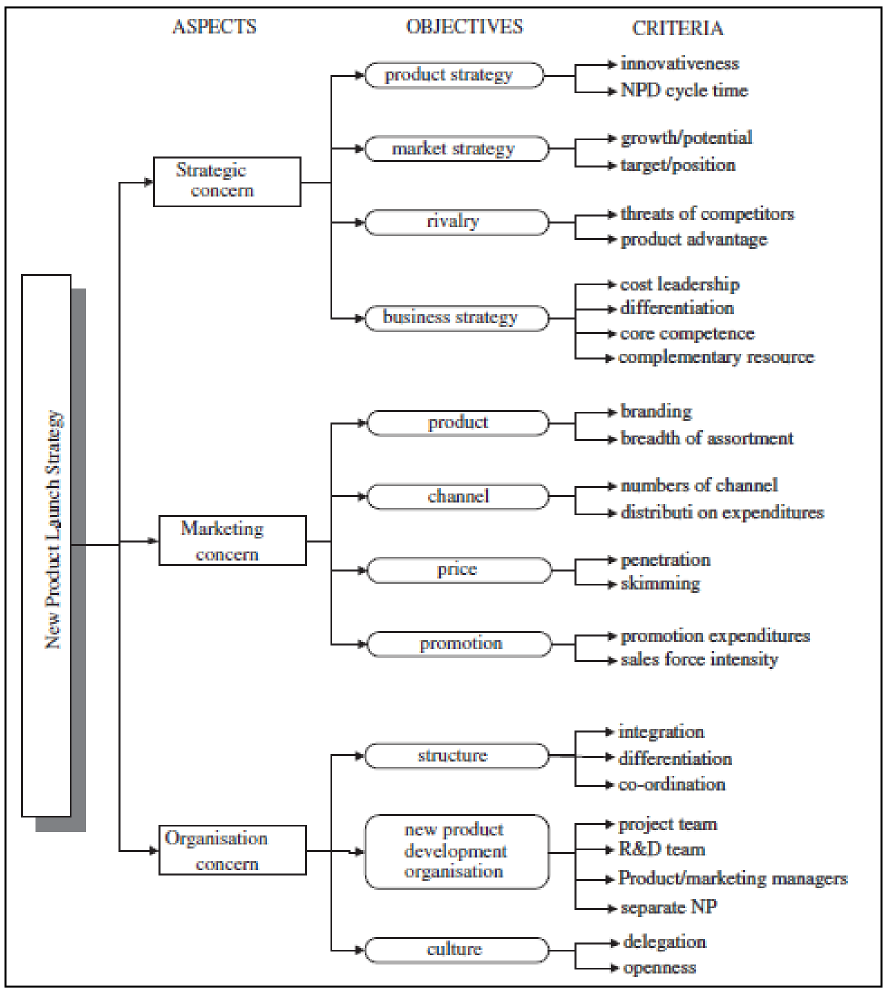

Figure 2. New product launch strategy , (Chiu et al., 2006)

Moreover, Battistoni et al.(2013), have emphasized on the importance of the Analytic Hierarchy Process (AHP) in investigating the implementation of new product ideas, since the technique allows the decision maker to clearly define the main criteria behind the success of the product and eliminate the product ideas which scored the lowest after the ranking of alternatives. Additionally, different questionnaires were gathered for the purpose of having unbiased pairwise comparisons, and the Analytic Hierarchy Process (AHP) technique provided an indication of would could be the best product idea to develop.

2.6 Shortcomings of the Analytic Hierarchy Process (AHP)

Past researchers have noted that even though the Analytic Hierarchy Process (AHP) has benefits in decision making, there are still shortcomings of the technique which should not be ignored. In some cases, the final ranked value priorities can be very close to each other where the managers must be cautious and revise the judgments or consider additional criteria that could help in making some discrimination between the alternatives. Moreover, the technique is only a decision support tool and the results should only be taken as a close indication to the final decision, since human decision cannot be replaced (Triantaphyllou & Mann, 1995).

Furthermore , and as Chin et al., (2008) stated , in the area of new product screening uncertainty can be divided into two major reasons , the incomplete data and the imprecise judgments. Researchers have stated that the reason for incomplete data is due to the insufficient information at the early stages of product screening.

Moreover , the imprecise judgments like the unavailability of engineering and financial figures can make the decision unreliable since the Analytic Hierarchy Process (AHP) cannot tackle the problem of uncertainty , it only relies on the provided information by the decision maker whether the source is questionnaires , future forecasts , or experts judgments (Triantaphyllou & Mann, 1995).

2.7 Decision making through the use of Monte-Carlo Simulation

In the area of new product development, each product has different characteristics, some products require high investments, while others require long lead times. With those uncertain factors, the risks keep on increasing and can lead to the loss of a firm. Thus, risk management is playing nowadays a very important role since different uncertainties are taken into consideration to improve the accuracy of the final estimated value. According to (Li Rui-mei,2015) there are different tools in which the uncertainty of project can be evaluated to the different possible risks, and one of the most important tools is the Monte Carlo simulation method. The method accounts the influence of different variables which contribute for risks, and models them in a certain number of iterations giving all the possible outcomes of the iteration based on different probability distributions. Additionally, the technique aids managers to eliminate the undesired projects in a certain area based on the computations of all probable values of the scenarios, therefore saving money , time and effort to go for further analysis and incur additional funds in investigating a project which tends to be unsuccessful from the very beginning.

2.8 Properties of Monte Carlo simulation and its Applications in new product screening

As Kroese (2012) stated , the Monte-Carlo simulation is used widely nowadays in different fields such as engineering , operations research , finance , economics and science. Its importance is increasing due to its effectiveness in a wide range of systems. In addition, it can be used in sampling, estimation, and optimization of different models with large complexities in real life situations. Recently, different approaches of Monte Carlo simulation are used to solve even more complex problems. The method gives the managers a picture of how likely the expected result will occur, or the uncertainty aligned with going for a certain project. No doubts that the Monte Carlo simulation method will continue to increase in in fields such as new products introduction to market, since the method is used to estimate the probable values of the maximum profit, the demand , and the total cost. The final values will give the manager an indication of all the possible scenarios of the distributed data which will provide a more realistic subset of values, instead of using only one value as a basis for further analysis.

2.9 Gaps of the academic literature

After analysing the different literature reviewers in the area of new products decision making , the main gaps noted in the academic literature are as follows:

1) Few studies were found regarding applying management science tools in the area of new product screening, although such types of studies are important since Qatar is in the stage of developing many new products aiming to introduce them to the market.

2) No published papers regrading applying the Analytic Hierarchy Process (AHP) in the area of product screening in Qatar were found,
3) No exact approach fits the situation of the project’s case study needed to be analysed, so a combination of the Monte-Carlo Simulation along with Analytic Hierarchy Process (AHP) will be used in order to fill this gap.

CHAPTER 3 METHODOLOGY

This chapter provides the proposed methodology for the project where it includes the project problem statement, the tools used to collect the data, the outcomes of the project and the limitations of the project.

3.1 Project problem definition

Q-COOL is an innovative smart patented air conditioning system designed by Company X. Q-COOL products compromise of small chillers and large chillers. The small chillers are used in low to mid rise buildings, townhouses and villas and the large chillers are mostly used in high rise buildings. Furthermore, the CEO of Company X noted that although it is a great opportunity for the company to hit the market by introducing the chillers by the end of 2018 in Qatar, at the same time it is very costly and risky to manufacture in Qatar for the first time both small and large chillers of the new patented air conditioning system. Therefore, the CEO needs to know what type of chiller will tend to be more successful in the market depending on several quantitative and qualitative factors and complex multiple objectives.

3.2 Project Contribution

The project work will follow a systematic analysis of data collected from Company X through the use of management science tools which are the Monte-Carlo Simulation and the Analytic Hierarchy Process (AHP) in order to reach the final decision. Moreover, the project will provide criterion which can be applicable in the area of new product screening and can help managers assess their new product ideas which tend to have a high risk and cost , but a great opportunity at the same time.

3.3 Project objectives

The project objectives are as follows:

1) State the importance of using management science tools to aid managers in the process of multi-objectives decision making under uncertainty.
2) Apply the Monte-Carlo Simulation at a case study for Company X to investigate about the probability of success of two new innovative product ideas which are small and large chillers of Q-COOL HVAC system.
3) Apply the Analytic Hierarchy Process (AHP) at Company X to investigate which type of chiller will tend to be more successful when introduced to Qatar’s market.

3.4 Project limitations

The limitations of the project arise due to data collection methods where both the qualitative and quantitative approach are used. In the qualitative approach the criterion is measured through managers interviews and the CEO of Company X, therefore the final results of the decision-making tools can be biased to some extent by the judgments provided and translated into factor weights. Also, since the smart chiller products are the first to be developed in Qatar, data regarding the initial costs and demand may not be very accurate and can affect the scores of the final decision. In addition, the criterion developed fits Company X particularly , and since the case is unique for the smart chillers it might not be applicable for every situation in the area of new product screening. Furthermore, in order to overcome the issue of data uncertainty the Monte-Carlo simulation was adopted to have a more realistic overview of the data scenarios. In addition, different sensitivity scenarios were illustrated and the pairwise comparisons were revised by the company's marketing managers, planning managers, and finally the CEO of Company X.

3.5 The use of Analytic hierarchy process (AHP) technique

The (AHP) technique is suitable in decision-making when several criteria are all crucial in reaching the final decision. The method will be used to compute the overall score of the types of chillers to manufacture, and the goal to be reached is which type of chiller will tend to be more successful in the Qatar's market.

The steps of the (AHP) technique as Gorener et al. (2012) simplified are as follows:

1) To define the practical issue that has to be solved, which is identifying which type of chiller will tend to be more successful according the decision-making tool (AHP).
2) To establish the decision-making criteria, which are the suggested from the academic literature and revised by the managers of Company X to fit their situation and needs. The set of criteria in the matrix is C= [Cj] where j=1…m, where m represents the number of criteria.

3) To establish the decision-making alternatives , and in this project the alternatives were narrowed into only two of Q-COOL system products which are the small smart chillers and the large smart chillers due to time limitation and the unavailability of necessary data required for the analysis. The alternatives represent the matrix A=[Ai] , where i=1…n , represents the number of alternatives.

4) To determine the relative weight of each criteria by conducting pair-wise comparisons based on verbal assessments for the data that is unquantifiable and by interpolation for the data that can be quantified according to the fundamental (AHP) scale as shown below:

Values/Rates	Description
1	Equally preferred or it does not matter (equal importance)
2	Equally preferred, but with certain moderate differentiation tendencies
3	Moderately preferred
4	Preferred towards strongly preferred
5	Strongly preferred
6	Strongly preferred towards obviously preferred
7	Obviously preferred
8	Obviously preferred towards extremely preferred
9	Extremely preferred

Figure 3 AHP judgment scale

5) To fill the data according to the new matrix which will contain the total on every column and is calculated by the formula:

$$Sj = \sum_{j=1}^{m} cij$$

6) To normalize the comparisons between all criteria by dividing the values of the comparison results with the total value at the end of the column, the normalized values are calculated by:

$$nij = \frac{cij}{Sj}$$

7) To transform the values into weights of the decision criteria *Kj*, by taking the average of the normalized vales on each row as follows:

$$kj = \frac{\sum_{j=1}^{m} nij}{Sj}$$

8) To determine the inconsistency factor between the criteria matrix. A ratio of a 10% is accepted, however if the factor was exceeded then the criteria weights are revised. This is calculated by ‘Super Decisions’ software which its application is furtherly demonstrated in the analysis chapter.

9) To determine the weight of alternatives with respect to each to criteria, where m is the number of alternatives and normalize the comparisons between alternatives with respect to the criterion.

10) To fill in the performance matrix, where each alternatives performance will be identified according to the criterion. The performance matrix is represented as P=[*Pij]*.

11) To determine the total priorities values for each alternative by multiplying the weight of each alternative with its related criteria with the weight of each criteria and finding the sum. Where Pi represents the total value of the alternative priority

, and pij the weight of each alternative with its related criteria. The final decision is then made by finding the highest value among the alternatives.

$$Pi = max \sum_{j=1}^{m} pij.kj$$

3.6 Use of Super Decisions Software

Super decisions software is used for the purpose of calculating the inconsistency level and ensuring that a factor of 10% inconsistency level or less is the case for each matrix while applying the judgments. Also, the software generates sensitivity reports to show the behaviour of each alternative with respect to the criterion which make it clearer to analyse different scenarios of a ‘what if’ analysis.

3.7 Data Collection

Data collection is based on the quantitative and qualitative approach, where the gathered data including calculated values, priorities and judgments will all be translated into the decision-making tool (AHP).

Qualitative approach: the qualitative approach used in data collection is by interviewing several managers at Company X including the marketing manager and the planning manager. The purpose of conducting the interviews was to know which critical criteria obtained from the academic literature serve as success factors to the company. After several meetings and useful discussions, a group of criteria were suggested and revised by the planning and marketing managers of the company and their importance were given according the type of chillers and the initial (AHP) was structured.

Quantitative approach: some data were given based on history values of similar products in other companies and forecasts, and such data were used as a guide to measure the probability of failure of the products through the Monte-Carlo simulation. In addition, judgments in the (AHP) in quantitative criterion will be given according to the exact values of the results.

Both the qualitative and the quantitative approach are crucial in using the (AHP), since human judgments are not enough for solving an issue of new product ideas, and numerical figures must exist to distinguish between the values of the criterion and reduce biased opinions.

3.8 Proposed methodology

The methodological steps and the approach used in the project is through accomplishing three main phases. The first phase includes the problem identification, where several meetings were conducted to understand the situation and what is the objective of Company X's managers. The main issue to be solved will answer the following question:

- Which type of chiller will tend to be more successful in the market?

The complexity of the decision which needs to be made arises from the fact that several criteria and objectives affect the final decision of which type of smart chiller to manufacture. Although both types of chillers are highly innovative and unique, the risk associated with manufacturing both of them is very high and can have high costs. It was stated by Company X's CEO that only one type of chiller which tends to be more successful will be manufactured , since if the Company selects to manufacture both chillers at the same time, it can lose its business in case of failure.

Moreover, after an intensive view of how other researchers have addressed the same decision making issue , it was noted that the academic literatures have used the Monte-Carlo simulation in decision making under uncertainty and the (AHP) approach in solving new product screening problem scenarios which require multiple objectives.

In addition, (Calantone et al., 1999) has suggested that the (AHP) can be combined the results of other management science tools in order to have a more realistic picture of what might be the best choice among all alternatives. Different forecasting techniques, simulation tools and linear programming models results can be integrated into the (AHP) model to provide a comprehensive analysis in different application of new product screening. Therefore , in this project the results of the Monte-Carlo Simulation will be combined with the (AHP) model in order to have a more realistic view and find which type of chiller will tend to be more successful in Qatar's market.

Furthermore, quantitative and qualitative data was collected in the initial phase along with criteria that fits Company X's case, and the initial (AHP) model structure was introduced to Company X's planning and marketing managers. After that, the second phase was conducted, and it included revisions and adjustments of the initial (AHP) model structure, along with confirming the pairwise comparisons at each level of the model.

Finally, the last phase included revision of the judgments and ensuring that the inconsistency level is below 10% through 'Super Decisions Software which is a software that aids in calculating complex (AHP) models in a fast manner.

The figure below shows the project proposed approach used in the (AHP) model which includes three main phases.

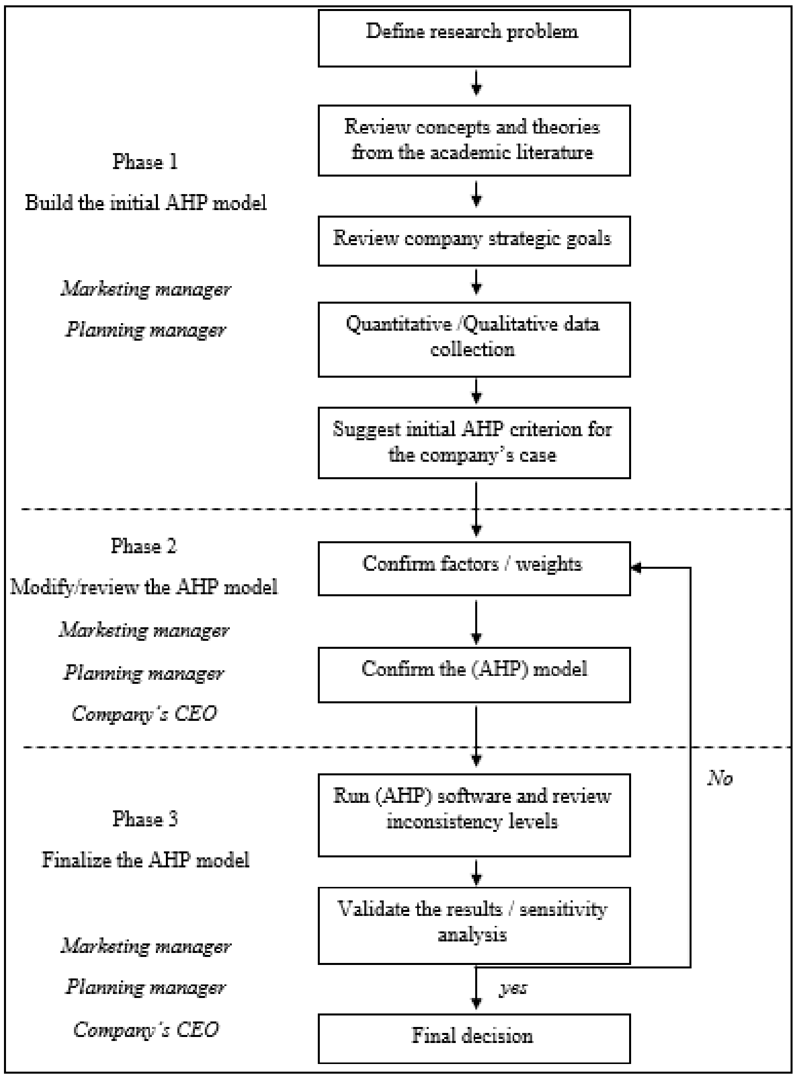

Figure 4: Proposed methodological steps for AHP

CHAPTER 4 DATA ANALYSIS

This chapter provides the data analysis part of the project for the small and large chillers. The data presented in the analysis are multiplied by an x factor due to confidentially of some figures gained from Company X data reports. Additionally, the first part of the chapter represents an application of the first management tool which is the Monte-Carlo Simulation. The technique is used to find the probability of success of the small and large chillers and aid the CEO of Company X in taking the final decision based on the gathered quantitative data which translate the risk amount for each chiller type. Moreover, the second part of the analysis presents an application of the (AHP) which will be applied to enhance the final decision taken by the CEO through introducing qualitative factors in the analysis and will be combined with the gained results of the Monte-Carlo Simulation as past researchers suggested.

4.1 The Monte-Carlo Simulation

The Monte Carlo simulation is a mathematical method which allows a firm to account for risk in different types of analysis and decision making. The method works by considering the uncertainty aligned with different values or the probability of occurrence of the data needed to be computed. The simulation generates hundreds or thousands of iterations randomly by following the distribution types to give a reasonable output of the result, which will give an estimate of how likely the desired result may occur. Furthermore, each of the data may have the same or different probability distribution types , and in the next section the application of the Monte-Carlo will be presented at Company X.

4.1.1 Case Study: Application Monte Carlo Simulation in Company X

In this part of the project, the Monte-Carlo simulation method is applied in Company X to manage and assess the impact of risk in the organization allowing for better decision making under uncertainty. The organization has developed the first Qatari-patent smart Air-Condition system. The system can save up to 60% electricity and its main products compromise of small and large chillers. However, as stated by the CEO of Company X, introducing both type of chillers in the market at same time has a large risk on the company, so the Monte-Carlo simulation is suggested as an initial management tools as a first step to ensure if the large and small chillers have a high probability of success.

Additionally, Company X has gathered different data about manufacturing the smart Air-conditioning products including the small and large chillers, such as static data including administrative and advertising costs, unit price of each chiller type, and variable data including the demand, the direct labour cost per unit and the material cost per unit. The data presented in following section are gathered from Company X where some data include assumptions based on previous historical data, data from existing contracts, and forecasts for future demand. The case is further analysed as follows:

Product: First Qatari-Patent Smart Air-Condition system which includes small chillers suitable for residential buildings and large chillers suitable for large and open space areas.

Objective: Investigate through Monte Carlo Simulation the probability of the loss of the new smart system for both the small and large chillers.

4.1.2 Analysis of Small Chillers

The static variables are shown in the table below along with the corresponding costs per unit of small chiller. Those values do not depend on any probability distributions since they are static and will not change or influence the number of iterations in the Monte Carlo simulation:

Table 3. Small chiller static variables for and the corresponding costs

Static variables	Cost (Qatari Riyals)
Selling Price/unit	80000 QAR
Administrative and Advertising Costs	500000 QAR

On the other side, the date presented in the following table are random or have uncertain values due to market fluctuations, different contractor's wages and variability or uncertainty of demand which is associated with the introduction of a new product in the market. Each uncertain variable cost in this case will follow a certain type of probability distribution gathered from experts findings and history data. The random variables will including the demand and direct costs will have a best, base and worst value.

Table 4. Small chiller random variables and the corresponding costs

Uncertain variables	Distribution type	Best value	Base Value	Worst Value
Direct Labour Cost/unit	Historical Relative Frequency Distribution	1500QAR	2000 QAR	2500 QAR
Material Cost/unit	Uniform Distribution	8000 QAR	12000 QAR	16000 QAR
Demand	Normal Distribution (mean 10000, standard deviation 8000)	34000 units	10000 units	0 units

Since the direct labour cost/unit follows a historical relative frequency distribution, a probability for each value in the range must be assigned based on history data or previous experience. The following table summarizes the probability of each uncertain direct labour cost and the total cumulative probability.

Table 5.Small chiller direct labour cost/unit and the corresponding probabilities

Direct Labour Cost/unit	Probability	Cumulative Probability
1500 QAR	0.1	0.1
1650 QAR	0.15	0.25
1800 QAR	0.2	0.45
2000 QAR	0.25	0.7
2150 QAR	0.15	0.85
2300 QAR	0.1	0.95
2500 QAR	0.05	1

The data illustrated in tables 4 and 5 above are used to compute the total profit for the small chillers, and the formula is for the total profit is as follows:

Total Profit = (Demand* Unit Price – Labour cost/unit – Material cost/unit) – Total administrative and marketing costs)

So, the best case for selling the product would be the case with the maximum demand and lowest costs, and the worst case would be generated if the demand was zero, or no units were sold. A total loss in the case would occur because of the total spent administrative and marketing costs.

The gathered data will give different generated scenarios with a worst and best value for the profit margin, however it does not give any information about how likely the small chillers are profitable, or the un-certainty of introducing it to the market. The probability of loss can be computed by linking all the data above through the Monte-Carlo simulation in Microsoft Excel.

After the costs , probabilities and demand data was entered into Microsoft-Excel, a sample of one total profit value was computed, and there will be 10,000 iterations for this profit value, in order to analyse all the different possible outcomes of the random variables in the model which will give different values of the total profit margin whether it was a negative value or a positive value.

The direct labour cost/unit follows a historical relative probability distribution and the function in Excel which will choose a random variable is LOOKUP(RAND() , ArrayValues). One value of the different labour costs will be randomly selected according to the cumulative probabilities and the corresponding cost values.

For the Material cost/unit, the values follow a uniform probability distribution therefore Microsoft Excel will choose a random value between the maximum Material cost/unit and the minimum Material cost/ unit by using the function RANDBETWEEN (bottom,top).

For the last random variable which is the demand following a normal distribution with a mean and standard deviation, Microsoft Excel will use the function NORM.INV (RAND(),mean, Standard Deviation) in order to generate a random variable for the demand distributed normally. In order to have a more meaningful term of the normal function of the demand (since it cannot have a negative value) the previous function will be adjusted in a way that Microsoft Excel will automatically set any negative value of the demand to be zero, therefore the new adjusted function will be MAX(0, NORM.INV(RAND(),mean, Standard Deviation)). Furthermore, in the adjusted function, Microsoft Excel will set any negative demand value to zero, and keep and positive demand value as it is. The following table shows a sample of one iteration for the total profit by using the three previously mentioned functions.

Table 6.Calculation of one sample total profit iterations for small chiller

Direct Labour Cost/unit	Material Cost/unit	Demand	Total Profit Revenues – Total Cost
1650 QAR	13054QAR	5832	974128658

Copying the previous table 10,000 times (number of selected iterations), will give a large table with different random values for the profit. By using Microsoft Excel, the total profit mean, max, min, and probability of loss will be computed.

The following table summarizes the most important data analysed by Microsoft Excel through the Monte Carlo simulation iterations, and the total probability of loss value is calculated by finding the amount of negative profit values generated by the 10,000 iterations by using COUNTIFS(totalIterations,"<0") divided by the total number of iterations. The average is the mean of all values, the minimum value will be the Total administrative and marketing costs (since demand is 0), and the maximum will be the highest possible profit (which is very unlikely to be). Appendix A illustrates 80 sample iterations.

Table 7. Analysed Monte Carlo Simulation results for small chiller

Average	Min	Max	Total iterations	Probability of loss
675136296	-500000	2645897207	10,000	0.11

Now, after the Monte Carlo simulation is applied, Company X have determined a picture of the probability of small chiller product success and loss which is around 11% for loss and 89% for success.

4.1.3 Analysis of Large Chillers

The same analysis is repeated for large chillers in order to compare the probability of success, or risk amount of each type of chiller.

The static variables including the price and administrative and advertising costs are for the large chiller are shown in following table:

Table 8. Large chiller static variables and the corresponding costs

Static variables	Cost (Qatari Riyals)
Selling Price/unit	400000 QAR
Administrative and Advertising Costs	700000 QAR

The random variables along with the probability distribution type for the large chiller are illustrated in the table below:

Table 9. Large chiller random variables and the corresponding costs

Uncertain variables	Distribution type	Best value	Base Value	Worst Value
Direct Labour Cost/unit	Historical Relative Frequency Distribution	12000QAR	13000 QAR	14000 QAR
Material Cost/unit	Uniform Distribution	10000 QAR	11000 QAR	12000 QAR
Demand	Normal Distribution (mean 900, standard deviation 1000)	3900 units	900 units	0 units

The corresponding probabilities for the direct labour cost/unit are as follows:

Table 10. Large chiller direct Labour cost/unit and the corresponding probabilities

Direct Labour Cost/unit	Probability	Cumulative Probability
12000 QAR	0.1	0.1
12200 QAR	0.15	0.25
12500 QAR	0.2	0.45
13000 QAR	0.25	0.7
13300 QAR	0.15	0.85
13600 QAR	0.1	0.95
14000 QAR	0.05	1

The table below shows a sample of one Monte-Carlo simulation iteration and Appendix A illustrates 80 sample iterations.

Table 11. Calculation of one sample of total profit iteration for large chiller

Direct Labour Cost/unit	Material Cost/unit	Demand	Total Profit (Revenues – Total Cost)
12500 QAR	11672 QAR	792	297120422

Finally, the table below shows the final results of the Monte-Carlo simulation for the large chiller, where the probability of loss is around 18%

Table 12.Analysed Monte Carlo Simulation results for large chiller

Average	Min	Max	Total iterations	Probability of loss
38100996	-700000	178575733	10,000	0.18

4.2 Analytic Hierarchy Process (AHP)

The (AHP) is presented in this section as a tool for aiding the CEO of company X in expressing his qualitative concerns, where the quantitative results of the Monte-Carlo simulation in the previous section will be combined with the (AHP) as readily measured data.

4.2.1 The AHP model

The criteria shown in the figure below is based on the academic literatures suggestions along with Company X's main concerns.

Figure 6. Proposed AHP criterion for company X product screening

The table below summarizes the meaning of each criteria with respect to Company X's definitions:

Table 13. Company's X definition of each criterion

Criteria	Sub-Criteria	Definition
Strategic Concern	Innovation level	The product's level of innovation is high enough to compete in the market.
	Product advantage	The product gives a differentiated value to its market segment due to its uniqueness.
	Competitor threats	The product has minimum threats of foreign competitors
	Time	The product matches the desired introduction time to the market as required by our market segment.
Marketing concern	Price	The product's price is competitive and will be offered below price point for out market segment.
	Demand	The product's demand is steady, with some fluctuations at peak times.
	Material cost	The product's total cost of materials.
	Packing cost	The product's total cost of packaging the final product.

Cost of sales	Direct labour cost	The product's direct labour cost per unit chiller.
	Utility expenses	The product's overall utility expenses.
Management uncertainty (Product Risk)		The product's probability of loss.
Revenue		The product's maximum generated revenue.

4.2.2 AHP computations for Small/Large chiller

In order to find the best type of chiller to manufacture based on the criteria mentioned earlier, a series of systematic steps must be followed. In Company x's case. The main goal is to find which type of chiller will tend to be more successful in Qatar's market and the alternatives are both types of chillers. Moreover, the highest overall score gained from the (AHP) tool will give an indication to the CEO of what might be the best alternative. The steps for one matrix of values are shown below:

1) The scale used in this project for the AHP quantitative/qualitative rankings is presented in Appendix B.
2) After interviewing the marketing manager, the planning manager and Company X's CEO to find the decision criteria that drives the company, the final criteria were developed. The decision criteria comprised of five main factors which are the strategic concerns, marketing concerns, cost of sales, management uncertainty (risk profile) , and generated revenue for each type of chiller.

3) Pair-wise comparison matrixes were developed for the main criteria based on management indications and judgments. The first pair-wise matrix is developed for the main criteria is as follows:

Table 14. Pair-wise comparisons for main criteria

	Cost of Sales	Strategic Concern	Marketing Concern	Management uncertainty (Risk)	Revenue
Cost of Sales	1	3	4	1/3	1/3
Strategic Concern	1/3	1	2	1/5	1/5
Marketing Concern	1/4	1/2	1	1/7	1/7
Management uncertainty (Risk)	3	5	7	1	2
Revenue	3	5	7	½	1

Inconsistency ratio 0.02<0.1

4) After that, the pair-wise comparisons were normalized and the average sum for each row is calculated to find the relative weight of each main criterion where the sum of the total weights must equal to 1. The table below shows the values after the total weight was computed for the cost of sales, strategic concern, marketing concern, management uncertainty (risk), and revenue criterion:

Table 15. Main criterion weights after normalization

	Cost of Sales	Strategic Concern	Marketing Concern	Management uncertainty (Risk)	Revenue	Average
Cost of Sales	0.1319	0.2069	0.1905	0.1532	0.0907	0.1546
Strategic Concern	0.0440	0.0690	0.0952	0.0919	0.0544	0.0709
Marketing Concern	0.0330	0.0345	0.0476	0.0657	0.0389	0.0439
Management (Risk)	0.3956	0.3448	0.3333	0.4596	0.5441	0.4155
Revenue	0.3956	0.3448	0.3333	0.2298	0.2720	0.3151

5) The pair-wise matrix was then developed for each of the sub-criterion , and the same approach was used to find the relative weights for each sub-criterion matrix shown in Appendix C.

6) Then, pair-wise comparisons were developed for each of the sub-criterion with respect to the alternatives which are the large chiller and the small chiller.

7) After that, normalized values and average rows representing relative weights were obtained for each sub-criterion with respect to the small chiller and the large chiller shown in Appendix C.

8) The overall weight of each of the main criterion with respect to the small chiller and the large chiller is found by combining the weights of each sub-criterion with its main criterion. For example, the marketing concern main criteria is comprised of demand , time and price sub-criterion.

9) The final values are obtained by combining the each of the main criterion weighted average, along with the weight of each criterion with respect to the small chiller and the large chiller, and a sample calculation is shown below:

= (Cost of sales main criterion weight * Cost of sales criterion with respect to each alternative) + (Strategic Concern main criterion weight * Strategic Concern criterion with respect to each alternative) + (Marketing Concern main criterion weight * Marketing Concern criterion with respect to each alternative) + (Management uncertainty main criterion weight * Management uncertainty criterion with respect to each alternative) + (Revenue main criterion weight * Revenue criterion with respect to each alternative)

For the Small chiller:

(0.1546 * 0.8388) + (0.0709 * 0.1459) + (0.0439 * 0.6259) + (0.4155* 0.875) + (0.3151* 0.8888) = 0.81

For the Large chiller:

(0.1546 * 0.1611) + (0.0709 * 0.854) + (0.0439 * 0.374) + (0.4155* 0.125) + (0.3151*0.1111) = 0.19

4.2.3 AHP Sensitivity Analysis for small/large chiller

In this section, different scenarios of factors adjustments for the small and large chiller are illustrated, since the priorities of the alternatives are influenced by the weights assigned by pair-wise comparisons conducted at the initial part of the analysis. A ‘what-if’ analysis is of vital importance at this stage to know how the priorities of the alternatives are behaving, and it is developed with help of ‘Super Decisions Software’ which helps in calculating the inconsistency ratio and ensuring that it is below 10% for each matrix.

The chart below illustrates the sensitivity of the five main criteria with the original weights (base values) , base values with 10% adjustments , and base values with 20% adjustments :

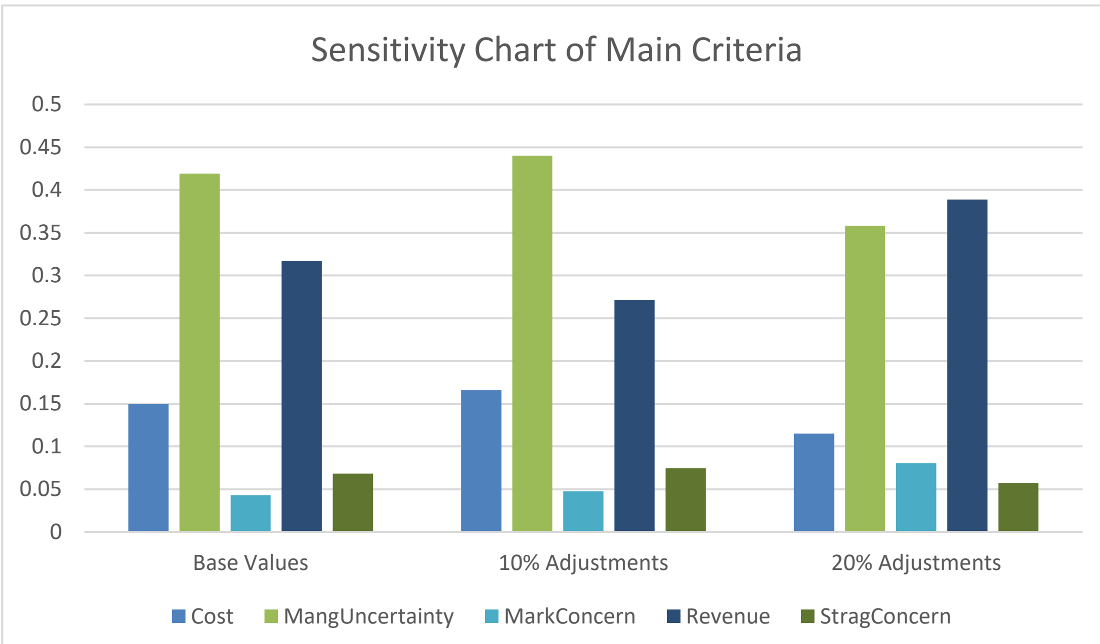

Figure 7: Sensitivity chart of main criteria

As shown in figure 6 above , in the first case where the base values were developed , the main driver among all criterion is the management uncertainty (Risk) of each chiller type, and its value is around (0.41) of the total, while maximum generated revenue comes as the second main driver which will influence the final decision , and its corresponding value is (0.317).

The thirdly ranked factor is the cost of sales , with a weight of (0.15) and then comes the strategic concern with a value of (0.068) and finally the marketing concern with a value of (0.043).

However, with the 10% adjustments the total weight of the criterion has changed keeping the order of factor priorities the same. The weights of the factors after the adjustments in their descending orders is as follows:

-Management uncertainty (Risk) with a value of (0.44)

-Revenue (0.27)

-Cost of sales (0.165)

-Strategic concern (0.074)

-Marketing concern (0.047).

For the 20% adjustments, it is clearly shown that the order of factors importance has changed. The factor with highest weight is now the revenue with a corresponding value of (0.388), then comes the management uncertainty (Risk) with a value of (0.35).

The last three factors with descending order is as follows, cost of sales (0.11), marketing concern (0.08) and finally the strategic concern (0.05).This shows how changing the weights of the factors can influence the final decision and the sensitivity analysis is repeated for all the nodes shown in Appendix D.

4.2.4 Final values of the AHP model for Small/Large chillers

The final values for the small and the large chiller are illustrated in following table, the small chiller tends to be most favourable in all the three scenarios

Table 16. Final values for small/large chiller for three scenarios.

	Small Chiller	Large Chiller
Base case	0.81	0.19
10% Adjustments	0.778	0.222
20% Adjustments	0.766	0.234

CHAPTER 5 DISCUSSION OF THE RESULTS

This chapter presents a discussion of the gained results from applying the management science tools in Company X. The first part of the chapter discusses the results of first used tool which is the Monte-Carlo simulation, and the second part of the chapter discusses the results of the Analytic Hierarchy Process.

5.1 Results of the Monte-Carlo Simulation

Based on the academic literature, it was noted that a successful company has the ability to perform a well conducted risk management analysis, which will have a big impact on to the overall business success or failure in terms of introducing new products to the market. The Monte-Carlo simulation was used which is a mathematical method that allows a firm to account for risk in different types of analysis and decision making was suggested in this project as an aid for the CEO of Company X to evaluate the management uncertainty and account the risk of introducing each type of the new chiller to Qatar's market.

Furthermore, after the analysis of data from the Monte-Carlo simulation , the probability of loss of the small chiller was 11% and 18% for the large chiller. The Monte-Carlo simulation gives an indication of what might be the most successful type of chiller with minimum risk , which was the small chiller having a lower probability of loss based on the quantitative values analyzed earlier and at the same time , a higher generated revenue.

In addition , the Monte-Carlo simulation has helped in making use of the history data based on several probability distributions , giving randomly generated values for 10000 iterations , however the final decision of the Company's CEO should be made through striking a balance between the risk of each chiller type and the generated profit.

However, the final decision to be made was still not clear for the CEO of Company X . The reason for this is because both types of chillers tend to be successful in the market even though the risk of the small chiller tend to be lower. In addition, it was noted by the CEO of Company X that the results arise from quantitative values only, without addressing any of the qualitative concerns.

5.2 Results of the (AHP)

The Analytic Hierarchy Process was applied in order to show the CEO of Company X how different conflicting objectives can be addressed in one problem at the same time. It was noticed that after presenting the Monte-Carlo simulation results, the qualitative and intangible objectives were not incorporated in the problem scenario.

5.2.1 Criteria assigned weights

The main criteria earlier mentioned in chapter four include the strategic concerns, the marketing concerns, the generated revenue, the cost of sales and the management uncertainty (Risk) of each type of chiller. According to past studies, different factors can be incorporated in the (AHP) model such as technical fit , distribution channels , energy saving percentage. However, the final criteria selected for the (AHP) model were the most relevant to the case study, and adding the number of criterion will increase the sensitivity of the model without adding a distinction value to the final decision

. For instance, not adding the technical issues in the final criterion which will enhance the final decision is because the small and large chillers tend to have very close values of energy saving percentage, and an equal weight will not add any value to the final decision. Also, the CEO of company X did not want to include the logistics part of the two chiller types, as the main focus was what drivers will make the product more successful in the market based on Company X's internal issues and not any external issues.

Furthermore, regarding the assigned weights of each criterion , several meeting were conducted with the marketing manager , the planning manager and the Company's CEO to revise and validate the assigned weights. The base values of the first matrix showed that the management uncertainty or product risk is of vital importance, since most of the quantitative figures gained from the Monte-Carlo simulation are aligned in this factor. The least important factor as mentioned by the CEO of Company X is the marketing concern since its sub-criterion are not steady and can increase/decrease rapidly.

Moreover, the strategic concern included three main sub-criteria, and the reason behind favouring each type of chiller according to each sub-criterion is as follows:

- Innovation level: in the level of product innovation sub-criterion, the level of technology inhered in the large chiller is *moderately more favourable* than the small chiller.

- Product advantage: the advantage of the large chiller is *strongly more important* than the small chiller, due to the fact that large chillers operate for high rise buildings and open areas including stadiums and farms, covering larger areas.
- Competitor threats: regarding the threats of foreign competitors, the large chiller can compete in the market more than the small chiller due to banning similar technology chillers from areas in the gulf region. Therefore, in this case the large chiller is *very strongly more favourable* than the small chiller.

The marketing concern included the demand, price and time as the three main sub-criteria, and the following justifications explain how each of the sub-criterion was weighted with respect to the small chiller and the large chiller:

- Demand: according to the mangers forecasts, the demand level for the small chillers which are operated in residential buildings tend to be more stable, and the demand for large chillers is expected to highly drop after finishing constructing FIFA world cup 2022 projects including stadiums. Furthermore , the demand units for the small chillers is higher than the demand for large chillers making the small chiller strongly to *very strongly more favourable* than the large chiller.
- Price: the price offered for the large chiller makes it in a position to better compete with other brands, since it is offered at a lower price than most competitors, however for the small chiller it is offered at a slightly higher price than other competitors making the large chiller *moderately to strongly* more favourable than the small chiller.

- Time: the time of introducing the type of chiller to the market is *strongly more favourable* for the large chiller than the small chiller, due to the large number of projects requiring open space cooling systems making the time to hit the market more crucial for the large chiller.

Regarding the cost of sales, the main types of cost concerns for Company X's CEO included four types, the following shows how the priorities of each types of chiller was developed :

- Direct labour cost: according to the mangers estimations and assumptions, the direct labour cost for the large chiller is higher than the small chiller. In this case, the lower incurred costs are more favourable making the small chiller very *strongly more important* than the large chiller.
- Material cost: regarding the material cost, lower amount of materials and less incurred costs for the small chiller are expected as per managers of Company X estimates, making the small chiller *strongly to very strongly more important* than the large chiller.
- Packaging cost: the cost of packaging the small chiller and the large chiller are almost the same, with the large chiller have a slightly higher cost. Therefore, in this case the small chiller is *moderately more important* than the large chiller.
- Utility expenses: regarding the utility expenses, according to the estimates of Company X's managers both small chiller and large chiller require almost the same expenses, with a slightly higher expense for the large chiller for the extra space. In

this case, the small chiller is *equally to moderately more important* than the large chiller.

Furthermore, the management uncertainty (Risk) of each type of chiller was calculated in the earlier section as a result of the Monte-Carlo simulation. The obtained results show that the small chiller contains less risk than the large chiller. As the CEO of company X claimed that the limit of product success is 30%, and any probability below 30% will be too risky for the company's case. Therefore, in term of risk account the small chiller tends to be *very strongly more important* than the large chiller.

The final criterion is the revenue for each type of chiller, and based on demand forecasts, incurred costs and price of chiller, the maximum generated revenue for the small chiller is much higher than the large chiller. In this case, the small chiller tends to be *very strongly to extremely* more important than the large chiller.

5.2.2 Results of the sensitivity analysis

The 'what if 'analysis was conducted in order to show the CEO of company X how the pair-wise comparisons assigned in the base case directly affect the priority of the alternatives. Three scenarios were presented based on original weight values, 10% weight adjustments and 20% weight adjustments, and each scenario gave a different total overall priority value for the small chiller and the large chiller.

In the first case with base values, the total priority was 0.81 for the small chiller and 0.19 for the large chiller, making the small chiller more favourable in this case. Moreover, after adjusting the weights with +10% / -10% for all the criterion and sub-criterion with respect to the alternatives, the small chiller had an overall priority of 0.778 and the large chiller had a total priority of 0.222, keeping the small chiller more favorable. In the last scenario, with +20% / -20% adjustments the small chiller was still more favorable with a total score of 0.766 and the large chiller having a score of 0.234.

The CEO of Company X was more confident with the scenario of with +10% / -10% adjustments for all the criterion and sub-criterion with respect to the alternatives, even though all three scenarios results gave the small chiller as more successful.

CHAPTER 6 CONCLUSION AND RECOMMENDATION

The first part of the chapter presents the conclusions of the project, and the second part suggests some recommendations for future studies being applied in the area of new products screening.

6.1 Conclusions

The main objective of the project was to show the CEO and managers of company X how management science tools lead to effective decision making. In Company X's case, the decisions were done unsystematically due to the complexity of objectives leading to a loss of opportunity costs and a waste of time and resources. Therefore, it is important for managers nowadays to follow a systematic approach in taking final decision, with the aid of different management science tools to be confidant about the final decision to be made.

This project illustrated two of the widely used management science tools which are combining the Monte-Carlo simulation results with the (AHP) as suggested per academic literature. Although the tools are widely used in different areas nowadays, the researcher's papers obtained from the academic literature claimed that they are still not widely being used in the area of new product screening, which is the project's main contribution.

In addition, after applying the Monte-Carlo simulation and the (AHP) for Company X's new product ideas and analysing the final results of each technique , the small chiller tended to be more successful in both techniques , which was against the CEO's first perception who was more excited about introducing the large chiller into the market. After presenting the results of each technique, the CEO of Company X realised that only some objectives were taken into consideration which was the strategic and competition concerns, however with the thorough analysis of all available data and addressing all the company's concerns, the small chiller tended to be more successful in the market.

Furthermore, it is very crucial to note that the management science tools do not determine the final decision that should be made, in fact the results should be interpreted in order to know which alternative is more consistent with the allocated weights for each criterion and the human belief remains the first driver for taking the final decision.

On the other hand , it is hoped that after presenting this project the firm managers will value such decision aiding techniques and be encouraged to use them in new product screening areas , since the best choice may not always be as obvious as it looks.

6.2 Recommendations

This section suggests a number of recommendations for future studies, and the main recommendations are as follows:

- Update the (AHP) pair-wise comparisons and criteria as time elapses, since new data may be available and new concerns might need to be addressed.
- Combine the (AHP) tool with different management science tools to enhance the criterion and allocated weights and make the final results to be more realistic and reliable.

- Further investigate in needed data such as future demand by applying different forecasting tools and use benchmarking techniques in order to integrate them in (AHP) model.
- Online surveys, experts or third-party judgments can be used to reduce the biased data gained from asking the same people in Company X about each factor, since employees working in the same area will tend to have same objectives and close insights about each factor in the presented tools.
- The number of main criterion and sub-criterion can be increased depending on the situation and the firm's concerns, however it is suggested in this case to use a software for handling complex scenarios such as ‘ Expert Choice ‘ and ‘ Super decisions ‘.

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Appendix – A: Monte-Carlo Simulation for 80 Sample iterations

Small chiller	Direct labour cost/unit	Material cost/unit	Demand	Profit
Simulation	1500	13530	5347	346872169
1	1500	11371	30173	2025013673
2	1800	9444	13678	939963185
3	1800	10863	4660	313273765
4	2000	15211	11644	730601607
5	1800	12523	9715	637566412
6	2150	14404	1472	92891170
7	2000	14745	1114	69981958
8	2000	13231	2965	191541654
9	2000	10759	22998	1545917498
10	2000	12606	29578	1933743262
11	2000	10545	13634	919160827
12	1500	8059	11246	791669828
13	2000	8070	18124	1266910901
14	2300	15970	8229	507498568
15	1500	14231	18178	1167759201
16	1650	9076	1092	75139353
17	1650	14893	7790	493859389
18	1800	9717	15493	1060493671
19	2000	8445	19765	1374255564
20	1650	12814	6380	417599611
21	1500	11092	12989	875040314
22	2500	8671	6258	430198158
23	1800	11312	10898	728456190
24	2150	10470	0	-500000
25	1650	12309	17954	1185177856
26	1650	10469	19862	1347740919
27	1800	8646	12616	876995081
28	1500	12485	12042	794478781
29	2000	15291	12040	754510871
30	1800	14452	0	-500000
31	2500	11049	27074	1798577971
32	1500	13415	18679	1215226746
33	1650	14582	20606	1313528131
34	2000	14608	3899	246682804
35	1800	11163	0	-500000
36	2000	10268	789	52923191
37	1800	12174	9770	644587050

38	2150	8144	872	60295051
39	2000	8189	10098	704479417
40	2000	13106	0	-500000
41	1500	12736	15432	1014396746
42	2150	10266	20487	1384068349
43	1800	12670	22516	1475000259
44	2150	11803	23555	1555257927
45	1800	9902	17631	1203687803
46	2000	13243	15486	1002332566
47	2000	8196	15782	1101128350
48	1800	13507	15281	988043723
49	2150	14268	16812	1068412611
50	1650	12986	6286	410367979
51	2300	14068	4065	258195525
52	1800	12465	8460	555610863
53	2150	12486	13946	911049175
54	1650	11695	25441	1695285379
55	1650	12532	8922	586760549
56	1500	12372	13537	894690355
57	2000	15250	7555	473558915
58	2150	13762	9565	612492534
59	2150	9510	4033	275092609
60	2000	8623	8853	613671152
61	2150	12967	28334	1837925084
62	2000	12988	13466	874943591
63	2150	15246	0	-500000
64	1800	8297	7509	524431512
65	1650	11533	8621	575561046
66	1800	14375	22146	1412962791
67	1800	8432	14791	1031448614
68	2000	11086	15914	1064402779
69	2000	14981	31180	1964421728
70	2150	8024	5638	393178731
71	2150	9631	17015	1160264006
72	1500	10146	17281	1180735520
73	1800	11909	20493	1358008822
74	2300	15141	14817	926445146
75	2000	10496	23162	1563048600
76	1650	13560	0	-500000
77	2000	11598	6669	442341277
78	1650	11255	7796	522566322

79	1800	10915	13699	921235510
80	1650	15145	1727	108684289

Large Chiller	Direct labour cost/unit	Material cost/unit	Demand	Profit
Simulation	13600	10884	1921	720852956
1	12000	11401	1124	422495677
2	12200	11256	406	152191715
3	13300	10688	0	-700000
4	13000	10146	1028	386785196
5	13000	11854	1489	557740662
6	12200	11620	1464	550093045
7	12500	10225	1469	553395924
8	13000	11866	493	184241769
9	14000	11211	91	33544884
10	12500	11883	838	314214093
11	13600	10580	941	352935019
12	13000	11717	2404	901374996
13	12500	10343	0	-700000
14	13300	10119	0	-700000
15	12200	10134	394	148045383
16	14000	10557	3091	1159937840
17	13300	10872	798	299189120
18	12500	11788	950	356381220
19	12500	11369	606	227249927
20	12000	11355	117	43221175
21	12500	11414	730	273818773
22	13000	11824	0	-700000
23	13300	10663	1299	487815435
24	12000	11290	649	243758028
25	13300	10065	1961	737976982
26	13000	10177	1388	522166182
27	13300	11992	0	-700000
28	12200	10450	1877	707679447
29	12500	10866	950	357000991
30	12000	10662	1208	454973937
31	12500	11259	114	42234086

32	13000	10089	938	352874505
33	12500	10117	1253	472349554
34	12500	10173	0	-700000
35	13000	11337	817	306061248
36	13000	11576	857	320889445
37	12200	10020	185	69153212
38	13600	11920	170	62824054
39	13000	10495	13	4261600
40	12500	10295	639	240460044
41	13000	10640	437	163626220
42	13300	11511	1977	741056354
43	13000	10570	2437	916669683
44	14000	11126	1489	557393095
45	13600	10920	852	319385405
46	13000	11812	707	264663783
47	12500	11229	342	128023573
48	12500	11390	1930	725235866
49	12500	11816	1237	463866542
50	12500	10762	1051	395308075
51	13000	10762	1381	518957486
52	12500	11235	2247	844658444
53	12500	10929	2558	962454060
54	13000	10393	0	-700000
55	13000	11284	1715	643763881
56	12500	11845	146	54266732
57	12000	11422	2559	963015452
58	12000	11302	329	123064385
59	13000	10738	696	261235492
60	12200	11095	285	106628886
61	12000	10644	0	-700000
62	13000	10394	2219	835017884
63	12200	10335	941	354666025
64	12500	10688	0	-700000
65	13300	10408	630	236287490
66	12200	11685	1322	496696441
67	12500	11352	831	311944252
68	12000	11830	1573	591140820
69	12200	10616	626	235455277
70	13300	11502	352	131461860
71	13000	11524	2288	858385806
72	12200	10710	900	338639921

73	13000	10960	1579	593221856
74	13300	10716	1453	545528382
75	12000	10460	576	216809860
76	13000	10620	640	240077962
77	12000	10484	737	277563574
78	12500	11067	0	-700000
79	12500	11627	1605	602714220
80	13300	11620	1134	424518103

Appendix – B: AHP Scale

The following (AHP) scale was used for conducting the pair-wise comparisons for the criterion and the sub criterion for both small and large chillers:

Table 17. AHP used scale

Preference Level	Numerical Value
Equally preferred	1
Equally to moderately preferred	2
Moderately preferred	3
Moderately to strongly preferred	4
Strongly preferred	5
Strongly to very strongly preferred	6
Very strongly preferred	7
Very strongly to extremely preferred	8
Extremely preferred	9

Appendix – C: Criteria / Sub-criteria pairwise comparisons

Table 18. Pair-wise comparisons for cost-of-sales sub-criterion

	Material cost	Packaging cost	Direct labour cost	Utility expenses
Material cost	1	5	2	8
Packaging cost	1/5	1	1/3	3
Direct labour cost	1/2	3	1	5
Utility expenses	1/8	1/3	1/5	1

Inconsistency ratio 0.019<0.1

Table 19. Cost-of-sales sub-criterion weights after normalization

	Material cost	Packaging cost	Direct labour cost	Utility expenses	Average
Material cost	0.5479	0.5357	0.5660	0.4706	0.5301
Packaging cost	0.1096	0.1071	0.0943	0.1765	0.1219
Direct labour cost	0.2740	0.3214	0.2830	0.2941	0.2931
Utility expenses	0.0685	0.0357	0.0566	0.0588	0.0549

Table 20. Pair-wise comparisons for chillers with respect to material cost

Material Cost		
	Small chiller	**Large chiller**
Small chiller	1	6
Large chiller	1/6	1
Sum	1.166667	7

Table 21. Chiller weights with respect to material cost after normalization

Material Cost			
	Small chiller	**Large chiller**	**Average**
Small chiller	0.8571	0.8571	0.8571
Large chiller	0.1429	0.1429	0.1429

Table 22. Pair-wise comparisons for chillers with respect to packaging cost

Packaging Cost		
	Small chiller	**Large chiller**
Small chiller	1	3
Large chiller	1/3	1
Sum	1.3333	4

Table 23.Chiller weights with respect to packaging cost after normalization

Packaging Cost			
	Small chiller	**Large chiller**	**Average**
Small chiller	0.75	0.75	0.75
Large chiller	0.25	0.25	0.25

Table 24. Pair-wise comparisons for chillers with respect to direct labour cost

Direct Labour Cost		
	Small chiller	**Large chiller**
Small chiller	1	7
Large chiller	1/7	1
Sum	1.1428	8

Table 25. Chiller weights with respect to direct labour cost after normalization

Direct Labour Cost			
	Small chiller	**Large chiller**	**Average**
Small chiller	0.875	0.875	0.875
Large chiller	0.125	0.125	0.125

Table 26. Pair-wise comparisons for chillers with respect to utility expenses

Utility Expenses		
	Small chiller	**Large chiller**
Small chiller	1	2
Large chiller	1/2	1
Sum	1.5	3

Table 27. Chiller weights with respect to utility expenses after normalization

Utility Expenses			
	Small chiller	**Large chiller**	**Average**
Small chiller	0.6667	0.6667	0.6667
Large chiller	0.3333	0.3333	0.3333

Table 28. Pair-wise comparisons for strategic concern sub-criterion

	Product advantage	Competitor threats	Innovation level
Product advantage	1	¼	3
Competitor threats	4	1	6
Innovation level	1/3	1/6	1

Inconsistency ratio 0.051<0.1

Table 29. Strategic concern sub-criterion weights after normalization

	Product advantage	Competitor threats	Innovation level	Average

Product advantage	0.1875	0.1766	0.3000	0.2214
Competitor threats	0.7500	0.7059	0.6000	0.6853
Innovation level	0.0625	0.1176	0.1000	0.0934

Table 30. Pair-wise comparisons for chillers with respect to product advantage

Product Advantage		
	Small chiller	**Large chiller**
Small chiller	1	1/5
Large chiller	5	1
Sum	6	1.2

Table 31. Chiller weights with respect to product advantage after normalization

Product Advantage			
	Small chiller	**Large chiller**	**Average**
Small chiller	0.1667	0.1667	0.1667
Large chiller	0.8333	0.8333	0.8333

Table 32. Pair-wise comparisons for chillers with respect to competitor threats

Competitor threats		
	Small chiller	**Large chiller**
Small chiller	1	1/7
Large chiller	7	1
Sum	8	1.1428

Table 33. Chiller weights with respect to competitor threats after normalization

Competitor threats			
	Small chiller	**Large chiller**	**Average**
Small chiller	0.125	0.125	0.125

Large chiller	0.875	0.875	0.875

Table 34. Pair-wise comparisons for chillers with respect to innovation level

Innovation level		
	Small chiller	**Large chiller**
Small chiller	1	1/3
Large chiller	3	1
Sum	4	1.3333

Table 35. Chiller weights with respect to innovation level after normalization

Innovation level			
	Small chiller	**Large chiller**	**Average**
Small chiller	0.25	0.25	0.25
Large chiller	0.75	0.75	0.75

Table 36. Pair-wise comparisons for marketing concern sub-criterion

	Time	Demand	Price
Time	1	1/6	1/3
Demand	6	1	3
Price	3	1/3	1

Inconsistency ratio 0.017<0.1

Table 37. Marketing concern sub-criterion weights after normalization

	Time	Demand	Price	Average
Time	0.1000	0.1111	0.0769	0.0960
Demand	0.6000	0.6667	0.6923	0.6530
Price	0.3000	0.2222	0.2308	0.2510

Table 38. Pair-wise comparisons for chillers with respect to demand

Demand		
	Small chiller	**Large chiller**
Small chiller	1	6
Large chiller	1/6	1
Sum	1.6667	7

Table 39. Chiller weights with respect to demand after normalization

Demand			
	Small chiller	**Large chiller**	**Average**
Small chiller	0.8571	0.8571	0.8571
Large chiller	0.1429	0.1429	0.1429

Table 40. Pair-wise comparisons for chillers with respect to time

Time		
	Small chiller	**Large chiller**
Small chiller	1	1/5
Large chiller	5	1
Sum	6	1.2

Table 41. Chiller weights with respect to time after normalization

Time			
	Small chiller	**Large chiller**	**Average**
Small chiller	0.1667	0.1667	0.1667
Large chiller	0.8333	0.8333	0.8333

Table 42. Pair-wise comparisons for chillers with respect to price

Price		
	Small chiller	**Large chiller**
Small chiller	1	1/4
Large chiller	4	1
Sum	5	1.25

Table 43. Chiller weights with respect to price after normalization

Price			
	Small chiller	**Large chiller**	**Average**
Small chiller	0.2	0.2	0.2
Large chiller	0.8	0.8	0.8

Table 44. Pair-wise comparisons for chillers with respect to revenue

Revenue		
	Small chiller	**Large chiller**
Small chiller	1	8
Large chiller	1/8	1
Sum	1.125	9

Table 45. Chiller weights with respect to revenue after normalization

Revenue			
	Small chiller	**Large chiller**	**Average**
Small chiller	0.8889	0.8889	0.8889
Large chiller	0.1111	0.1111	0.1111

Table 46. Pair-wise comparisons for chillers with respect to management uncertainty (risk)

Management Uncertainty (Risk)		
	Small chiller	**Large chiller**
Small chiller	1	7

Large chiller	1/7	1
Sum	1.1428	8

Table 47. Chiller weights with respect to management uncertainty (risk) after normalization

Management Uncertainty (Risk)			
	Small chiller	**Large chiller**	**Average**
Small chiller	0.875	0.875	0.875
Large chiller	0.125	0.125	0.125

Appendix – D: Sensitivity charts of (AHP) criteria

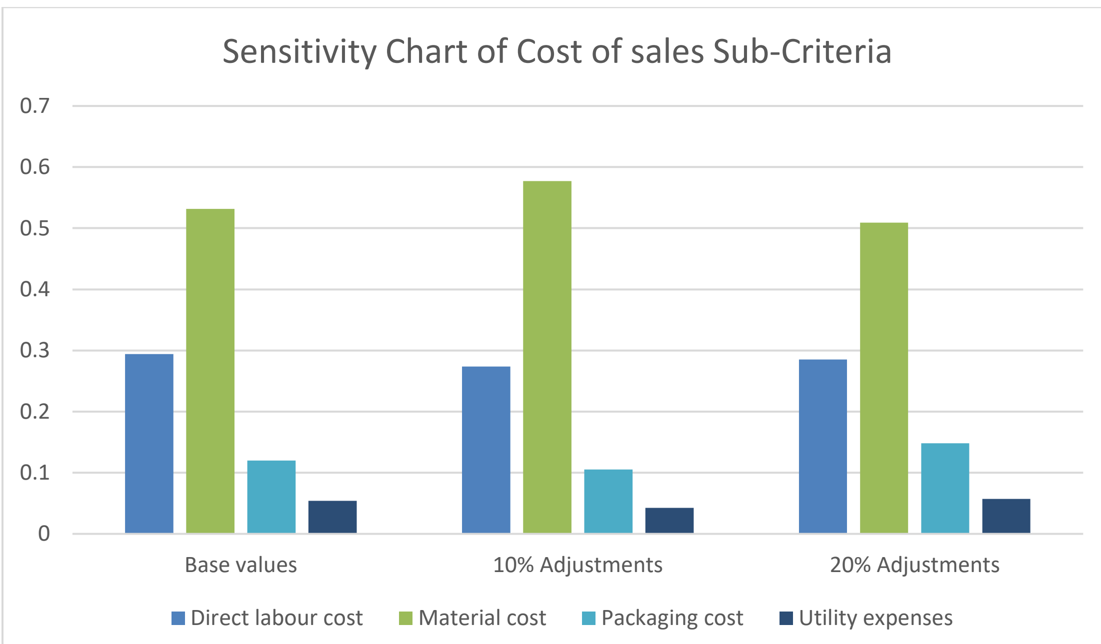

Figure 8. Sensitivity chart of cost-of-sales sub-criteria

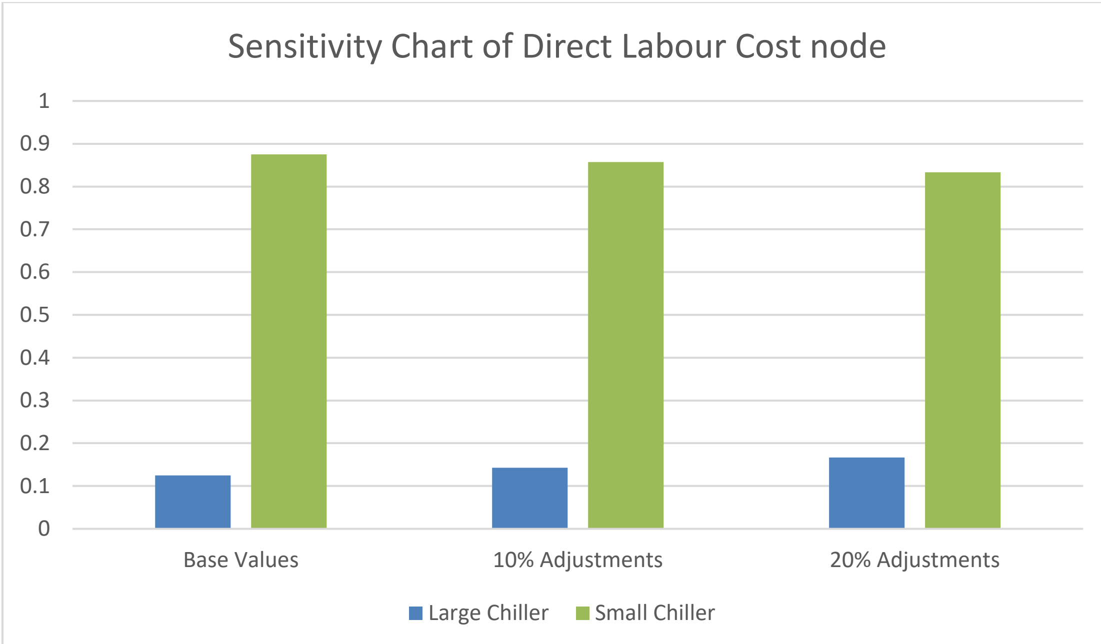

Figure 9. Sensitivity chart of direct labour cost node

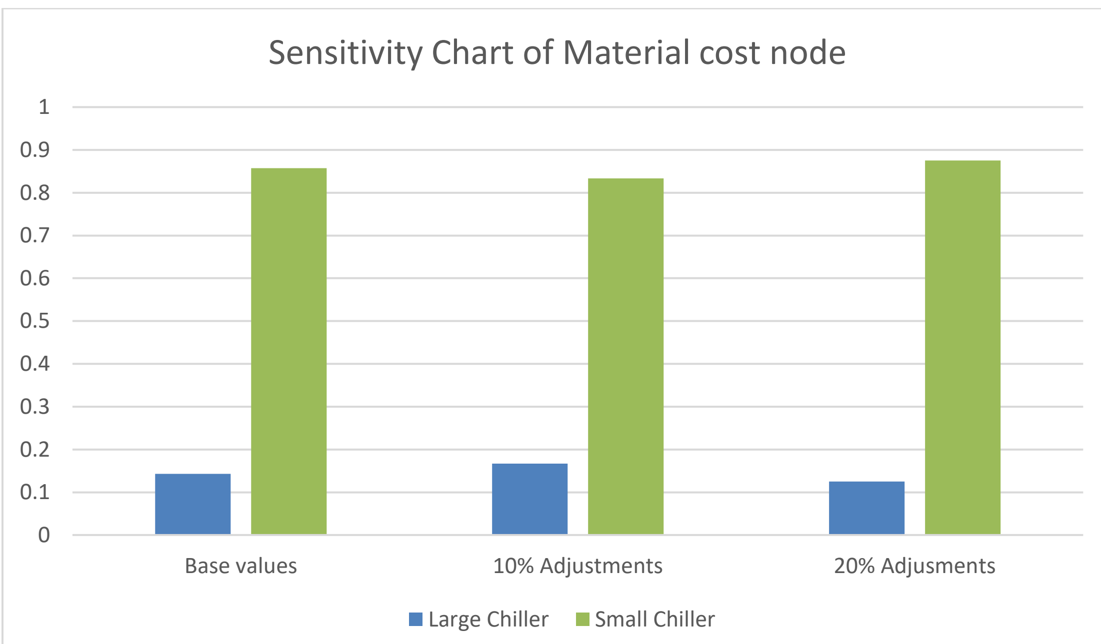

Figure 10. Sensitivity chart of material cost node

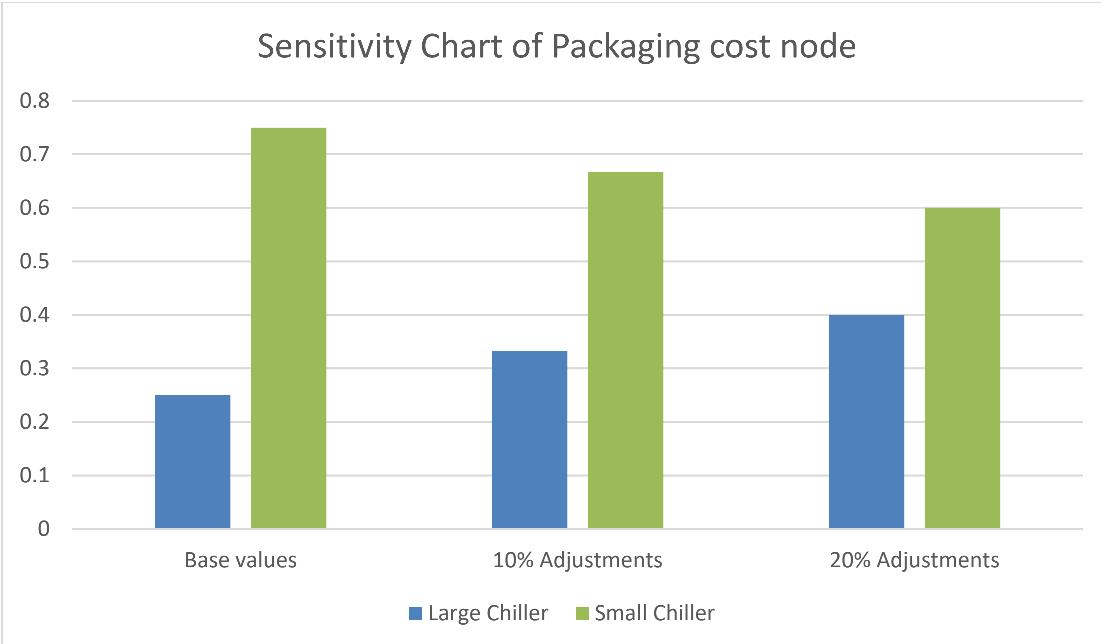

Figure 11. Sensitivity chart of packaging cost node

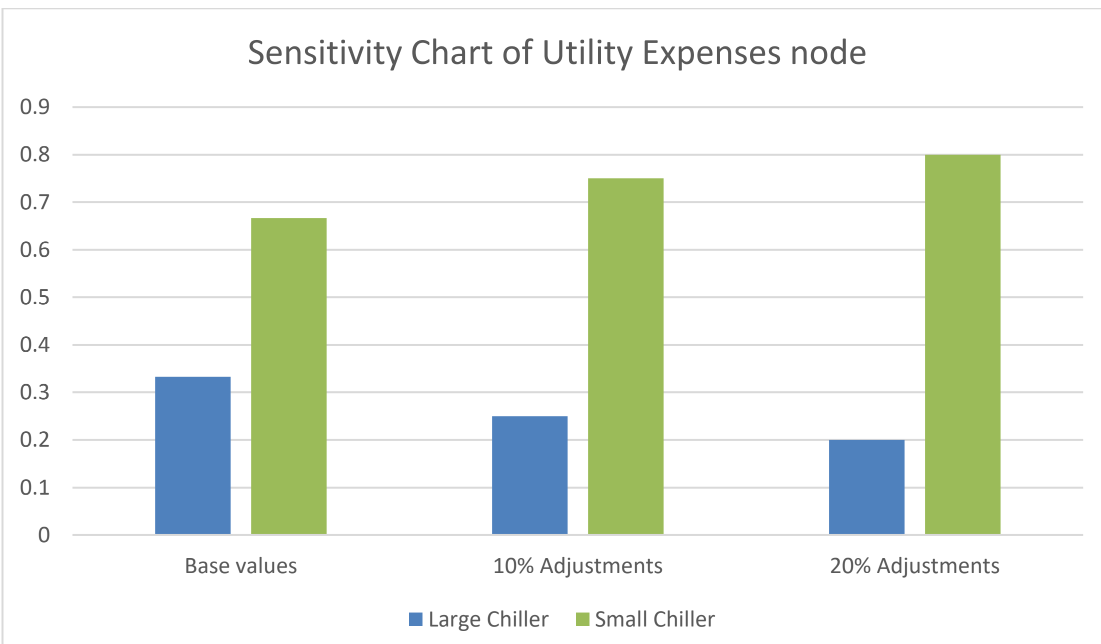

Figure 4. Sensitivity chart of utility expenses node

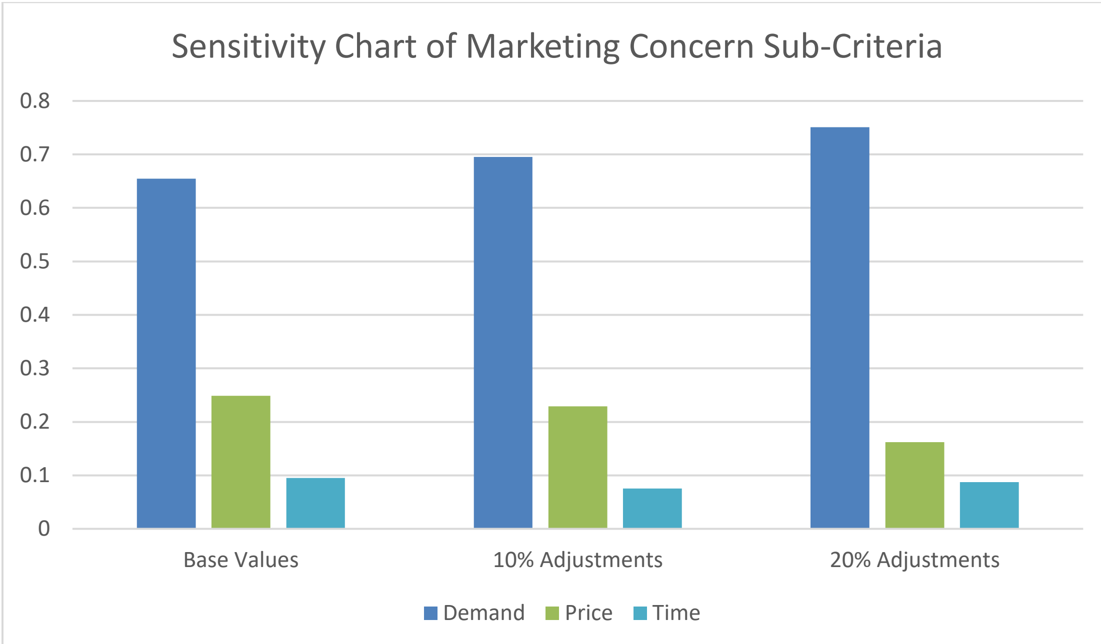

Figure 5. Sensitivity chart of marketing concern sub-criteria

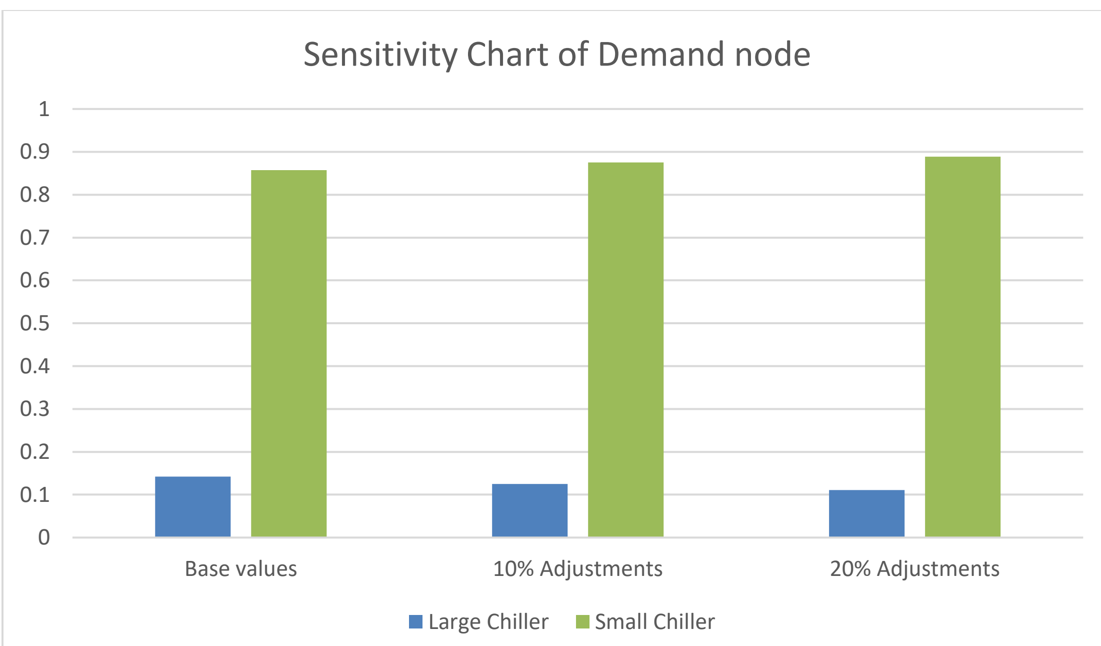

Figure 6. Sensitivity chart of demand node

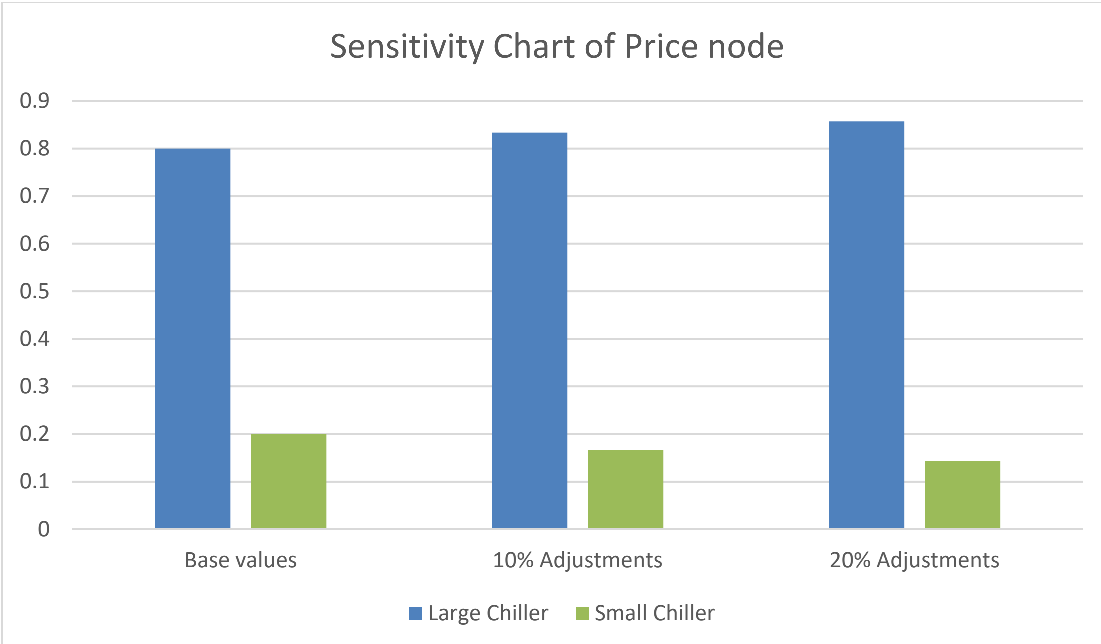

Figure 7. Sensitivity chart of price node

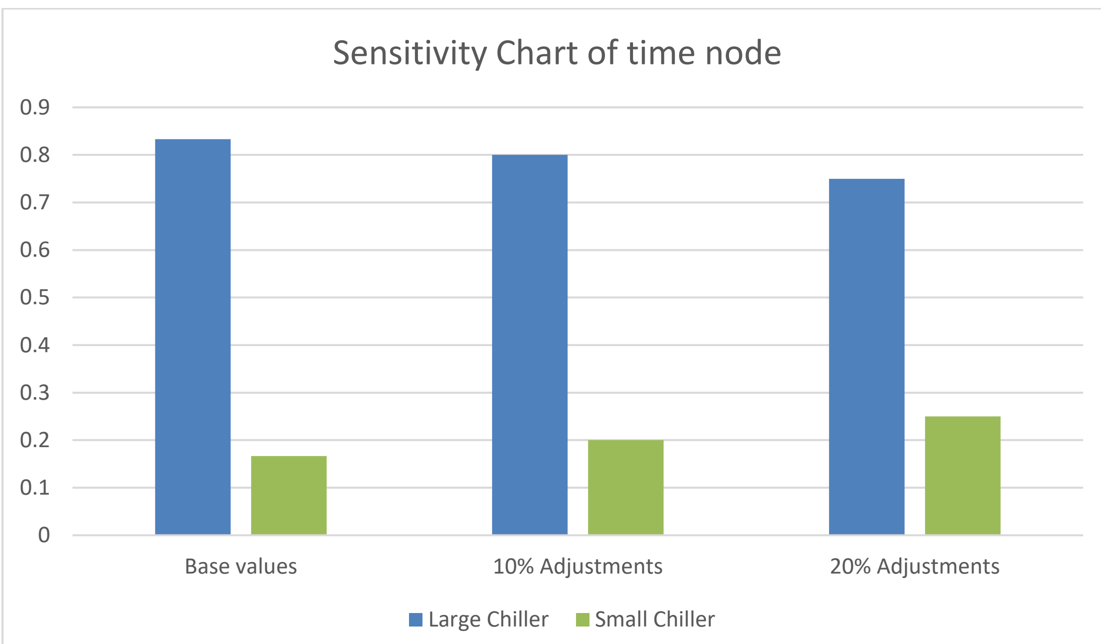

Figure 8. Sensitivity chart of time node

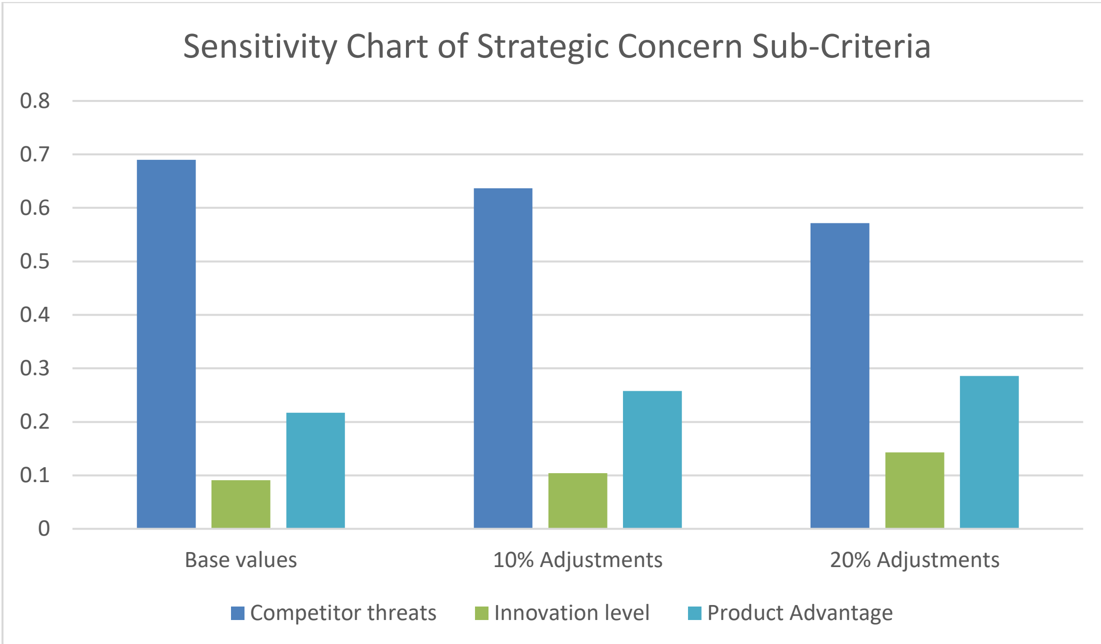

Figure 9. Sensitivity chart of strategic concern sub-criteria

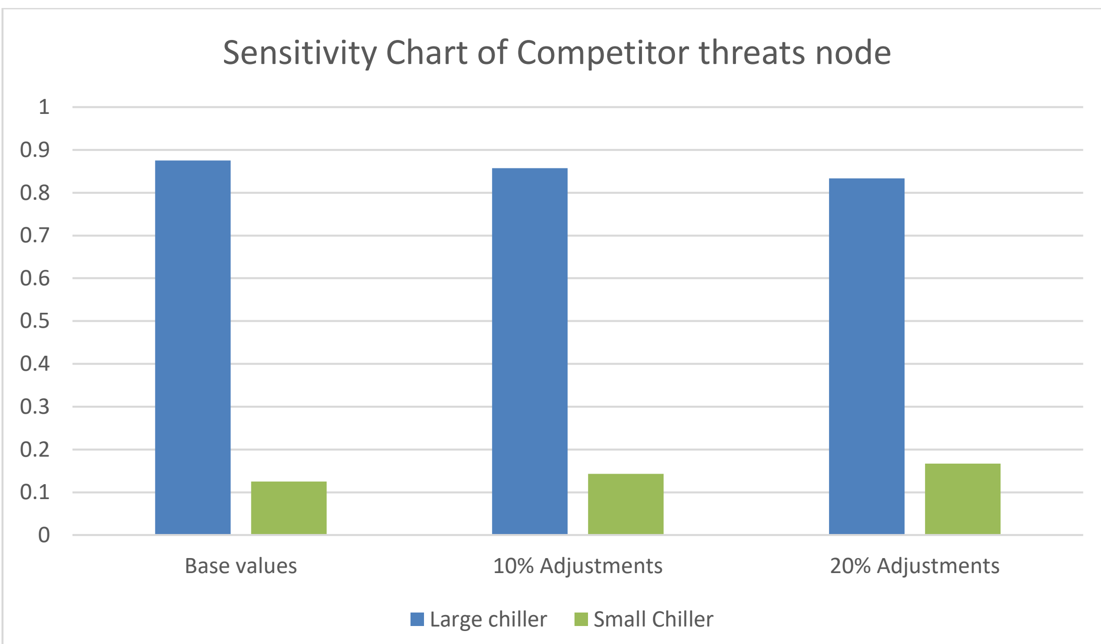

Figure 10. Sensitivity chart of competitor threats node

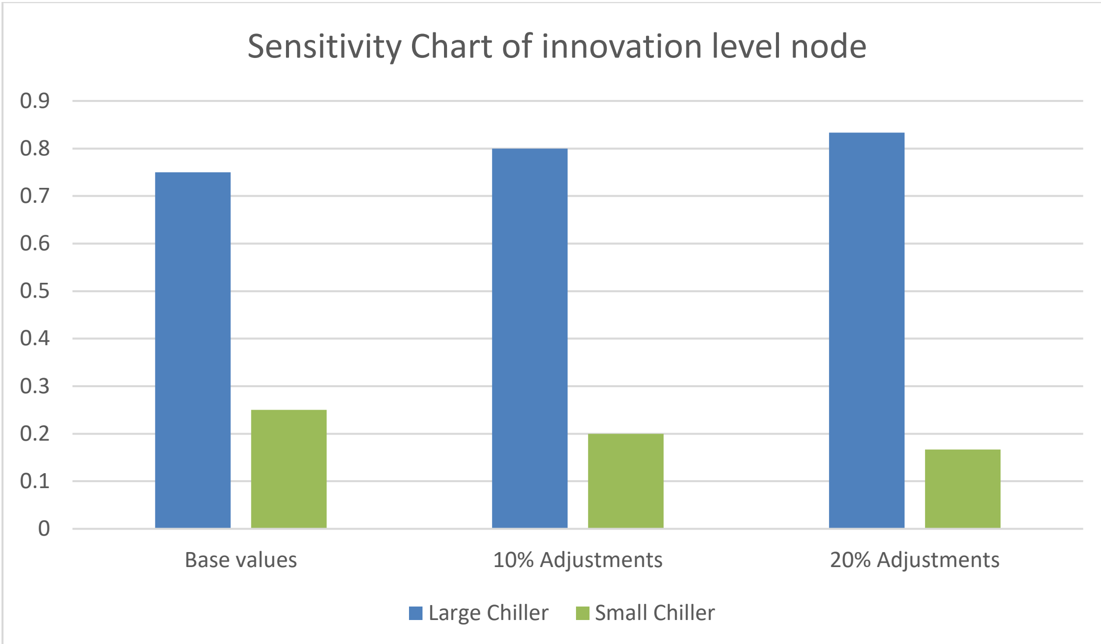

Figure 11. Sensitivity chart of innovation level node

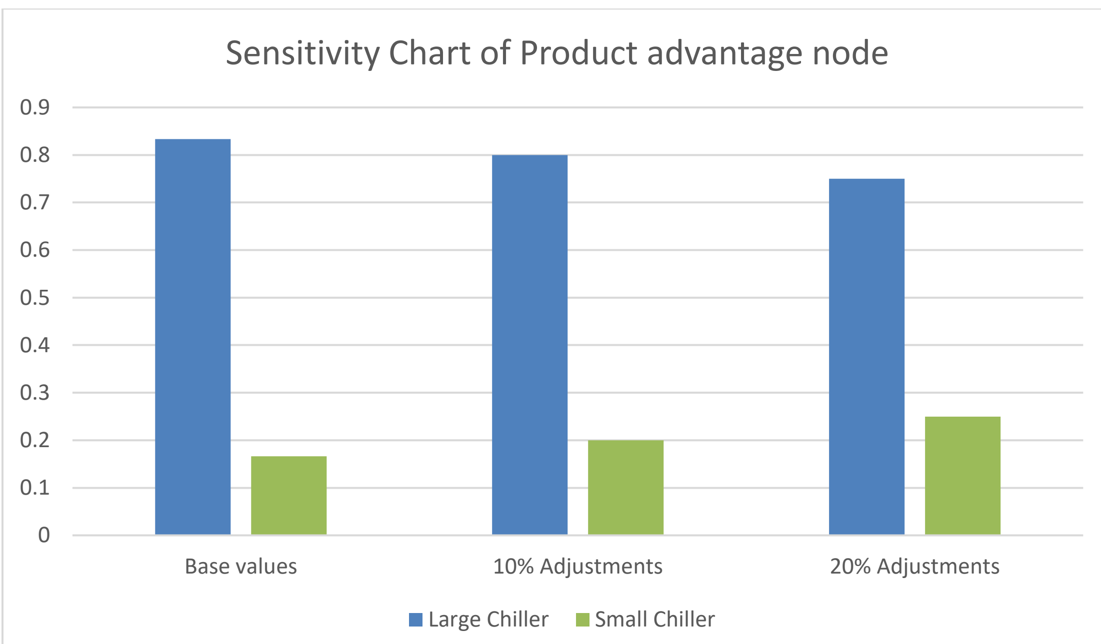

Figure 12. Sensitivity chart of product advantage node

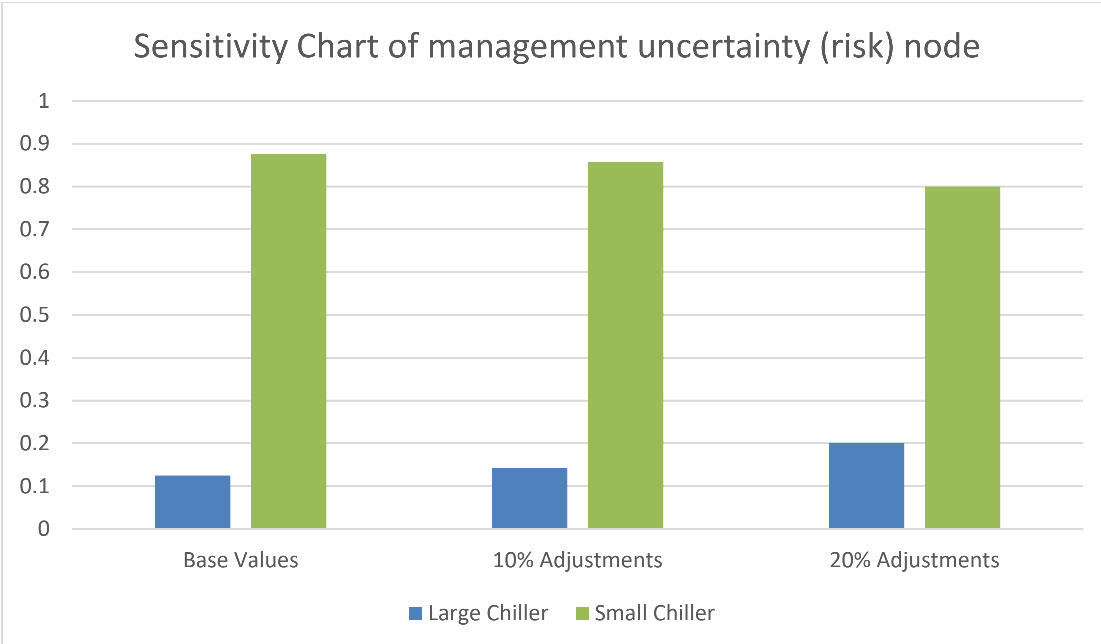

Figure 13. Sensitivity chart of management uncertainty (risk) node

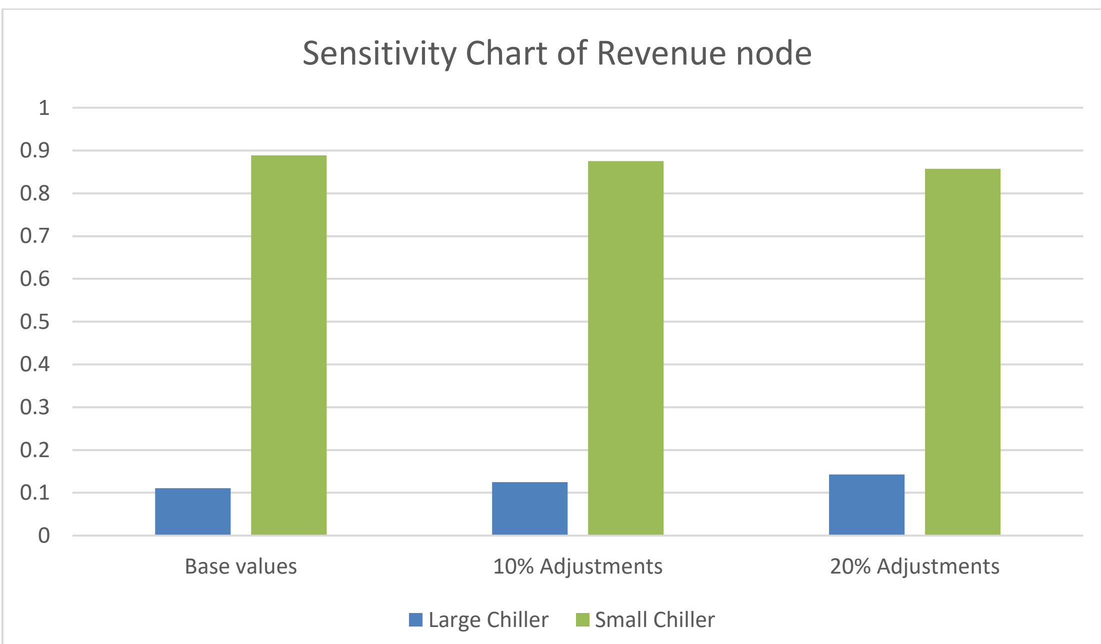

Figure 14. Sensitivity chart of revenue node