Strategic Maintenance Decision Making using Real Options

by

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Abstract

Maintenance decisions impact company's costs and profits in various ways. These decisions can be incurred as a part of everyday repairs or heavy replacements or as an investment in future asset or technology. Large corporations with physical assets have maintenance practices to ensure proper operations and to minimize costs. With innovation and development, it is possible to improve the maintenance practices to implement a more effective future technology. These changes may require significant investment decisions, and therefore, it becomes critical for decision-makers to use the best available information with respect to market conditions and potential benefits of every future option under consideration. In this study, condition-based maintenance practice is analyzed in different scenarios, both qualitatively and quantitatively. A strategic maintenance decision for future investment is evaluated using real options approach. The proposed framework is then explored for the airline and trucking industries.

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Table Of Contents

List of Tables

List of Figures

Chapter 1 Introduction

1.1 Problem Setting and Thesis Motivation

There is a scope of enhancement for the tools and frameworks in industry that can help reduce risks and improve decision outcomes of potential future technology projects. It is necessary for decision-makers to evaluate the benefits and the challenges before investing in any future opportunity. However, at early development stages, it becomes difficult to have evidence for the success of the project (Mattar, 2017). Therefore, there is a possibility that technological development may have some risks that should be evaluated to define the worth of the opportunity. Other factors such as initial commitments in a project, resource allocations or market demand can also change at any stage of development and innovation. When such situations occur, flexibility to revisit and reassess the project or investment can help decision-makers to reduce risks and expenses for long-term or short-term goals (Kang et al., 2017). The motivation of this work is to help managers improve their decision-making framework to understand critical risks and evaluate the costs and benefits of a project before the investment, and to provide flexibility to make changes during the technology project with any new information if that becomes available.

Companies try to have no disturbance in the operation of their systems and environment and maintain a continuous flow of everyday work when they are on the path of exploring and evaluating the potential future opportunity (in an ideal condition); however, they do bear loss of production sometimes (Lipsett, 2021).

Generally, industries have guidelines and streamline processes to deal with possible challenges for everyday functioning. For future decision-making, companies prefer to explore areas where there is an opportunity to grow, generate more profit, or reduce their costs. Areas such as Investing in technological development or launch of a new product are some examples where generally traditional approaches such as discounted cash flow and net present values are applied. A strategic decision for any future opportunities also considers the risks and costs of the present-day performance of the company. One of such fields in industry is maintenance.

In various industries, maintenance practices have their predesigned set of maintenance checks. For example, maintenance of railroads is done by preventive maintenance scheduling where one of their routines (spot) maintenance practices (Budai et al., 2006) is inspection of switch, level crossing, overhead wire, and other small repairs, which are performed few times a year. A timely maintenance check is very essential for some systems as it helps in the reduction of premature replacement costs and deterioration of a system and its parts (Vineyard et al., 2000). Therefore, many large corporations have fixed regulated maintenance checks to avoid unnecessary costs. Regulated maintenance checks help companies to avoid system downtime and make the system available for its maximum use for operation. An uninterrupted, timely repaired and a proper functioning system will contribute to low operating and maintenance costs and high production value. Maintenance strategies can be based on various factors such as the type of equipment, nature of failure, criticality, cost of equipment, nature of business, operating conditions, environment, market, etc. Preventive, breakdown, predictive, shut down, condition-based, contract and risk-based maintenance are some of the methods used in different industries. These maintenance practices are discussed in detail in the literature review.

Companies generate profit when their systems are available for production/use. An appropriate maintenance strategy ensures the optimum performance and maximum availability of the equipment for operations. Earlier, maintenance practices were only limited to fixing the system quickly (Wisdom et al., 1992). However, over the years companies have evolved to understand the impact of maintenance strategy and its costs on the overall operating costs of the company and lost profit associated with opportunity cost of lost production. Maintenance management is not only a technological approach but also has a deeper relationship with the business model of the industry (Jantunen et al., 2019). The cost of maintenance, the downtime required for maintenance, labor hours, cost of repairs and replacements also have a major effect on the operating costs of a company. Hence, maintenance management has become a combination of strategic and operational decisions (Márquez et al., 2015). Companies continually try to find and adopt new methods to improve the availability and efficiency of their systems while exploring different ways to reduce their maintenance cost. Hence, it has become a practice in many companies to have maintenance as a center of strategic thinking as it is not only needed to maintain the reliability of a system but also contributes to generating profit in business (Liyanage et al., 2001). The grounds of the work conducted in this study are based on the combination of maintenance decisions with a future investment decision to make a strategic business decision for a company.

In the application of maintenance strategies, the state of the equipment plays an integral role. The state of the equipment is studied from the information collected during its operation. Condition-based maintenance is one such maintenance strategy that monitors the condition of the system and sends alerts if the system reaches the predefined trigger points of the need for maintenance (Campbell et al., 2015). Condition-based maintenance takes account of current risks and abnormalities in a system and helps in the prediction of future complications to ensure proper functioning of the system. It monitors the health of the equipment and identify the problems with real-time inspections before potential damage. The application of condition-based maintenance can be very valuable for the industries to help prevent future failures without incurring unnecessary costs and associated risks.

This work proposes scenario framework that explores decision factors qualitatively in three scenarios and a quantitative approach to explore future investment options with the ability to modify the strategy in the fourth scenario. The motivation is to improve the framework that takes care of the current needs for the maintenance of the system without heavy costs and supports the idea of investment in future technological developments. Traditional valuation methods such as net present value analysis are not sufficient to understand the potential of such projects as they lack the option to change decisions in future if needed (Pivorienė et al., 2017). Though it is difficult to assess the costs and benefits of developing technology, however, there are ways that are used to evaluate them. Real options analysis is one such technique that takes account of a company's fiscal matters, provides flexibility for decision-makers, and has an effective approach to assess the value of future development (Pivorienė et al., 2017). The pliability of decision-making with a substantial financial evaluation of an option defines real options. Option to abandon, delay, growth, choose, expand, switch a project because of any reason can be assessed and evaluated with the help of real options analysis. Real options analysis also has the ability to determine the success and failure of the executed option in a situation, allowing the flexibility in decision-making at various stages of a project. Implementation of real options helps industries to understand future risks and value of the project/investment, thus, incorporating an efficient strategic path for the company. Therefore, real options analysis can be used to overcome the gaps in traditional valuation methods. Hence, the quantitative approach is explored with real option analysis, to evaluate technological development for future investments which can help to reduce maintenance costs of a company and aid to generate more profits.

1.2 Objective of the Thesis

The objective of this thesis is to suggest strategic decision-making for maintenance practices. The hypothesis is based on the fact that real options valuation methods are used for strategic decision-making in industry. Therefore, they can be applied to strategic decision-making related to maintenance practices and future technology investment. To address this hypothesis, condition-based maintenance strategy is selected, factors affecting the decision-making are investigated. Then the real options method is explored for a future investment option with the idea to reduce maintenance costs. This study will state the importance of condition-based maintenance to analyze the factors affecting decision-making for different maintenance scenarios. The option of future investment will be evaluated through real options analysis with various assumptions and estimations of future technological options. Therefore, the combined approach of condition-based maintenance with real options analysis is explored in one of the scenario analyses. The other three scenarios state the importance of condition-based maintenance qualitatively with the factors affecting the decision-making for different maintenance options. Real options analysis is performed in scenario four with traditional financial methods. This methodology is applied to case studies of two different companies from two different industries, a Canadian airline company – "WestJet Airlines" and a North American trucking company – "TFI International Inc.", using data from publicly available financial reports. A "timing/deferral" options analysis is performed for its success and failure for its future implementation.

1.3 Structure of the Thesis

This thesis is arranged into five chapters. After this introductory chapter, chapter two presents a literature review related to the proposed framework of the analysis. The literature review introduces the importance of decision-making and different kinds of maintenance practices with a detailed description of condition-based maintenance. Various traditional financial methods used in industry, common risks in development and innovation are also examined in various sections. A brief introduction on real options is also mentioned. Chapter three considers how the real options framework is applied to maintenance decision making, including options for future technology investment decisions and timing. Chapter four applies the real options framework for maintenance strategy selection in two different industries: the commercial airline industry and the trucking industry. It also explains various maintenance checks and their costs and procedures for both industries. The application of condition-based maintenance and real options analysis on case studies will be conducted through four scenario analyses. Calculation of discounted cash flow, net present value, sensitivity analysis with a potential real options analysis is presented. A brief discussion of the study and its limitations is also mentioned in chapter four. Chapter five discusses the study and offers conclusions and recommendations for future work.

Chapter 2 Literature Review

This chapter explains and reviews concepts related to the field of strategic decision-making for maintenance practices and economics with a focus on real options analysis. A brief description on importance of decision-making is discussed. Different maintenance strategies practiced in the industry and their impact on operational and financial expenses are reviewed.

Common risks in future investment for development and innovation are described and popular traditional valuation approaches and financial methodologies used in industries to evaluate their projects are also mentioned. Finally, the importance of real options and their advantages for future decision-making is presented. Various kinds of real options and their steps are also introduced.

2.1 Decision-Making- Importance and Concepts

Identifying a situation/problem, understanding it by gathering information, assessing its risks and impact, and proposing a solution is a general concept of decision-making. In business, every decision has an impact on the company; and a decision can be related to the value of any tangible or intangible asset (Vaidya, 2006). Effective, and flexible decision-making strategies have become an essential requirement for companies to address practical and complex problems (Zavadskas et al., 2011).

In large corporations, consistent criteria for decision-making are necessary for effective strategic planning and for financial and operational management (Bhushan et al., 2007). Questions such as what kind of decisions need to be made, what kind of resources are needed, how are the resources allocated, how will the success or failure of the decision be measured, and can we revise the decision in the future, are important for the present and future operations of the company and therefore, play a crucial part in the dynamic world of decision-making (Bhushan et al., 2007). Hence, decision criteria and potential alternatives are important factors for decision analysis. Multi-criteria decision-making is considered an important tool to help decision-makers compare and evaluate various options. Its framework provides flexibility to explore problems for multiple options in an organization. Data and information are also vital parts of decision analysis. For management to make a decision, every piece of information (old or new) that is relevant to the requirement helps to establish the relationship between various variables tangible or intangible to make an informed decision.

2.2 Multi-Criteria Decision Making

To assess and select the most profitable and effective option from all potential decisions is the main objective of the decision-making process (Zavadskas et al., 2011). However, with many competitive numbers of alternatives, it becomes difficult for the decision-makers to make that choice. MCDM is one such technique that helps to analyze these decision options and ease the task for decision-makers (Ananda et al., 2009). It is a combination of both qualitative and quantitative strategies (Ahire et al., 1995). In corporations, one of the main objectives is to maximize profit, hence the efficient allocation of capital and resources is a major goal of making decisions (Hallerbach et al., 2002). It is believed that for financial decisions MCDM provides quality in the economic decision-making process and the resulting decisions as well (Hallerbach et al., 2002). From (Kangas et al., 2001), the general steps of MCDM are the following:

1. data acquisition and assessment of the present state
2. Identifying the goals and preferences

3. generating alternative treatments/methods
4. Selecting the appropriate scale for the method according to their impact
5. Selecting the most efficient options concerning the objectives
6. Choosing an alternative if required.

There are various other techniques and methods to achieve successful decision-making. Some of the techniques (Velasquez et al., 2013) are Multi-Attribute Utility Theory, Analytical Hierarchy Process, Data Envelopment Analysis, Weighted Product Model, Simple Multi-Attribute Rating Technique, Goal Programming, ELECTRE, PROMETHEE. These techniques are not only used in financial decisions but have applications in all functional areas in a company such as engineering design evaluations, supplier evaluations, marketing strategies, production, etc. (Ahire et al., 1995).

Each decision-making method has different strength and limitations, and they are applied according to the assumptions, perspectives, need of the company and their desired outcome. Sometimes, two techniques are integrated together to fulfill the requirement and to achieve the best outcome (Dotoli et al., 2020). MCDM helps to solve issues with different evaluation criteria, is super-efficient, can deal with the variation of data, and assess the alternatives (Almahdi et al., 2019). There are different approaches to decide on a decision-making technique (Abdelli et al., 2020). The information available to the companies, time, and cost to obtain final results can be some parameters to determine which method to use for a specific problem (Abdelli et al., 2020).

2.3 Risk

Any potential loss or injury or uncertainty in a system can be determined as risk. It can be material, operational, human, social, or environmental. Risk is also associated as a product of the probability of an event and its consequence (Lipsett, 2016) as described in the following equation:

Risk = Probability (P) x Consequence (C)

Generally, risk is considered as a negative factor but the decision of a positive risk or a negative risk is made after weighing all other elements in a system. Risks are not only positive and negative; they can be qualitative, quantitative, or both. Qualitatively, any situation that draws exposure to danger/hazard is defined as risk. Quantitatively, it is the likelihood of the event and the evaluation of its consequences.

Qualitative Risk Analysis- This method is used to classify risks according to their probability and impact values. In this approach, various factors of risks such as likelihood, its effect on small and big term goals, its measure, response time, and exchange of its information, discussion, and communication, play an important role in the realistic assessment. Risk categorization, probability impact matrix, scenario analysis, interviews, surveys, expert judgment are some of the techniques of qualitative risk analysis.

Quantitative Risk Analysis- One of the major disadvantages of qualitative risk analysis is to measure the potential of uncertain assessment as it is subjective to human judgment, therefore, to quantify the uncertainty, quantitative methods come into play. Probability distributions and Monte-Carlo simulations are some of the common techniques. From, a decision-making perspective, quantitative techniques assess uncertain variables to output recognition (Abbas et al., 2020).

It is a common practice to combine assessment, management, and communication to form a complete analysis. Similarly, Risk Analysis are divided into risk assessment, risk management, and risk communication. The cause, frequency, and magnitude of risk are measured in the risk assessment. It is the first step for decision-making. The effects and causes of risks are minimized and controlled as part of risk management. Risk communication is the last step of the analysis, it is the process of exchanging information about risk assessment and risk management between administrators, stakeholders, and other members of the organization.

There is vast research on risks associated with different kind of systems. Risk assessment is affected by an understanding the risk and its perception (Yarong et al., 2021). Risks cannot be classified into one category, as they vary from different stages of an idea, development, implementation, and application. Risks can be operational, financial, external, strategic, technological, market, economic, social, managerial, technical (Snieska et al., 2020), organizational, political, regulatory, environmental (Sun et al., 2020), business, commercialization, customer, and more (Mattar, 2017). This section provides a general list of references associated with maintenance and new technological developments. Financial, market, organizational, technological are some of the risks explained in the section below.

1. **Financial Risks:** Any risk involving capital, funding, investment, credit activity, insurance is termed as financial risks (Sava et al., 2018). It is an important category of risks as financing is critical for industrial factors such as resources, operation, development, and maintenance. Financial risks are present at all stages in a company and therefore, should be managed by the firm and its shareholders (Lasloom, 2021). Less financial distress and reduced cost of bankruptcy, proper corporate coordination for financing and investment are some of the advantages of management of financial risks by the firm itself (Lasloom, 2021).

2. **Market Risks**: Market can be called as the amalgamation of demand, supply, distribution, the customer wants, competition with other manufacturers or providers, better/efficient or cheaper products, change in policies or regulations or climate/natural disasters as these factors influence companies and therefore entire market. Therefore, any risks associated with these factors affecting a company are known as market risks. Sometimes market risks are missed by companies as more importance is given to technology (Mattar, 2017). The assessment and conditions of the market should be explored and compared before the decision-making for the product/technology (Mattar, 2017).

3. **Technological Risks:** There can be many risks related to this category. Design technology, manufacturing technology, platform development, process development, IP, technical, technology life cycle (Schuh et al., 2020). At the early stages of the development of technology, design and technical risks play a crucial part as they lead to the next phase of development. As the development process mature, process, manufacturing, and platform development risks play a higher role.

4. **Organizational Risks:** Factors such as their employee selection, legal, reputational, security, leadership, cooperation between teams may affect a deliverable that is a firm is not able to put the product on the market. Risks from these internal factors are called organizational risks. Uncertainty from these factors may not compromise a product completely but can seriously impact its implementation (Durst et al., 2019).

2.4 Maintenance

For asset-intensive companies, the maintenance and operations departments are often the largest. For example, in refineries, the operations and maintenance departments account for 30% of total staffing (Dekker, 1996). Maintenance strategies have evolved to corrective maintenance to risk-based maintenance over the years. According to (Arunraj et al., 2007) corrective and reactive maintenance was introduced as the first generation. Over the years, many other strategies, such as preventive, time-based, condition-based, reliability-centered, and computer-aided maintenance were found. These maintenance strategies are described in the following section.

Common Maintenance Strategies

2.4.1 Reactive Maintenance

This type of maintenance is appropriate when a small piece of equipment usually a non-critical component fails. It refers to the failure of one part, not the entire system. Run-to - failure and breakdown maintenance falls under this category. The process results in a short repairing time of the particular component (Lee et al., 2017) but there is a very low opportunity cost of lost production. In some cases, an unexpected production delay or lower efficacy rate can occur due to labor shortage, parts of supply chain, or consequential damage to other systems. (Lee et al., 2017). Generally, no huge amount of capital investments is required, the loss is controlled by low-cost spares. This maintenance is generally applied with the consideration that the equipment will not cause any safety or environmental risks.

2.4.2 Preventive Maintenance

Preventive maintenance is a proactive strategy, also known as routine maintenance or planned maintenance. This approach requires maintenance activities to be performed before any failure is likely to occur. Activities such as lubrication, cleaning procedures, and timely replacement of machine parts are part of preventive maintenance. Preventive maintenance restores full functionality and extends the life of an asset. However, some activities may cause disturbance in production, more downtime giving rise to the opportunity cost of lost production. Any new secondary damage due to maintenance errors will also cause an increase in downtime and cost. Preventive maintenance ensures the intended performance of the equipment (Palma et al., 2010). Long-term strategies with a pre-defined interval period are the key requirements of preventive maintenance (Basri et al., 2017).

2.4.3 Shutdown Maintenance

Major inspection, repairs, and replacement of some or all systems are the causes of shutdown maintenance. Most of the time, it is pre-planned and controlled by maintenance management systems for large assets. Unlike a maintenance strategy, it's a kind of implementation for maintenance. Sometimes, unforeseen shutdown maintenance is carried out causing major loss of production and capital as a stoppage to operations occurs. One of the key principles of maintenance activities is to ensure the optimization of the equipment to increase its availability for production and its reliability and, also to minimize operational risk (Hameed et al., 2016). In the case of shutdown maintenance, if the shutdown interval is small, downtime/shutdown time will be less, but the cost of maintenance and potential production loss will be high (Hameed et al., 2016). On the other hand, if the interval is too long, maintenance cost, production loss will be low but there is a high-risk exposure (Hameed et al., 2016). Therefore, Improper planning and implementation of shutdown maintenance can lead to significant consequences.

2.4.4 Condition-based maintenance

In this kind of maintenance, information on the current state of the system plays a very important factor. The state of the equipment is identified, and its health is analyzed to predict the possible failure in the system (Lee et al., 2017). Various statistical tools and techniques are used to process and analyze data collected from the equipment (Lee et al., 2017). Depending upon the information and state of the system, maintenance is carried out. This maintenance strategy can be used to save cost, downtime as some regular checks that are part of preventive maintenance strategy in many companies can be avoided here. Condition-based maintenance is also referred as the alternative of predictive maintenance (Lee et al., 2017), but with more prominence to real time assessment. Wireless sensors/networks, Radio Frequency Identification (RFID) devices are used for monitoring and failure prediction in this type of maintenance. Other technologies such as Micro-Electro-Mechanical System (MEMS), Supervisory Control And Data Acquisition (SCADA), Product Embedded Information Device (PEID) are also used for monitoring the status during the usage period (Shin et al., 2015). Some of the warning signs used for condition-monitoring are temperature rise, vibrations, noise levels, cracks and deformation, particles release, resistance, etc. (Tsang, 1995).

A condition-based maintenance strategy is a very dynamic and flexible approach. It determines maintenance decisions based on the deterioration state information of the system (Zhou et al., 2019) and therefore, a targeted maintenance plan can be formed. As a result, economic losses from the system breakdown and expenses from unnecessary repairs are reduced considerably (Tahan et al., 2017). This maintenance strategy not only focuses on fault detection but also monitors the degradation of the equipment and helps in failure prediction (Shin et al., 2015). Therefore, condition-based maintenance identifies and solves problems before any damage takes place (Shin et al., 2015).

To assess the health of a system in condition maintenance system, different methods such as vibration monitoring, acoustic analysis, thermography, tribology, visual inspections, etc. are used (Lee et al., 2008). A small description of three popular techniques is mentioned below:

1. **Vibration Monitoring**

   It is used to detect system malfunction based on measured vibration signals. System malfunction can be caused by misalignment, unbalance, resonance, loosened assemblies, turbulence, etc. (Tsang, 1995) (International Atomic Energy Agency, 2007). Sensors are used to detect system malfunction. The sensitivity of sensors used for parameters such as amplitude, velocity, and acceleration vary with the frequency of vibration (Tsang, 1995). Generally, for low-frequency signals, amplitude sensors are used, for middle ranges, velocity sensors are used, and accelerometers are used for higher frequencies (Tsang, 1995) (International Atomic Energy Agency, 2007).

2. Thermography

Thermography uses instruments to measure absolute or relative temperatures of key parts of the system (International Atomic Energy Agency, 2007). When a certain part of the system reaches temperatures beyond a certain point, the abnormal temperatures are taken as alarm signals of developing problems (Tsang, 1995). There are two types of equipment used in this technology. Thermometers and thermocouples are popular ways to measure a system's temperature and are referred to as the contact method (Tsang, 1995) (International Atomic Energy Agency, 2007). The non-contact method uses infrared sensors and infrared imaging to capture thermal data (Tsang, 1995) (International Atomic Energy Agency, 2007).

3. Tribology

It is also called Lubricating Oil Analysis or Oil-based monitoring in condition-based maintenance (Tsang, 1995) (Lee et al.,2008). In this method, the condition of both the lubricant and the internal surfaces in contact with the lubricant is monitored at regular intervals (International Atomic Energy Agency, 2007). When oil reaches an alarming state, it is replaced to maintain and improve the system operation (Lee et al.,2008). The typical oil analysis is done to check the presence of contamination that can be internally generated, externally generated, water/moisture based, or from by-products from the chemical breakdown of lubricants (International Atomic Energy Agency, 2007). One of the major limitations of this method is expensive equipment and the accuracy and testing of oil samples.

2.4.5 Reliability Centered Maintenance

This maintenance procedure is used when there is more than one maintenance strategy is required for any physical asset in its operating environment. It is used to find balance with the mix of maintenance strategies for different parts of the system as well as its design and production operations. It is based on the concept that all failures do not occur equally and affect the system function differently (Tsang, 1995). The RCM technique is outlined in following steps by Smith, 1993 :

1. 1.The system under maintenance is selected and necessary information is collected to define system boundary.
2. A functional block diagram is prepared, and system functions and failures are identified.
3. For maintenance procedure, Failure mode and effect analysis (FMEA) is carried out. (FMEA is an approach to find and correct system failures. It is a procedure not a maintenance strategy and is not exclusive to reliability centered maintenance. A brief description of FMEA is mentioned below).
4. A decision-tree analysis is performed for maintenance task selection.

In reliability centered maintenance, maintenance strategies are implemented and optimized to preserve the system and maintain its productivity. It identifies the most critical parts of the system and minimize its failures to increase its availability and reliability. It is used for complex systems in industries like steel plants, railway networks, ships maintenance, etc. (Cheng et al., 2008).

Failure Mode and Effect Analysis

FMEA is an inductive approach use to analyze system failures in a system. This method also gives detail about the source, reasons, and consequences of system failures and helps to formulate ways to reduce them. FMEA analysis can be implemented on a component, on an entire system or any subsystem. FMEA helps to correct system failures at design and production levels. FMEA identifies functions and failure modes of functionally significant items (Cheng et al., 2008). FMEA tells us about the qualitative information of a system and its operations. An improved technique of FMEA called FMECA (Failure Mode and Effect Criticality Analysis) results in a quantitative form of information about failures.

FMEA Procedure:

The following are the steps that are performed for FMEA analysis in general:

1. Examine the system for FMEA analysis. Define its subsystems and their components which includes all the internal and connecting parts of the system.
2. Depending upon the relationship of the components and the aim of the analysis, construct block diagrams. The block diagrams can be structural, functional, or combined.
3. Identify all failure modes, the causes and effects of every component, subsystem, and its related function in the system.
4. Assess each failure mode on the level of its worst potential consequence and assign a severity classification number.
5. Identify failure detection techniques and mitigation methods for each failure mode.
6. Calculate Risk Priority Number (RPN).

   The RPN is a critical rating that is a product of severity, occurrence, and detection of the failure modes. A higher rating of RPN results in higher risk in a system.
7. The need for corrective action or design is determined on the basis of the RPN.

8. Propose and implement a method to correct failures and improve system performance.
9. File the analysis in the tabular form of the FMEA report.

2.4.6 Contract Maintenance

All types of maintenance practices can be used for contract maintenance but here a part or all the maintenance work is outsourced. It is usually done to reduce the operational costs in a company, but it also involves extra costs of outsourcing and some risks related to it. Contract maintenance is carried out when the benefits provided by the service provider outmatch the meets of the in-house maintenance. Some of the advantages are reduction in labor cost, reduction in the cost of carrying extra inventory, and special equipment and other associated overheads. Maintenance providers may use the latest methods and techniques available in the market. Large air carriers outsource some of their maintenance requirement. Generally, for labour intensive maintenance checks (heavy maintenance checks) in airlines that require large hanger space, testing equipment, contract maintenance is used (McFadden et al., 2012). For cost savings, Delta airlines use facilities from the Far East for the heavy maintenance of their wide-body aircrafts (McFadden et al., 2012).

2.4.7 Risk-based maintenance

Risk-based maintenance is the framework involving risk assessment, risk management, and communication. This methodology lays out the systematic way to determine maintenance plans for the assets that carry the most risk of failure. Risk-based maintenance is very popular in transportation and industrial systems (Arunraj et al., 2007). This practice also takes care of the strategic and operational needs of the company.

Risk-based maintenance helps to minimize the risk of failure in an economical way. Systems/assets that possess a higher risk of failure are monitored and maintained more frequently than the ones that carry lower risk. For regular monitoring and maintenance, generally, condition-based maintenance is implemented. Hence, Risk-based maintenance is considered as an addition to condition-based maintenance for various operational conditions (Leoni et al., 2019). (Krishnasamy et al., 2005) divided the methodology of risk-based maintenance into four steps: identify the scope of the failure, assess the risk, evaluation of the risk, and develop a maintenance plan.(Khan et al., 2004) (Krishnasamy et al., 2005) (Abbassi et al., 2016) have proposed various risk-based maintenance techniques with similar methodology steps as mentioned above. Risk-based maintenance consists of identifying the fault/failure events and their consequences. A Fault tree analysis (FTA) or Event Tree Analysis (ETA) can be used to perform probabilistic failure analysis (Leoni et al., 2019). With the results of failure analysis, risks are evaluated and compared for critical components and maintenance planning. For complex systems with dynamic parameters, an advanced probabilistic model-Bayesian network can also be used (Arzaghi et al., 2017). An optimum maintenance plan is formed according to the evaluated associated risks. Decision-makers prefer a maintenance strategy that can provide a continuous uninterrupted operation of a system with minimum cost (Arzaghi et al., 2017). A maintenance plan can have any possible solutions such as major repair, major replacements, capital investments, and many more. Different maintenance techniques can be included in the maintenance planning for economic aspects, providing flexibility to decision-makers for the desired outcome (Arzaghi et al., 2017).

2.5 Financial Valuation Options Overview

Financial valuation methods have evolved over the years and there is a large amount of literature available to discuss various models and methods. Discounted cash flow (DCF) and net present value (NPV) analysis are traditional valuation methods that are widely used and accepted (Schwartz, 2013). These methods are easy to adapt for managers and provide opportunities and options for further valuation.

2.5.1 Discounted Cash Flow and Net Present Value Analysis

The Present value method is used to calculate present expected gain or loss by discounting all expected future cash flows (Carras et al., 2020). It calculates the value today based on the projections of value generation in the future, i.e., a present value is used to determine the potential future value (Li, 2020). If the calculated value is higher than the investment cost, it is considered as a profitable investment. DCF is carried into three steps (Li, 2020) : forecasting of free cash flow is done for a defined period, the second step is to calculate the predicted level of cash flow based on the assumptions. For the results, free cash flow is discounted on discounted rate/weighted average cost of capital (Li, 2020). The formula (Mattar, 2017) for net present value is mentioned below. Here, C_t is the cash flow for the year t and r is the expected rate of return/discount rate/weighted average cost of capital which is typically the opportunity cost of capital (Carras et al., 2020).

$$PVt = \frac{C_t}{(1 + r)^t}$$

$$NPV = \sum PVt - \text{Initial Cost}$$

NPV is calculated using the sum of all future cash flows of a given project discounted to present day which is $\sum$ PVt and subtration of the cost of the initial investment. The higher the value of NPV, the better is the project from a financial perspective. DCF and NPV are easy to implement and are widely used, however, these methods, however, have some disadvantages. The discount rate chosen for valuation is considered constant and the possibility of any changes in the decision-making criteria is ignored (Pivorienė et al., 2017). In the traditional methods, the projects are considered independent, but a long-term strategic goal is usually interrelated. Traditional methods do not consider strategic decision-making and assume the expected run of the project regardless of any uncertainty (Lee, 2011).

Besides traditional financial methods, there are many financial option theory methods. Financial option theory deals with the variables such as volatility, interest rate, underlying asset etc. (Mattar, 2017). Most common are Monte-Carlo simulations, Binomial model, and Black-Scholes model. Uncertainty is expressed as parameters in these methods which gives the management the flexibility to make valuable decisions. These options also provide the ability to make decisions that are interrelated to each other. The Black-Scholes model is popular in the R&D and technology industry (Black et al., 2019) for investment approaches, whereas the Binomial Model is most used for risk-neutral probabilities and is found simpler to use.

2.5.2 Monte Carlo Simulation

Monte Carlo Simulation is applied to continuous distributions that incorporate random variability of parameters (Bonate, 2001). From the sampling distribution of parameters, a random set of inputs are drawn to obtain a possible set of outcomes (Raychaudhuri, 2008). The most challenging step in this method is to define the distribution of the inputs in the system because of limited knowledge (Bonate, 2001). However, distributions can be determined by examining a variable's conditions in the previous stages of the analysis (Mattar, 2017) or created from expert knowledge (Bonate, 2001). The data for input variables can be empirical data or data from system models (Raychaudhuri, 2008). For example, A minimum distribution is assigned to the variable where there is an equal likelihood of minimum and maximum values (Mattar, 2017). For a random variable of unknown distribution, a sensitivity analysis is carried out with the assumptions of best-case and worst-case scenarios and can be used for simulation.

One of the limitations of Monte Carlo Simulation, is the large computational requirements of simulations, especially when there is a large number of variables (Smid et al., 2012). Also, when the projects are at initial or early on stages of research and innovation, there is very limited knowledge of variables or characteristics of variables. Monte Carlo simulation should not be implemented in that scenario.

2.5.3 Black Scholes Model

The Black-Scholes equation (Pivorienė et al., 2017) (Mattar, 2017) for a call and put option are:

$$c = N(d_1)S - N(d_2)Xe^{-rT}$$

and

$$p = N(-d_2)Xe^{-rT} - N(-d_1)S$$

where $N(d_1)$ and $N(d_2)$ are the statistical measure, representing the values of standard normal distributions, their values (Pivorienė et al., 2017) (Mattar, 2017) are:

$$d_1 = \frac{\ln(S/X) + (r + \sigma^2/2)T}{\sigma\sqrt{T}}$$

$$d_2 = d_1 - \sigma\sqrt{T}$$

where

S = current value of an underlying asset

σ = stock price volatility

T = time to the maturity/expiry

R = risk-free rate of return

Black Scholes theory is considered a successful approach to estimate market volatility of an underlying asset (Teneng et al., 2011). However, there are certain limitations to it. The prediction of market/stock direction (Teneng et al., 2011) is not always consistent as many economic factors control the market. Similarly, it does not account for any changes in the value of assets or interest rates (Teneng et al., 2011) (Mattar, 2017).Black Scholes model considers assets to follow a lognormal distribution, which is not always true for real assets (Teneng et al., 2011) (Mattar, 2017).

2.5.4 Binomial Model

The binomial model follows a discrete-time approach that uses binomial lattice to determine the changes in the value of an option (Brandão et al., 2005). It can be viewed as a probability tree resulting in binary branches with values moving up (upswing)(u) or moving down (downswing)(d) (Brandão et al., 2005). In this model, at start time, t=0, the value of the underlying asset is considered as S_0. Over the next period (example t=1), the value of the underlying asset will take an upswing i.e., S_0u or a downswing S_0d (Dar et al., 2017). The value of upswing is considered as when the value of the asset goes up and hence the value is considered as greater than one. Similarly, the value of d is considered as less than 1 (Dar et al., 2017) . The values of u and d are calculated with the formula (Dar et al., 2018):

$$u = exp(\sigma\sqrt{\delta t})$$

$$\mathrm{d} = \frac{1}{\mathrm{u}}$$

The values of S_0u or S_0d are weighted by their probabilities to calculate the value across the lattice (Dar et al., 2018). The risk neutral probability is calculated from the formula (Dar et al., 2017) (Dar et al., 2018):

$$\mathrm{p} = \frac{\exp(\mathrm{r}\delta\mathrm{t}) - \mathrm{d}}{\mathrm{u} - \mathrm{d}}$$

where r is the risk adjusted discount rate.

The decision to exercise an option is calculated with the backward induction method (Mattar, 2017). If the value of the difference between the asset value and investment value is negative, the option is not considered otherwise ways to exercise investment are explored (Mattar, 2017).

2.6 Real Options

To prevent the errors from traditional valuation methods and to help decision-makers to make more informed economic and strategic decisions in uncertain environments, real options are applied (Pivorienė et al., 2017). The term "real option" was formed in 1977 (Yu et al., 2008). The word option is for "alternative" or "possibility" (Trigeorgis et al., 2017). An option is right but not an obligation for the specified decision (Trigeorgis et al., 2017). Real Options provide an opportunity to evaluate uncertain future possibilities. It also provides flexibility to modify decisions in the future if needed. It provides flexibility to manage many strategic decisions (Lipsett, 2018) too and plays an important part to manage or reduce any risks involved in business decisions.

There are many ways to evaluate market values of investment projects, research and development, expansions, and other initiatives (Copeland et al., 2004). Real options are not only the financial options, but financial options are a part of the real option analysis or valuation. Real options are used to make or modify decisions in uncertain, volatile or risk environments to achieve a favourable outcome in business. Organizational theories and financial theories of investment may not always be in sync when there is a business decision, they both share several techniques (like NPV) and risks involved in the decision (Bowman et al., 2001). Real options gain popularity and importance over financial decisions because of the belief that decision-makers will have flexibility and ability to expand, invest, modify or abandon the course of a project at any given point of time and still try to achieve an overall strategic decision for the company.

According to (Atari et al., 2019), real option valuation is an extension of financial options theory for real and physical assets. To evaluate a value of an investment, the options trading approach was introduced by option pricing by Black and Scholes (Black et al., 1973). That model calculates the price of a call option and options in general by incorporating a constant price variation of the asset, the money value, the price of the option, exercised, and the maturity or the expiration value (Black et al., 1973). Later, a new option valuation approach called Monte Carlo Simulation was introduced by (Boyle et al., 1977), where random variables were generated to get the pricing value by the traders. However, the evaluation of an option price (Glasserman, 2004) was more acceptable than the MCS approach.

The nature of uncertainties and risks are also different for real options and financial options. When exercising a real option, sometimes, stakeholders are more concerned with the exercise of the option than its value because the dynamics of the underlying process can be modified (Kang et al., 2017). However, in financial theory, when the stock price is higher than the exercise price, companies like to exercise the option (Black et al., 2019).

Net present value approach and discounted cash flow method are generally used to explore investment projects as decision-makers find it easier to model and explain and implement (Pimentel et al., 2020). These traditional approaches however do not consider uncertainty, flexible options or delay (Balliauw, 2021). In investment decisions, even if the uncertainty is very low, the NPV approach for decision may not be correct (Balliauw, 2021). However, in projects with large investments, irreversible projects, delayed implementation, real options are more suitable as they provide managerial flexibility to alter decisions for best outcome (Dixit et al., 1994) It is important to know that real options are not the replacement for NPV and DCF approaches. It is an additional and complementary approach to calculate the value of the project with minimum risks and more options (Dixit et al., 1994).

2.7 Types of Real Options

Real options analysis helps decision-makers to fulfil strategic targets and increase the company's profit and help investors and shareholders (Peters, 2016). General Motors from the automobile industry, HP-Compaq from the computer industry, Boeing from the airline industry, AT&T from the telecommunication industry and many other companies from sectors of oil and gas, real estate, pharmaceutical and e-business have implemented real option analysis (Mun, 2012). These companies are using this tool to make strategic decisions that can be exercised in different ways. Common ways in which real options are exercised are the following:

1. Option to Expand
2. Option to Abandon
3. Option to Contract
4. Option to Switch Resources
5. Option to Delay
6. Option to Choose

Option to expand refers to scale up the conditions favorable for the company to make more profits or expand resources. **Option to abandon,** states the termination of the project. The real option to abandon gives flexibility to stop a project if it doesn't meet the needs of the company. **Option to contract**, is similar to the option to expand. If the conditions of the project are unfavorable, the management can reduce the extent of the project. **Option to switch resources**, provides the management the ability to change their demand and supply. The factors for switching to a different reason can be anything from change in market trends, to customer needs or better expertise. **Option to delay,** refers to a company's decision to strategically delay a project until the uncertainty is resolved. The reasons for delay can be technology, market, performance, inventory, etc. **Option to choose,** this option gives complete flexibility to a company, to change any part of a decision based on the current situation of the project/asset. Other options of real options are **option to grow, option to outsource, compound options, option to license in and option to collaborate**. Every real option exercised by the management takes consideration of many factors. Some of them are risks, uncertainties, costs, downtime, maintenance, operations, assets, new technologies, market, government, environment.

The framework of real options is based on the flexibility of decisions to make strategic choices to continue the project or abandon or modify it. If the risks and costs incorporated for a project change in an uncertain environment, managers have the option to revisit the investments in the project to have positive outcomes. According to Mun, 2012, real option analysis is carried out in eight steps that are listed below. The following are the general steps of real options analysis. These steps are further explained in the next chapter (chapter 3) of this study. These steps are modified to lay out a framework for this study, which is also mentioned in the next chapter.

The following are the general steps of real option analysis:

1. Qualitative management screening

2. Time-series and regression forecasting

3. Base case net present value analysis

4. Monte Carlo simulation

5. Real Options problem framing

6. Real options modelling and analysis

7. Portfolio and resource optimization

8. Reporting and update analysis

The steps of real options can also be analyzed as modified phases of risk analysis. Apart from assessment and management, other phases are risk identification, risk prediction, risk modeling, risk mitigation, risk hedging and risk diversification. Real option analysis focuses on uncertainties, but the analysis is done ahead of time for business decisions, with a scope of revisiting the decisions if needed.

2.8 Discussion

Maintenance strategies and decision-making techniques are part of industries, and the management of every company tries to find and adapt the strategic ways to mitigate the losses and use the resources for their maximum advantage. The real options framework provides freedom to decision-makers at all stages in the industry, whether it is to evaluate the investments or revisit a business decision.

This chapter discussed the importance of decision-making. Different kinds of maintenance strategies used in the industry were described. In the next section, different kinds of risk categories were defined and discussed. Different financial valuation methods of the industry were explained, with their advantages and disadvantages. The last section described real options, their importance, and advantages. Further, various real options are described briefly with the steps of the framework of real option analysis.

Chapter 3 Framework of the Analysis

The framework in this study is developed by following the general eight steps of real options analysis for strategic decisions (Mun, 2012). In the first section of this chapter, the general steps of real option analysis are explained very briefly. Further, the framework for strategic maintenance decision-making using the real option approach is described. The uncertainty of the future gives rise to midcourse alterations for the investments in a company. Decision-makers sometimes revisit the strategic options when the risks and the value of the project changes. Real Options analysis provides the flexibility for these alterations for the best possible outcome for decision-makers.

3.1 Major Steps of Real Options Analysis

1. Qualitative management screening

2. Time-series and regression forecasting

3. Base case net present value analysis

4. Monte Carlo simulation

5. Real Options problem framing

6. Real options modelling and analysis

7. Portfolio and resource optimization

8. Reporting and update analysis

Qualitative Management Screening

The first step of real options analysis is very critical for the management as it involves consideration of all kinds of projects and strategies of the company. Decision-makers factor in the investments and plans of the future by focussing on the vision and goal of the company. This step also identifies various risks to the organization along with the growth and globalization objectives.

Time-Series and Regression Forecasting

After the qualitative screening, plans for the next step are forecasted in this step. There are various methods used for forecasting, cash-flow time series analysis, or if comparative or previously documented records are available. Qualitative methods like expert opinions, subjective assumptions, Delphi method can also be used as forecasting methods.

Base Case Net Present Value Analysis

Decision-makers develop a discounted cash flow model for the projects that pass the initial first two steps of the real options analysis. After a discounted cash flow is generated, a risk-adjusted rate of return is considered to calculate net present value analysis. The discount rate chosen varies subjectively and can cause an error in the calculation (Dzyuma et al., 2012). In this step, predicted cash flows are based on future revenues and costs without considering the changes and uncertainties in the circumstances (Hu et al., 2015). The net present value is accounted as the base case for the project under the analysis.

Monte Carlo Simulation

There can be many uncertainties in the parameters of the future events, which will lead to an arrangement of possible net present values. This can lead to inaccuracy in the analysis. Also, one of the disadvantages of the static discounted cash flow is that it gives rise to single -point results which can also lead to possible errors. Therefore, Monte Carlo simulation can be used for finer estimates of a project for different variables. Sensitivity analysis (Mattar, 2017) can also be used for best-case and worst-case scenarios to obtain better results which can be represented graphically using a Tornado chart.

Real Options Problem Framing

Real options are the possible actions that decision-makers would make for a project. Decision-makers can invest or divest in the asset/project as a corporate option without any obligation (Miller et al., 2005). These options are decided strategically during the qualitative management screening of the analysis. These options may include Option to Expand, Option to Contract, Option to Abandon, Option to Switch, Option to Choose, Option to Growth, or others. The cash flow series developed in step two is modified in this step after the real options are added. Risks involved in the project are also calculated again after the addition of real options.

Real Options Modelling and Analysis

The results from the Monte Carlo simulation in step 4 are considered as the underlying variable for the future cash flow series in this step. The future cash flow value is then taken as the underlying asset value for real option modelling and analysis. The analysis can be performed by many different methods such as binomial lattice or decision trees to calculate the values of the proposed strategic options.

Portfolio and Resource Optimization

If the company is performing real options analysis on multiple projects, the future values of the projects, risks involved in those projects can be correlated. These projects should never be assumed as individual opportunities as they are associated in most cases. A company also has many restrictions on the resources involved in the strategic planning of the options, hence optimization becomes necessary. Portfolio optimization results in the ideal allocation of the company's resources across the opportunities. This is also considered an optional step of the real options analysis.

Reporting and Update Analysis

The process and the results of the analysis are reported in this step with precise explanations of the assumptions, value propositions, project objectives, costs, and risks for the management.

3.2 Methodology of the Study

The critical steps of the real options analysis mentioned in section 3.1 are used for the analysis for two companies. Some of the steps are combined and modified according to the requirements of the framework. The modifications were mentioned in the specific phases. Also, the optional step of the analysis, 'Portfolio and resource optimization' was considered out of scope for this study.

The analysis of this study is divided into qualitative and quantitative scenario analysis. The analysis is done in four scenarios. The first three scenarios examine different situations under condition-based maintenance qualitatively. Various risks, costs, and other factors affecting the decision-making in these scenarios are mentioned in the analysis. The real options framework is used in the quantitative scenario analysis- Scenario 4. This scenario "Maintenance with new technologies" is divided into two phases. Phase one and phase two in scenario 4 are done for both companies for a comparative analysis. The details of the two phases are mentioned below:

Phase 1:

Introduction and Data collection

Cash flow statements and net present value analysis

Sensitivity Analysis and Tornado Diagram

Phase 2:

Real option problem framing

Real option modelling and analysis

Reporting of the analysis

3.3 Phase 1

Phase one of the analysis begins with the introduction and background information of the company with its goals and maintenance strategies. The industries explored in the study are the Airline industry and the Trucking Industry. One of the reasons to choose these industries for the application of real options analysis is that real options analysis has been used in the valuation of assets of large transportation options such as aircraft (Hu et al., 2015). Airplanes and commercial trucks follow various industry-regulated maintenance checks during their lifespan. These maintenance checks differ according to the age of the aircraft/commercial truck. The cost and downtimes of these checks have their estimates before the maintenance procedure. Sometimes, heavy maintenance checks should be revisited if the costs proceed with the general estimates. Also, if the age and condition of the asset are not suitable for heavy maintenance checks, then the decision is revisited. Similar to these, there are many conditions where these decisions are taken by decision-makers by doing the financial analysis and understanding the risks, market, technology, and other economic factors. The maintenance practices and their costs for the airline industry and the trucking industry are also mentioned in phase one of the analysis.

After the introduction and relevant information of the companies, their public financial records were studied. For the Aircraft industry, the financial records of WestJet Airlines from the year 2014-2018 were considered, whereas, for the trucking industry, the financial records of TFI Inc were examined from the year 2015-2019. The reason for considering these years for the study was based on the availability of the public financial records of the companies. The record of the first year is considered as an initial investment year for both the companies. After the data collection, for the record of revenue and operating income was considered, various relevant assumptions were made for discounted cash flow and net present value analysis. Generally, it is preferrable to use cash flow from operations. However, with limited information, for analysis, operating income was used. Another important challenge in the study was to estimate the value of the weighted average cost of capital (WACC) and the minimum acceptable rate of return (MARR) for net present value analysis. A relevant value of WACC and MARR were selected for the analysis. The reasons and the record of value are mentioned in the application of the analysis in chapter 4.

According to the steps (Mun, 2012) of the real options analysis, after qualitative management, forecasting, net present value analysis, the next step is Monte Carlo Simulation. Monte Carlo simulation is not performed here as its application can become challenging with limited data. Here, a sensitivity analysis is performed to describe the variability in the factors like revenue and costs. Sensitivity analysis for factors- revenue, costs and MARR was performed and was represented in a Tornado diagram for both companies.

3.4 Phase 2

Phase 2 sums the three steps of the real options analysis which are, 'real options problem framing', 'real options modelling and analysis' and, 'reporting of the analysis'. Many financial option pricing techniques are followed in real options modelling (Miller et al., 2005). The real options analysis is performed by different techniques to determine the volatility of the project. Since, the maintenance practice and costs vary in different industry types, the type of real option considered may/may not vary.

In this study, after the sensitivity analysis, real options analysis is performed for a timing/deferral option. The maintenance needs, costs, and strategies of both companies are examined, and real options problems are framed. It is further modelled and analyzed by generating an incremental cash flow for both the companies. After the incremental cash flow, valuation of real options is done for two years with a value of upswing and downswing using binomial lattice valuation. The reason for selecting two years and the values of upswing and downswing is mentioned in the application of the analysis section (chapter 4).

The next step of the analysis is to calculate the value of the option with a weighted probability of best case and worst-case scenario. For the study, best case probability is considered as 65% and worst case is considered as 35% and therefore, a final value of the proposed real option is generated. The reasons for considerations and assumptions for the analysis are mentioned in the specific sections of the application (chapter 4).

Chapter 4 Condition-Based Maintenance Strategy Decision Making Using Real Options

This chapter comprises strategic maintenance decision-making analysis of two companies, WestJet Airlines and TFI International, where the importance and need of condition-based maintenance will be described in different scenarios. The maintenance practices of both the aircraft industry and the trucking industry will be mentioned in the chapter. The analysis will be divided into four different scenarios, where the first three scenarios will be the same for both companies and will be described qualitatively. It will discuss the need for CBM with the risks involved and the factors affecting the maintenance decision-making. In the last scenario, public financial records of both the companies will be considered to perform real options analysis under condition-based maintenance. These four scenarios are decided on the regulated maintenance practices of the industry, with the aspect of maintenance and operational costs and future opportunities.

The novel contribution of the study is to demonstrate a strategic pathway for maintenance decision-making with prospects of future technology investments, which is presented in Scenario 4. Scenario 4 is divided into two phases for both industries. Phase one will begin with the introduction and background information of the company. Data collection from the public financial records will also be reported in phase one. It will consist of discounted cash flow, net present value analysis, sensitivity analysis. Sensitivity analysis will be presented in a Tornado diagram. Phase 2 will be a real options analysis set up implemented in delayed time for future maintenance on incremental cash flow.

Scenario 4 will begin with the case study of WestJet airlines. Phase one and two will be performed on the data collected from the airline maintenance practices and financial reports of WestJet

Airlines. After the completion of scenario 4 analysis on WestJet airlines, the same will be performed on TFI International for a comparative study. The major challenge in the study was the collection of data. Information on the particulars of cost and specification of maintenance practices, repairs, replacements were very limited. Factors like the age of the aircraft/truck, kind of maintenance performed, residual value, whether the aircraft/truck is leased or bought by the company were unknown. Hence, many pertinent assumptions will be made for various aspects of the analysis. The assumptions will be explained for each industry in the chapter. Despite the restricted details and many limitations, an effective case study was performed, describing the importance of CBM with real options.

4.1 Condition-Based Maintenance - Goals and Risks

For any maintenance strategy to be applied, information plays an integral role. In maintenance management, sensors are used with data acquisition to give alerts depending on the changes in the state of the equipment that relates to faults. The application of such data collection is used in condition-based maintenance. Condition-based maintenance takes account of current situations and risks in a system and helps to indicate future complications. Condition-based maintenance regulates the condition of the systems which are part of large assets for a company. Therefore, CBM can be used in the current and future valuation of assets. Hence, CBM will not only help in improved maintenance practices and reduced maintenance costs but will also help a company to achieve the following goals:

1. Low maintenance costs

2. Less downtime

3. Fewer labor costs

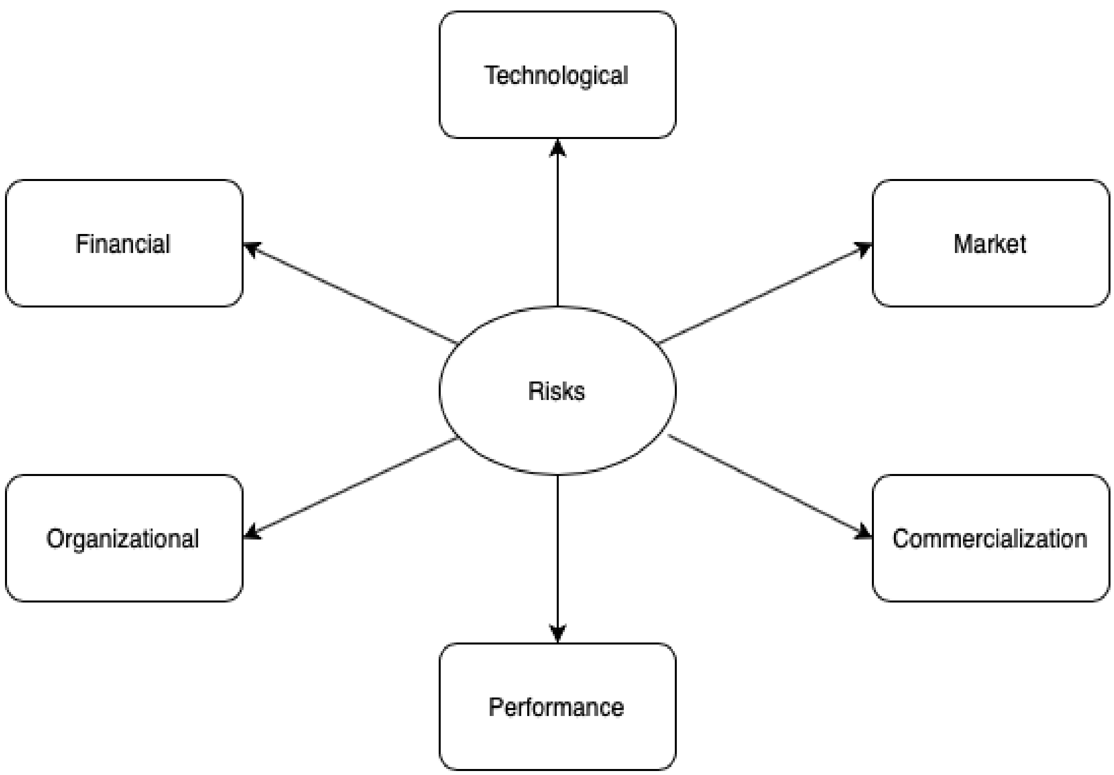
4. Increase in the availability of the (aircraft) equipment

5. Low operational costs

6. Increase in revenue

To incorporate a new maintenance policy or even make any small change in a company, there are risks involved. Many kinds of risks impact strategic decisions which can lead to major profits or losses in a company. These risks are analyzed by decision-makers of the company for current and future scenarios. These risks are explained in detail in literature review and are briefly described in the in the section below:

Figure 1: Different Kinds of Risks



1. Market risks (in an airline industry) consist of fuel prices, interest rates, and foreign exchange rates. There are a lot of volatile markets in these categories depending on the global demand and supply.

2. Financial risks are associated with credit risks and liquidity risks of the assets and liabilities, cash and cash equivalents, and long-term debts.

3. Performance risks are related to operations, labor, and maintenance, which directly impact the fleet (of the airlines) and therefore, affect the growth of the company. Performance risks also affect the experience of the customers.

4. Risks affecting the commercialization of the company depend on the seasonality, weather conditions, and new global trends.

5. Global regulatory changes, political, economic, and legal requirements, the company's reputation, and safety regulations are related to organizational risk factors for (airlines) companies.

6. Technological risks vary from new technical and technological developments worldwide. It also involves other factors such as the replacement/supply of the machine parts.

4.2 Airline Maintenance

The airline industry is one of the largest and most complex businesses in the world. An aircraft only makes money when it is flying with freight and/or customers (Knezevic, 1997). Therefore, risk and maintenance management are vital for this industry. It becomes essential to avoid any errors or delays in the operation or maintenance of an aircraft to attain high profits. Low operating and maintenance costs are key parameters to attain high profits for airlines. In this industry, about 10-20% of operating cost is used in maintenance activities depending on factors such as fleet size, age, and usage of aircraft (Ahmadi et al., 2010). However, regular checks can cause disturbance in operation, execution giving rise to an increase in lost opportunity cost. Also, in the traditional maintenance checks of airlines, any consequential damage may incur delay and potentially be expensive. Other important factors such as aircraft leasing, the residual value of aircraft, technology trends play a very essential role in an airline's maintenance practices.

According to IATA, generally, approximately 10-20% of the costs incurred by the airlines are direct operating costs. These direct operating costs include various sections like fuel costs, landing fees. It also contains maintenance and repairs. Maintenance cost directly affects the airport operations, flight hours, labor hours, downtime of airplanes, therefore it has a significant impact on the total operating expenses of the airlines.

An aircraft is composed of many different structures and systems, each structure and system require different maintenance (Saltoğlu et al., 2016). Therefore, the aviation industry has a set of regulations and procedures that are performed over the years for aircraft maintenance. Aircraft maintenance is divided into Checks A, B, C, and D, along with line maintenance checks (Saltoğlu et al., 2016). All these checks vary in duration, rate of performance, maintenance areas, and costs. The age of the aircraft plays a significant role in determining the type of maintenance for the aircraft (Saltoğlu et al., 2016). As the aircraft ages, other factors like labor costs required equipment, and materials, facility costs, supplies, overheads determine the type of maintenance.

Some of the other factors like depreciation, aircraft leasing, flight operations, and airport operations are interrelated to maintenance practices and therefore, play an essential part in framing the problem statement. Also, a part of the airworthiness of an aircraft comprises maintenance operations. Aircraft maintenance consists of activities like servicing, repair, overhaul, inspection which can restore the proper functioning of an aircraft (PeriyarSelvam et al., 2013). According to (Hölzel et al., 2014) maintenance downtimes and costs can be reduced remarkably when there is a shift from preventive to condition-based maintenance techniques. Condition-based maintenance systems will lead to a slight increase in the initial cost of an airplane, but it will result in significant cost reduction during the aircraft lifespan.

4.3 Commercial Motor Vehicle Maintenance

All kinds of motor vehicles require maintenance, whether they are big or small. Commercial motor vehicle industries like the trucking industry have large fleets and they make a major portion of their money (profit) when they are available to use. Regular usage of the fleet is delivered by regular maintenance checks. The maintenance of a vehicle also drives its cost, quality and performance, and fuel consumption. The average operating cost of a commercial truck is $1.38 per mile, which accounts for $180,000 total average operating costs (The Real Cost of Trucking - Per Mile Operating Cost of a commercial Truck, 2021). Many variables such as fuel consumption, maintenance, tires, repairs, depreciation, replacements are parts of operating costs (Shukri et al., 2002). Other important factors are labor costs, registration and license fees, insurance, administration fees. Approximately 10-20% of operating costs are consumed in maintenance costs (Shukri et al., 2002), depending on the type and size of the truck and the kind of maintenance needed.

Generally, commercial truck companies follow preventive maintenance which means maintenance tasks are performed on a scheduled basis (Preventive Maintenance Checklist-common tips for Trucks and Fleets, 2021) (Best practices for establishing a fleet preventive maintenance (PM) program, 2021) (A Fleet Manager's guide to Preventive Maintenance for Semi Trucks, 2021) (Elements of a successful preventive maintenance (PM) program, 2021). Similar to airline maintenance, maintenance checks for trucks are also divided into Check A, B, C and D (Elements of a successful preventive maintenance (PM) program, 2021). Check A consists of general safety checks and inspection of the truck such as brakes, tires, lights, and fluids (Elements of a successful preventive maintenance (PM) program, 2021) (Fleet Maintenance, 2021). Check B and C are more extensive than Check A and require in-depth checks of the engine (Elements of a successful preventive maintenance (PM) program, 2021) (Fleet Maintenance, 2021). Check C occurs every 11-12 months, it is an annual check for any engine or component inspection or replacement (Elements of a successful preventive maintenance (PM) program, 2021) (Fleet Maintenance, 2021). Each of these checks occurs at specific intervals as they are part of scheduled maintenance. There are many other checks like Yard checks or checks in Inspection Lane associated with the maintenance of trucks (Elements of a successful preventive maintenance (PM) program, 2021).

Maintenance records are kept to ensure the proper functioning of machine parts and to evaluate their performance. Information about previous maintenance records and next planned scheduled maintenance about every truck in a large fleet is a difficult but necessary task. Along with the work of keeping and updating maintenance records, there is also an opportunity cost of downtime for several scheduled tasks (A Fleet Manager's guide to Preventive Maintenance for Semi Trucks, 2021). Generally, in (any) trucking industry, average downtime costs $260,000 (Preventive Maintenance Checklist-common tips for Trucks and Fleets, 2021). In the maintenance of the truck, factors like labor costs, environment, fuel efficiency also play an important factor.

Maintenance strategies have a direct impact on the business (Pinjala et al., 2006). Companies are always looking for better and controlled maintenance systems with fewer expenses (Pinjala et al., 2006). The importance of condition-based maintenance in the trucking industry will be described. Condition-based maintenance is a dynamic approach to maintenance before a breakdown happens. It relies on real-time sensor measurements to indicate the condition of the system. An initial cost is involved in adapting the condition-based maintenance and regulate it. To further explore condition-based maintenance in the trucking industry, data is collected from the company TFI International Inc to perform real options analysis.

4.4 Scenario Analysis

Airlines and trucks are highly regulated, they are capital, labor, and safety intensive. The decision to assess the maintenance of their assets is an important strategic decision in a company. The maintenance expenses are part of operating expenses which hold a greater part in the value of a company's profit. For the analysis, a very important consideration is that both the industries follow a condition-based maintenance. Other factors of operating expenses can be materials and services, direct maintenance personnel expenses, depreciation, impairment, intangible assets, etc. Please note, many other elements are included in operating expenses which are ignored as the study focuses on maintenance costs.

In simpler words, it is considered:

Profit = Revenue – Operating Expenses (maintenance Expenses + other factors)

4.5 Scenario 1

No non-regulated (extra measures or untimely) maintenance is carried out. Equipment is used in the same condition.

For the safety, continuous and appropriate working of the trucks and airlines, they have specifically regulated maintenance checks that are in place for the proper running of the engine. But sometimes, with regular maintenance checks such as Check A, B, or C, sometimes, situations give rise to unplanned maintenance. These untimely maintenance measures affect companies on a large scale, by interrupting their service, extra downtime, extra labor, and hence, extra costs. In this scenario, it is assumed that the system follows condition-based maintenance, along with regulated checks and no non-regulated/unplanned maintenance will be performed, which means the equipment will be used until it breaks.

The decision-making in this scenario will be affected by the following factors:

1. An important aspect here is the risk of safety. However, the system follows condition-based maintenance, which monitors the system continuously and indicates the working of the system (with the help of sensors or temperature, etc.) and therefore, makes the risk of safety of the vehicle, goods, or labor negative.

2. There will be an extra cost of adding a condition-based maintenance system to the equipment, but that cost would be comparatively less than the cost of untimely maintenance.

3. Here, the machine/part is utilized until it breaks, that is, there will be continued use of equipment. It may lead to no or very minimum residual value of the equipment.

4. No non-regulated maintenance leads to no extra downtime of the truck. Therefore, more availability of the equipment, more usage to generate more profit.

5. Using the equipment until it breaks, might involve performance risks of the equipment. However, monitoring through condition-based maintenance will reduce that risk.

4.6 Scenario 2

Only replacement of the equipment (parts of the system) will be carried out

Maintenance tasks ensure the availability of the equipment for appropriate usage. Repairs and replacements both are part of the maintenance activity, but this scenario focuses only on the replacement which means, instead of using the equipment until it breaks (scenario 1), here an immediate replacement of the part is performed. The system is considered to follow condition-based maintenance; therefore, the regular functioning of the system is monitored.

The following factors will affect the decision-making in this scenario:

1. There will be an opportunity cost of the lost production during the replacement of the part. The set-up/replacement time of the new part will make the aircraft/truck unavailable to use during that period, hence reduced time for its usage.

2. During the set-up time of new equipment, the company is losing the availability of vehicle to generate profit. The setting of the new part will require downtime and labor costs. If the new part operates differently, a small training will be needed by the operators. Hence, leading to an overall increase in the costs.

3. One of the important risks in this scenario is the financial risk involving the long-term debts and liquidity of the assets. As no repairs are done, the replacement with the new part may increase

the lifespan of the equipment. It may also have a positive impact on the residual value of the aircraft/truck.

4.7 Scenario 3

Maintenance tasks are performed when needed

Here, the performance and maintenance of the truck are only regulated by condition-based maintenance instead of regulated maintenance checks. One of the many advantages of condition-based maintenance is the regular monitoring of the equipment, therefore, if any repair, replacement, oil change, etc. is indicated; the equipment will undergo maintenance it needs and gets back in service. As it is not preventive maintenance, the immediate decision on the maintenance may lead to some risks and extra costs.

The following factors are impacted in the decision making of scenario 3:

1. The unplanned repair and replacement might be done by possibly counterfeit parts and unverified procedures.

2. As the counterfeit parts are used to perform the needed maintenance. There is a possibility that those parts will need more unexpected maintenance in the future.

3. Unexpected maintenance may increase maintenance costs, labor costs, increase the unavailability of the truck, leading to an increase in operating costs.

4.8 Scenario 4

Maintenance with new technologies

The above three scenarios describe the condition of the aircraft/truck, their costs, maintenance scenarios along with the affected present and future factors qualitatively. In the following scenario, real options are explored when new technological opportunities in the future are available. Scenario 4 is performed on both WestJet Airlines and TFI International separately. Both companies' analyses are divided into two phases.

4.9 WestJet Airlines

Phase 1: Introduction, Data collection, NPV, Sensitivity Analysis and Tornado Diagram

WestJet Airlines is a Canadian airline founded in 1994 (WestJet About Us, 2020). It is a public company and is headquartered in Calgary, Canada (WestJet About Us, 2020). This company began as a low-cost airline but today, it is the second-largest air carrier in Canada (WestJet About Us, 2020). These airlines offer scheduled flights, travel packages, and charter and cargo services (WestJet About Us, 2020). The scheduled airline transportation services are offered in North America, Central America, Mexico, the Caribbean, and Europe (WestJet About Us, 2020). WestJet's public financial records from the year 2014-2018 (WestJet Annual Financial Reports, 2014-2018) will be studied and used to analyze this study.

The following were the considerations and assumptions applied in the analysis for WestJet Airlines. Any changes in the assumptions will be mentioned in the specific section of this chapter.

The general assumptions for DCF/NPV are:

1. All the financial data was collected from the public financial records of the WestJet airlines from the year 2014- 2018 (WestJet Annual Financial Reports, 2014-2018).
2. To calculate cash flow statements, the record of revenue and operating income were only considered. All other factors were ignored in the calculation. This was done to simplify the calculations in the work.
3. The Year 2014 was taken as year 0 for the calculation of net present value and a cash flow statement of 5 years is formed from the records of the year 2014 to 2018 (WestJet Annual Financial Reports, 2014-2018). The record from the year 2014-2018 is considered on the availability of the records of both the companies to have a similar timeline for comparative study.
4. Weighted average cost of capital was considered as 7% (Economic performance of the airline industry, 2018) (Economic performance of the airline industry, 2019) (Gibson, 2010). The estimate of the cost of capital is also sometimes used as a discount rate to calculate present values because in the airline industry there are some subjective estimates. From the economic performance of the airline industry by IATA for the year 2018 and 2019 (Economic performance of the airline industry, 2018) (Economic performance of the airline industry, 2019), it was observed that the value of WACC from the year was nearly between 6-8% It is obvious that over the years there had been some changes in the value of WACC but to simplify the analysis, a constant value was considered.
5. The value of 'Revenue' is taken from the financial reports of all the years, and it consists of guest revenue, interest income, charter, and others (WestJet Annual Financial Reports,

2014-2018). However, for the net present value analysis, net revenue is calculated by subtracting the expenses from the revenue.

6. Minimum acceptable rate of return was considered as 11%. This value is considered from the average value of ROIC from the financials of WestJet Airlines (WestJet Annual Financial Reports, 2014-2018).
7. Operating income considered for the analysis consists of aircraft fuel, airport operations, flight operations, and navigational changes, sales and distribution, marketing, general and administration, depreciation and amortization, aircraft leasing, inflight, maintenance, and employee profit share (WestJet Annual Financial Reports, 2014-2018).
8. The analysis does not take into account the change in the size of the fleet as each aircraft has different age, type, and size. Real options will be analyzed only on 10% of the fleet because the condition and age of the aircraft play an important factor to retrofit an aging aircraft with future real options. Also, as the future real options are new and developing, it is only strategic, to invest in a part of the fleet. The change in type and size of the airplanes is not mentioned because of limited information from the financial reports.
9. The analysis performed will be done only on operating income, not on maintenance expenses as the parameters involved in the analysis affect total operational costs. Therefore, to provide a larger viewpoint on the changes in the costs and profits, real options will be performed on operating income, although cash flow from operations would be preferred for a conventional analysis.

4.10 Base-Case DCF

Discounted cash flow for WestJet airlines is considered as a base case for the analysis where all the earlier assumptions are applied. The calculation assumes that there will be no change in MARR and WACC over the years. Also, this calculation does not take into account government or environmental regulations. Despite some unreliability, the values of DCF and NPV were considered as base cases in this study.

Table 1: Base Case DCF of WestJet Airlines

Year		FV	PV
		(In millions)	(In millions)
2014	0	-475	-475
2015	1	569.75	513.28
2016	2	440.1	357.19
2017	3	438.96	320.96
2018	4	155	102.1
		1128.81	818.5
		Income	**NPV**
		MARR	11%
		WACC	7%

DCF generates a positive NPV, however, "timing option" or in other words "option to wait and defer on making decisions" requires a large investment decision. The values of MARR and WACC are assumed to be constant for the analysis, but these factors are affected by the market changes. Also, the values of these parameters have important impacts on the investment decision as they can influence the profit and costs associated with the future options. Therefore, a well-thought sensitivity analysis is performed to explore the range of probabilities. A sensitivity analysis is chosen over Monte-Carlo simulation because of the lack of information. The values can change based on the development of technology, demand, competition, socio-economic, and many other factors Also, operating expenses, fleet conditions, regulatory changes, fuel prices have a direct effect on the value of gross revenue. The reality would be more complicated and different as it would have many associated costs of implementation, development, training the employees, promotion, production, maintenance, and other operating costs. The values are assumed to give a perspective on the parameters for the company to achieve an acceptable set of NPV values for the future. Three conditions were created and analyzed. Each condition with an upside and downside case. The following are the three conditions:

1. Net revenue was increased and decreased by 20%.

2. Costs were decreased by 10% and increased by 40%.

3. MARR was increased and decreased by 2%.

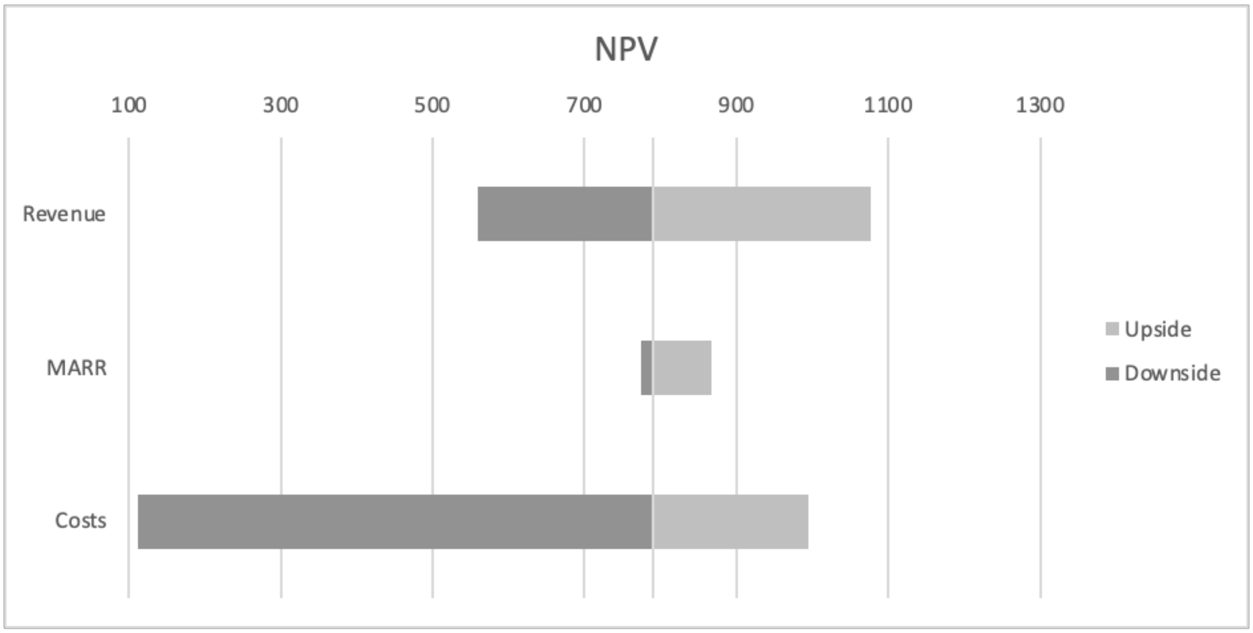
These conditions were assumed to perform the sensitivity analysis. These values are interrelated and interdependent. The value of revenue depends on the cost of technology and its implementation. Therefore, for possible sensitivity analysis, a change of 20% was considered for revenue. The value of MARR was not changed to a greater degree, as it is generally more regulated. The change in costs was increased to 40%, as there are many direct and indirect costs associated with the growing company but a case of a decrease of 10% in the costs was also considered as an upside case. The table below shows the sensitivity analysis of WestJet Airlines.

Table 2: Sensitivity Analysis of WestJet Airlines

	Expected NPV			Input		
Variable	**Downside**	**Upside**	**Range**	**Downside**	**Upside**	**Base Case**
Costs	111.23	995.6	884.37	26,999	17,356.50	19,285
MARR	773.61	866.97	93.36	13%	9%	11%
Revenue	559.98	1077.47	517.49	17,091.20	25,636.80	21,364
CF Year 0	-665	-427.5	237.5	-665	-427.5	-475
CF Year 1	307.97	615.94	307.97	341.85	683.7	513.28
CF Year 2	214.33	428.66	214.33	264.06	528.12	357.19
CF Year 3	192.66	385.33	192.67	263.37	526.75	320.96
CF Year 4	61.26	122.52	61.26	93	186	102.1

A major limitation of the analysis and the results is that they are based on assumed values that may not be accurate. There can be errors in estimation and assumptions and negligence of many parameters, however, the analysis still generates a certain set of values for decision-makers to understand the options and alternatives for similar conditions. The results from the sensitivity analysis are represented in a tornado diagram.

Figure 2: Tornado Diagram Range of NPV Results of WestJet Airlines



Phase 2: RO problem framing, modelling and analysis, Reporting of the analysis

Airline maintenance practices depend mostly on the age of the aircraft. As the age of the aircraft increases, the maintenance checks get heavier resulting in increased maintenance costs which leads to extra downtime and more labor costs. With research and development and new technology options, there will be new kinds of engines, different kinds of materials, and equipment that might make the system run better in the future. With the new technology option, there will be associated costs and risks, which gives rise to the analysis with the real options approach. As the system is under condition-based maintenance, it will be easier for the management to make a better strategic maintenance decision for a delayed period. The amalgamation of real options analysis with condition-based maintenance will rise to an approach that will help the company to have the pliability to have options to increase the overall value of their profits.

Out of the maintenance checks A, B, C, and D, Check D is considered as the heavy check (Saltoğlu et al., 2016). An airplane undergoes Check D two to three times in its lifespan. It usually happens every 6-10 years with a downtime of 2 months. The cost of Check D is also the highest expense in maintenance practices and can vary up to 4-6 million (Ackert, 2010). Check D is one of the mandatory checks that an aircraft goes through in its lifespan. However, once an aircraft reaches the point of maintenance to perform check d third time which is around 22-24 years of its lifespan, decision-makers should have an option to choose whether to undergo this heavy maintenance with heavy costs. This maintenance practice also decides the condition of the aircraft and therefore, plays an important part in the lifespan of the aircraft. These maintenance costs notably impact the operational expenses of the company which further affects the generation of revenue. Therefore, decision-makers should have a real option- An option to Choose before investing in heavy maintenance.

Options to choose can be an option to abandon the aircraft (retire), an option to lease/buy new aircraft, option to wait to implement new technology. These real options are assessed based on the current performance of the aircraft, estimated cost of the chosen option, expected revenue generation. These decisions are made in advance by the management, as retiring an aircraft or leasing a new aircraft, or adopting a new technology require huge capital investments. The 'Option to Choose' is determined to maximize the profits and minimize the maintenance expenses. However, a major limitation of the study as mentioned previously is the limited information.

Therefore, particulars about the number of aircraft, the type of aircraft, the type of maintenance for each aircraft, downtime for the specific maintenance for the aircraft, labor hours for the specific maintenance of the aircraft, cost of maintenance for specific aircraft, residual value, the value of new or leased aircraft from the WestJet airlines were not found.

To ensure proper safety and usage of the aircraft, the aging aircraft requires the third heavy maintenance Check D routinely. Hence, the cost of maintenance, the downtime required for maintenance tasks, and labor hours will be high for the maintenance of aging aircraft. Therefore, a large increase in the total cost of maintenance will be noted. A huge increase in maintenance costs will result in a substantial increase in operating expenses.

One of the options to avoid the large increase in the maintenance cost on aging aircraft is that the aging aircraft should retire in the same year and a beneficial residual value of the aircraft could be obtained. There will be no heavy maintenance costs leading to no downtime and no labor costs. The saved costs and the residual money from the aircraft could be used as some capital to buy/lease a new aircraft. The leased aircraft could be new or in the early years of the aircraft's lifespan. It is noted that a new aircraft is not only leased for the maintenance scenario (as mentioned above), but they could be leased when there are new technological/ technical/design developments in the airline industry. Also, when the company decides the business expansion-increase in the fleet size, then also new airplanes are leased.

Another option could be to invest in new aircraft with better technology and fuel options for the company's future growth. Some of the benefits of new technology can be better fuel efficiency with new design and less maintenance and therefore, reduced costs. It will require less maintenance for over next 6-8 years compared to an aging aircraft and thus, low operating costs. Option to

Choose can be used as a strategic tool by the decision-makers to value the future decisions with various aspects of technology, market shift, expansion, and many financial decisions.

The decision-making in this scenario will depend on the following factors:

1. Major maintenance cost of heavy Check D was saved.

2. No extensive labor hours and downtime for the aircraft which was retired.

3. Early retirement of the old aircraft gave rise to new opportunities of buying or leasing aircraft in new/better conditions and new design and technology.

4. New aircraft will be highly equipped and will require less maintenance for the next 6-8 years.

5. A new leasing cost gave rise to an increase in the annual expenses. A lease can be a short-term lease or a long-term lease depending on the aircraft financing guidelines.

4.11 Timing Option

One of the important aspects of real options is that they provide flexibility to the management by quantifying the financial options theory to values (Lipsett, 2021). Therefore, Investment in a new aircraft with new/better technology was modified to an approach of a "timing" option. The timing option consists of waiting and learning about the new trends, resolving the uncertainty before investing in the new technology (Lipsett, 2021). In this scenario, before making a strategic decision to choose a real option, the company decides to wait another 2 years to invest in the new technology. When the company decides to wait to invest in new technology, the current aircraft would have to undergo minimum maintenance tasks to ensure its safety and usage for the next 2 years. As mentioned earlier, this scenario analysis is performed assuming that the industries follow condition-based maintenance. Therefore, the proper functioning of the aging aircraft will be monitored regularly. Many factors are driving this decision, the most important of them is the cost of maintenance tasks and the residual value of the airplane. In this study, it is assumed that the aging aircraft will be used for the next 2 years with condition-based maintenance while exploring the new technology option. The wait of two years' time is a strategic decision by the company. In a two-year time, companies can explore if there are similar options in the market with improved costs and efficiencies. The costs claimed by their vendor are worth it or there is an option to decrease by market competitions. The certifications, testing, required for the new technology should take the approximate same time.

4.12 Real Options Analysis: Deferral

Assumptions and considerations for ROA

The option to defer making a decision or the timing of an option's investment decision is now explored using the real-option analysis method based on incremental cash flow.

- In the case of an airline, if Check D is not performed and the wait option is considered, then some maintenance cost will be required to use the airplane for the next two years. **The value of maintenance cost is considered as 2 million for the next two years**. The value of 2 million is considered from the range of costs for check D, which varies from 4 million to 6 million as mentioned previously (Ackert, 2010). As Check D is not performed but some maintenance is required to use the aging airplane for the next 2 years, costing 30%-50% of the costs of Check D.

- In the next two years, the number of airplanes considered for investing in new technology may vary. There will be the cost of implementation, training costs, and other operating costs. As there is no exact value of the future opportunity, and it is an investment option, assumptions and estimations are made to perform the analysis. **For this calculation, the estimated cost of new technology is assumed as one million per aircraft**. The assumption of the cost of the new technology in the airline industry is a tricky concept. Large companies invest millions and billions for a new development in the field, which makes it difficult to predict a value per aircraft at a development stage. Market research was performed to study new technological developments in the airline industry. According to the research, concepts like advanced inflight connectivity, facial recognition for biometrics, sustainable fuel, automated assistance, internet of things (IOT), autonomous travel are some of the popular technological trends in airline industry (12 technology trends for airlines and airports to focus in 2020, 2021) (How New Technology Will Impact Airlines in The Next Decade, 2021). From the research, it was found that the International Airlines Group invested $400 million to develop sustainable fuel in the next 20 years (How New Technology Will Impact Airlines in The Next Decade, 2021). In another reference, it was noted that the cost of electric regional aircraft was between $5 million - $10 million (Elizabeth J. Howell Hanano, 2021). Similarly, US based airline, Cape Air has decided to buy all electric passenger plane for $4 million per aircraft (Inside a $4 million electric plane, the first full-size, all electric passenger aircraft in the world, 2021). It was found that the cost to develop a smart integration device from IOT is minimum $50,000 (Mariia Lozhko, 2021), which leads to higher costs in airlines. Another source stated that in the year 2013 a cost of 1.37 million was allocated to test world's first IOT integration at London City Airport (10 stellar real-life examples of loT taking flight in aviation, 2021). Therefore, from various mentioned references, an average cost of new technology was considered as 1 million per aircraft for the analysis.

- The cost to retrofit an existing aircraft depends on the type of changes done in the existing aircraft. According to Peter B. Coddington, (1993), the cost of retrofitting Boeing 727- 200 is 10.1 M where modifications considered were replacing two side engines into one center engine, cutting fuel costs, and increasing flight performance, and some other changes for the cockpit. Also, as per Boeing, retrofitting an aircraft to carry packages instead of people can cost up to 30 M (Boeing Jumbo 747s get Extended Life as Airfreight Haulers, 2021). According to a market survey (Air India's Boeing 777 flies out for retrofit as VVIP plane, 2021) the cost of the retro fitment of a Boeing 777-300 was allocated as 20 M. The aircraft was modified for VIP enclosures, a press conference room, on-board wi-fi, among other applications. In these references, the type of aircraft and the kind of retrofit are different, therefore, the cost to modify/retrofit an aircraft varies on the type of changes executed in the aircraft. **For this study, the cost of retrofit is assumed as 10 M per aircraft**. These costs also include the installation and integration of new technology in the aircraft.

As mentioned above, the cost of new technology is 1 M. **Hence, the value of a total of 11 M is calculated as an assumption for RO analysis.**

- As the technology is new, and there are associated costs and risks, it is strategic to invest only in a few aircraft of the existing fleet. Also, for the company's current operations, most of the fleet should be in use. **For the execution of this analysis, it is considered that the company invests in new technology in 10% of its fleet**. The implementation of 10% of the fleet is a strategic decision as mentioned in the assumptions. An important factor for the implementation is the age and condition of the aircraft. Also, 10% is a small fraction to invest and explore the worth of the new technology.

WestJet's total fleet is 123 planes, which makes 12 planes to retrofit with new technological modification. **Therefore, the total value for real options analysis is considered as 11M * 12 planes= 132 M.**

- For the RO analysis, an important calculation is the value of the multiplication factors u and d. From the binomial lattice approach, the upswing value, u, is always a value above 1, while the downswing value d, is always less than 1. To calculate the values for innovative technology projects for an early stage is challenging and volatile. **Hence, the values of upswing and downswing are considered as u=1.5 and d=0.67.** These values are considered on the basis that the new technology has the potential of generating 50% of the positive values, however, there is always a fraction of associated costs and risks leading to the value of downswing.

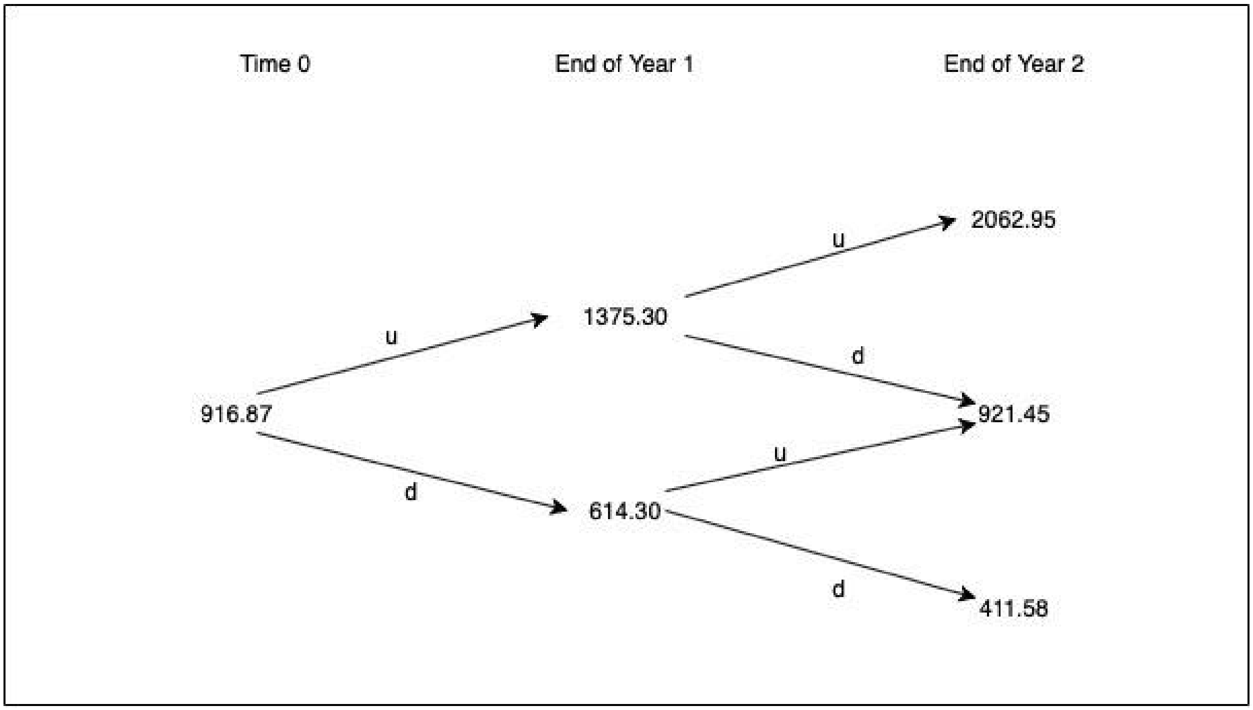
The entire proposition of strategic RO application is to drive the value of new technology/projects with time. As the company decides to wait for 2 years, to invest in new technology, the RO analysis performed on incremental cash flow, considered income for 2 years only (the year 2015 & 2016). The table below shows the incremental cash flow considered for real option valuation.

Table 3: Real Option Valuation of WestJet Airlines

Year		**FV**	**PV**
		(In millions)	**(In millions)**
2014	0	-475	-475
2015	1	569.75	532.47
2016	2	440.1	384.4
2017	3		
2018	4		
		MARR	11%
		WACC	7%

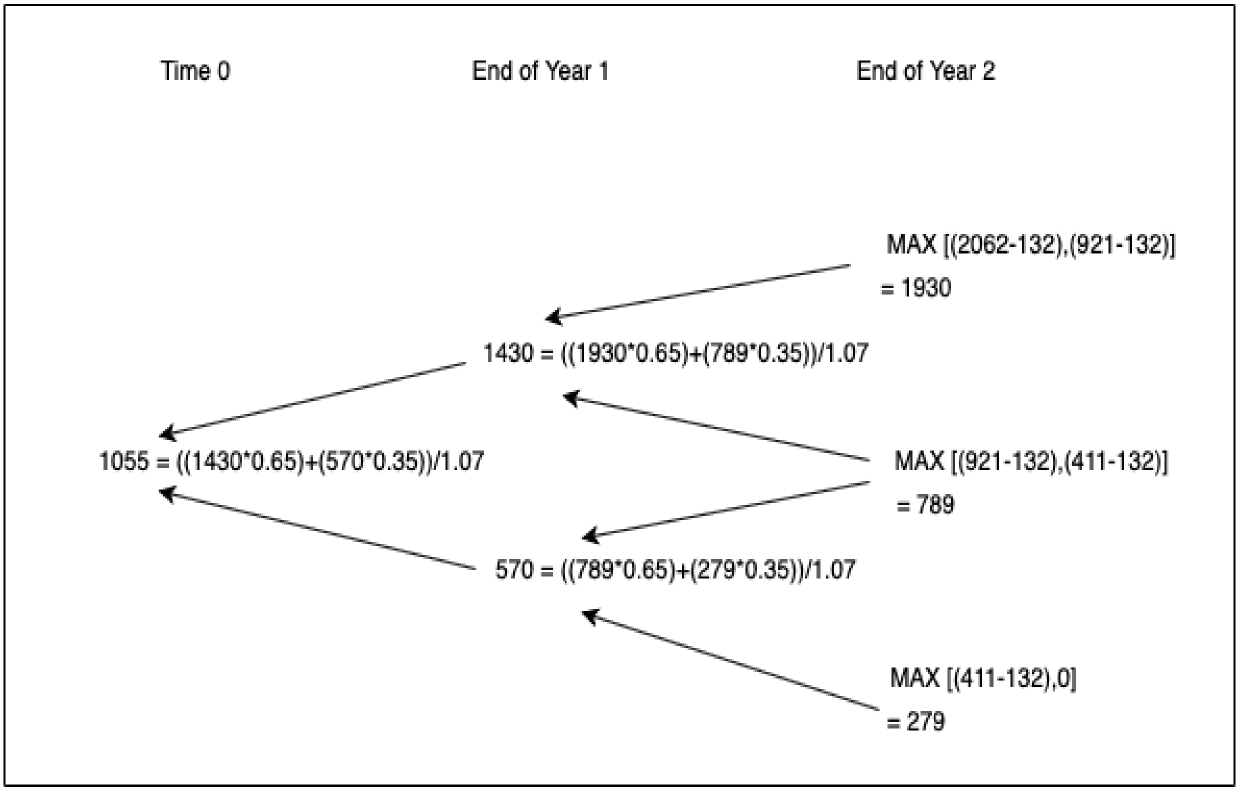
The calculations of the considered real options for the next two years from the incremental cash flow, with the upswing and downswing values, are shown in figure 3.

Figure 3: Real Options Valuation of WestJet Airlines



Value of Income at the end of year 1 and year 2 are positive, which is an indicator of positive investment, leading to "proceed" decisions. But there are associated costs with the investment, therefore, to understand the value of the option exercised, the cost of new technology (132 M) needs to be subtracted from the values at the end of year 1 and year 2 to time zero, and net present value is calculated considering the weighted probability of best-case as 65% and worst case at 35%. The best-case probability is considered as 65% because the new technology with condition-based maintenance will help increase better performance, fuel efficiency, reduced costs, and eventually higher profits. However, Heavy investment in a new technology comes with associated costs, market risks and competition, business conditions. Therefore, it is important to consider both best-case and worst-case scenarios for the RO analysis. The figure below explains the calculation performed to evaluate the exercised real option.

Figure 4: Back Calculation of Real Options of WestJet Airline



In this analysis, prelim investment is not considered because the existing aircraft is retrofitted. However, there were some costs of maintenance as mentioned before, of the amount 2 million. Therefore, the value of the option will be 1055- 2= 1053 million. As we can see from the net present value on the incremental cash flow and real options analysis, following the "timing" option or "deferral" option leads to a positive impact for the company. In other words, investing in the future technology seems a promising option to generate more profits for the company.

For a comparative study on the importance of condition-based maintenance and implementation of real options for future investment options, scenario 4 will be performed on TFI International Inc with similar assumptions and estimations.

4.13 TFI International Inc.

Phase 1: Introduction, Data collection, NPV, Sensitivity Analysis and Tornado Diagram

TFI International Inc. is a Canadian transport and logistics company that operates through four segments across Canada, the United States, and Mexico (TFI International, 2021) (TFI Annual Financial Reports, 2015-2019). Its four segments are package and courier, Less-Than-Truckload, Truckload, and Logistics (TFI International, 2021). It was founded in 1957 as a small trucking company based in Quebec (TFI International, 2021). It was incorporated in 1985 and the name was changed to "Cabano" (TFI International, 2021). In 1992, it was renamed Kingsway and now, it is known as TFI International (since 1999) (TFI International, 2021). The growth of this company is based on the complete acquisitions and management of the small trucking companies, which are further converted as its subsidiaries (TFI International, 2021) (TFI Annual Financial Reports, 2015-2019). For this study, the public financial records of TFI Inc. from the year 2015 to the year 2019 (TFI Annual Financial Reports, 2015-2019) will be studied and used to conduct real options analysis.

The following were the assumptions applied to perform the analysis. Any changes in the assumptions will be mentioned in the specific section of the study. The general assumptions for DCF/NPV are:

1. All the financial data was collected from the public records of TFI Inc. from the year 2015 to 2019 (TFI Annual Financial Reports, 2015-2019).
2. To calculate cash flow statements, the record of revenue and operating income were considered only. All other factors were ignored in the calculation. This was done to simplify the calculations in the work.

3. For the record of revenue, the value considered in the study is the value of revenue with the fuel surcharge from the public financial records of TFI International Inc (TFI Annual Financial Reports, 2015-2019).
4. Operating income considered in the study include the costs of a) material and service expenses, which are composed of the costs of independent contractors and vehicle operation; b) personnel expenses; c) depreciation, amortization of property; d) gain or loss on disposition of property and equipment and assets held for sale; e) other operating expenses, related to costs of office's and terminal's rent, taxes, heating, telecommunications, maintenance and security and other administrative expenses (TFI Annual Financial Reports, 2015-2019).
5. The Year 2015 was taken as year 0 for the calculation of net present value and a cash flow statement of 5 years is formed from the records of the year 2015 to 2019 (TFI Annual Financial Reports, 2015-2019). These records were considered only on the availability of the public records of the company.
6. Weighted average cost of capital was considered as 9% (TFI International WACC, 2021). The estimate of the cost of capital is also used as a discount rate to calculate present values because of various subjective estimates. It is obvious that over the years there have been changes in the value of WACC but to simplify the analysis, a constant value is considered for the analysis.
7. The value of MARR was considered as 12% from the average value of the return of investments for the company for the year 2020 (CSI Market- Transport & Logistics Industry, 2021). No changes in the value of MARR are considered over the years. A constant value of 12% is used throughout the analysis.
8. All other assumptions are the same as the WestJet airlines.

4.14 Base Case DCF

Discounted cash flow is considered as a base case for real options analysis. The real options analysis is carried out using operating income. The calculation assumes there will be no change in the value of WACC or MARR over the years. Any changes in the government or environmental regulations, taxation, fuel costs are ignored in this calculation. One of the major limitations of this study is the limited information. From the TFI Inc. financials, values of revenue and operating income were collected. The details of the maintenance, particulars on the type and number of commercial trucks, the age and the maintenance check performed on the commercial truck, downtime or labor required, the residual value of the truck, costs of the new truck were not collected from the TFI Inc. financials. The table below shows the base case discounted cash flow of TFI International where all the earlier assumptions are applied.

Table 4: Base Case DCF of TFI International

Year		FV	PV
		(In millions)	(In millions)
2015	0	-276.5	-276.5
2016	1	258.3	230.62
2017	2	243.72	194.35
2018	3	430.6	306.69
2019	4	511.66	325.27
		1167.78	780.45
		Income	**NPV**
		MARR	12%
		WACC	9%

Like the WestJet Airlines analysis, to explore the possibilities of net present values, a sensitivity analysis is carried out in the following section. The reality of the future development will vary in costs and implementation and therefore, the value of revenue will be different. The values are assumed to give an outlook on net present values and to execute an acceptable analysis. To perform sensitivity analysis, three conditions were considered. These conditions were analyzed with an upside and downside case. The following are the three conditions:

1. Net Revenue was increased and decreased by 20%.

2. Costs were increased by 40% and decreased by 10%.

3. MARR was increased and decreased by 2%

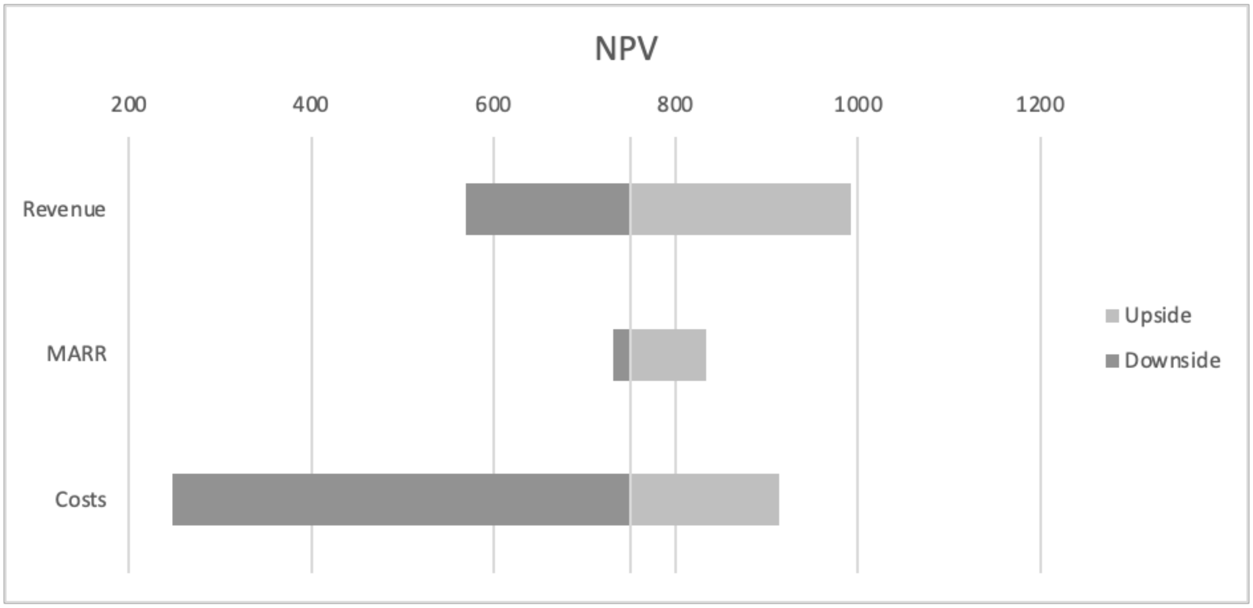
Assumptions of these conditions are considered to perform a sensitivity analysis to provide a viewpoint on real options application. The change in costs was increased by 40% and an upside case of a decrease in costs was considered as 10% only. The change in the value of revenue will also change in the future, therefore an upside and downside case of both 20% was considered. The value of MARR is highly regulated and does not vary to a greater degree in the next few years. Therefore, an increase and decrease of 2% are only considered. A major limitation of this analysis is that range of the values is assumed, there can be errors in assumptions and estimation, and therefore, they may not be accurate. Many parameters are ignored in this calculation, which will affect the analysis. However, the analysis still generates values to provide merit to understand the sensitivities in the values for decision-makers and possibilities under similar conditions.

Table 5: Sensitivity Analysis of TFI International

	Expected NPV			Input		
Variable	**Downside**	**Upside**	**Range**	**Downside**	**Upside**	**Base Case**
Costs	247.07	913.79	666.72	29,927.80	19,239.30	21,377.00
MARR	731.56	832.75	101.19	14%	10%	12%
Revenue	569.06	991.84	422.78	20,788.20	25,407.80	23,098
CF Year 0	-387.1	-248.85	138.25	-387.1	-248.85	-276.5
CF Year 1	138.37	276.75	138.38	154.98	309.96	230.62
CF Year 2	116.61	233.22	116.61	146.23	292.46	194.35
CF Year 3	184.01	368.03	184.02	258.36	516.72	306.69
CF Year 4	195.16	390.33	195.17	306.99	613.99	325.27

The results of the range of NPV from sensitivity analysis of TFI international Inc. are represented in a tornado diagram in figure 5.

Figure 5: Tornado Diagram Range of NPV Results of TFI International



Phase 2: RO problem framing, modelling and analysis, Reporting of the analysis

The maintenance needs of equipment depend on various factors like usage, fuel, environment, etc. and one of the important factors is the age of the vehicle. From all the regulated maintenance checks (Elements of a successful preventive maintenance (PM) program, 2021) (Fleet Maintenance, 2021), Check C and D are most extensive and require more downtime, heavy repairs or replacements, and therefore, extra costs. With technological developments, there might be new maintenance strategies, new and better engines, and equipment that may make the system perform better in the future and require less maintenance. In this study, it is considered that the system has condition-based maintenance, therefore, the safety and performance risk of the truck is monitored, which gives the management a choice to think about new developments. Investing in new technology, buying a newer model of the truck, waiting on a new and developing maintenance method, etc. are some of the strategic decisions that a company should make to have fewer costs and better profits. "Real options with condition-based maintenance", this combination gives the company a possibility to weigh the future options without discontinuing the current operation of the vehicle.

The cost of a new commercial truck varies from $50,000 to $200,000 (How much does it cost to start a Trucking company, 2021). The yearly maintenance and repair costs of a truck are estimated to be $15,000 - $18,000 (What are your Options to Cover the Cost of Semi-Truck Repair, 2021) with an additional cost of annual tire expenses from $4,000 - $6,000 ((What are your Options to Cover the Cost of Semi-Truck Repair, 2021). From the above values, **for the real options analysis, the maintenance cost of a commercial truck annually is considered as $20,000.** Therefore, in five to seven years, the maintenance costs will vary between $100,000 - $140,000. Approximately, a commercial vehicle's fuel costs $70,000 annually (What are your Options to Cover the Cost of Semi-Truck Repair, 2021) , which makes it to $350,000 - $490,000 in five to seven years. The need for maintenance and maintenance costs will increase as the age of the truck increases. Also, the cost of fuel is volatile, therefore, an overall increase in the operating costs of the company will be noted. **Hence, from the above values, only maintenance expenses and fuel expenses cost the company between $450,000 - $630,000**. Other expenses like depreciation, administrative costs, labor, insurance, etc. are not considered in the approximated costs. In five to seven years, there may be newer and better models of the vehicle, or new technological development for better fuel efficiency might be there. Therefore, management should have an option to choose to continue the usage of the vehicle after five years or retire the vehicle and buy/lease a new vehicle or invest in a new technological development. These decisions require huge capital investments and therefore, should be made or revised in advance. For real options analysis, it is considered that the vehicle follows condition-based maintenance. After an approximate **cost of $500,000** from five years of maintenance expenses and fuel expenses, along with condition-based maintenance costs and others, it is proposed that the company decides to **wait for 2 years** to invest in new technological/design development for the commercial vehicle, considering the "timing" option from many real options.

4.15 Real Options Analysis: Deferral

Assumptions and considerations for ROA

The option to wait and defer in making decisions or the "timing" option's investment decision will be further explored by the real options analysis on the incremental cash flow of TFI International. If the wait option is considered, some maintenance costs will be required to use the truck for the next two years.

- **The value of maintenance cost is considered as $20,000 as mentioned previously**.
- **For the analysis, an average value of investment/future technology is considered as $30,000 per vehicle.** This value is assumed from the following references obtained from the market research of the trucking industry. From the market research, it was noted that some of the new trends in the trucking industry (Top 8 Transportation Industry Trends in 2021, 2021) are cloud-based systems adoption, integrated, frictionless travel, self-driving trucks, blockchain in logistics, address delivery, etc. In another reference (New study focuses on timeline and cost of autonomous trucks, 2021), it was found that an extra cost of $23,000 will make trucks capable of driving themselves. Similarly, another reference (The price tag for autonomous trucks still

unclear, 2021) stated that the autonomous vehicle operation will take place in 5 stages where each stage value can vary from $4000 - $7000, leading to total value of operation between $20,000 -$35,000, with an extra cost of $5000 for automatic transmission. Another market source (Cost of TMS Software: Comparing Cloud vs Licensed Models, 2021), stated that the cost of transportation management system can vary between 10,000 to 250,000 for the license, with an initial and annual maintenance fee. The value can change based on demand, supply, competition, socio-economic factors, advanced technological advancements, and many other factors.

- In the next two years, the number of trucks considered for investing in new technology will vary. An important factor is the condition and age of the truck to retrofit with new technology. Similar to the WestJet airlines, **10% of the fleet is considered for the investment of the new technology.** It is a strategic step for the decision-makers as there are risks associated with new opportunities. Investing and implementation of new technology in a small part of the fleet to observe and examine will be a precautionary step for any major losses.
- The cost to retrofit a commercial truck also varies from type, model, age, kind of modification done on the truck. According to (Heavy Truck Engine ECM Programming, 2021), to program electronic control modules on an old truck, the cost can vary from 1,800 to 3,000. Similarly, for a commercial truck, the cost of diesel particulate filter retrofits starts from 18,700 (Congestion Mitigation and Air Quality Improvement (CMAQ) Program, 2021). Lifting a commercial truck to a higher scale costs between 10,000 to 15,000 (How Much Does It Cost To Lift A Truck?, 2021). According to (How Much Does A Class 8 Truck engine Overhaul Cost?, 2021), a certified engine overhaul can cost anywhere between 20,000 to 40,000. Another resource (Semi-Truck Engine Overhauling: What You Need to Know, 2021) from the market study mentioned that engine overhauls

can cost from 26,000 to 53,000. **Therefore, from the above references, an average value of 20,000 is considered as the cost to retrofit a commercial truck.** The cost of implementation and integration of new technology into business operations are also considered as a part of this cost.

Therefore, a total cost of 50,000 (cost to retrofit + cost of new technology) is considered for the analysis. The analysis is applied to 10% of the fleet. According to (Canada's Top 100 truck fleets topped by TFI International, 2021), in the year 2019, TFI had 710 straight trucks. Since TFI International operates into four different segments, the quantities of tractors, trailers are not considered here. **Therefore, the total costs considered is 50, 000 * 71 (10% of 710) = 3,550,000 million.**

- **The values of upswing and downswing are the same from the WestJet Airlines' analysis, which are u=1.5 and d=0.67.** Hence, from the above-mentioned values, real options analysis is performed on the incremental cash flow of TFI International.

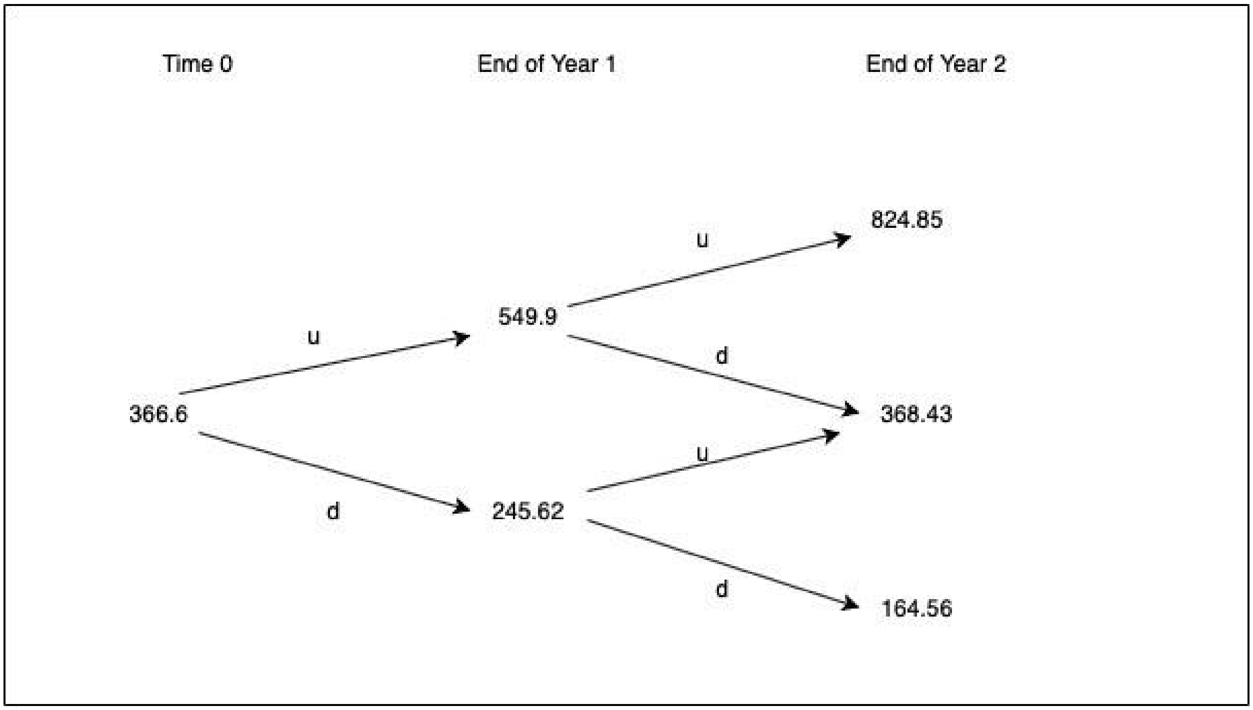
The table below shows the real option valuation of the incremental cash flow of TFI International.

Table 6: Real Option Valuation of TFI International

Year		FV	PV
		(In millions)	(In millions)
2015	0	-276.5	-276.5
2016	1	258.3	236.97
2017	2	243.72	129.63
2018	3		
2019	4		
		MARR	12%
		WACC	9%

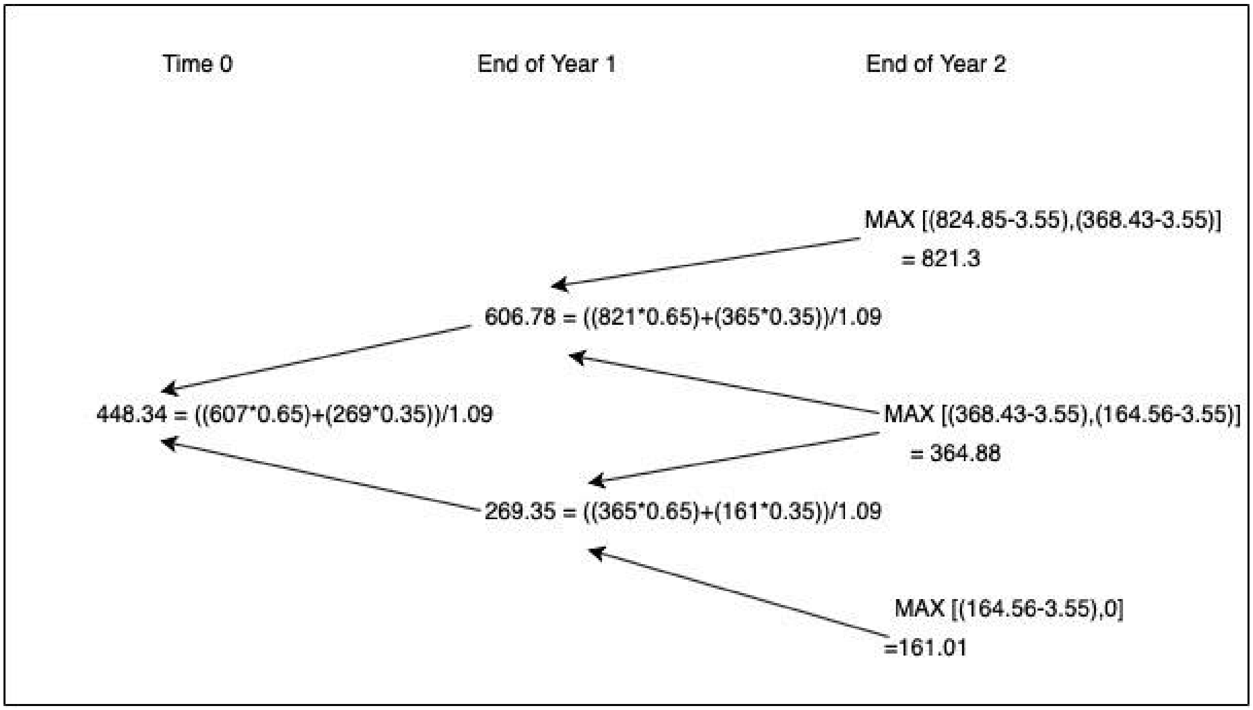
Real option calculations for the next two years for TFI International, from the incremental cash flow, with the upswing and downswing values, are shown below in figure 6.

Figure 6: Real Options Valuation of TFI International



From the above figure, it is stated that the value of Income at the end of year 1 and year 2 are positive, which is an indicator of positive investment, leading to a "proceed" decision. But, for the real option calculation, the investment costs need to be removed to calculate the profit for a company. There a back-calculation is done in figure 7 with the weighted probability of best-case as 65% and worst case as 35%. The reasons for the quantity of the weighted probabilities are the same as for WestJet airlines. As the new technology is believed to have the potential of many advantages for a commercial truck, hence, the probability of the best case is considered greater than the worst case. The figure below explains the calculation performed to evaluate the exercised real option.

Figure 7: Back Calculation of Real Options of TFI International



To exercise the investment option in the future, the cost of current maintenance was assumed to be $20,000 annually as mentioned in previous references. Therefore, a total of 40,000 (for two years) will be subtracted from the real option value. A final value of 447.94 million is obtained from the real options analysis which is positive. Also, from the incremental cash flow and real options results, it is observed that exercising the timing/deferral option will be profitable for the company.

4.16 Discussion of Real Options for CBM Strategy and Possible Limitations

The above-mentioned calculations can be used as an idea to support technological investment decisions that a company decides to make in the future. The cost of the idea of investing in a future technology at an early stage of development does not completely consume decision-makers. A significant analysis with a reference of future advantages and possible challenges and an estimate of finances (numbers) can provide insight to decision-makers to make plans for the company.

A crucial aspect while waiting on new technological development is the present maintenance of the aircraft/truck. Also, with the maintenance, safe working (no fatal risks) and required performance of the aircraft/vehicle is of utmost importance. These parameters are accomplished by the strengths of condition-based maintenance. Condition-based maintenance realistically allows decision-makers to strategically have long-term or short-term plans for the company without expecting an unfavorable or risky situation.

Condition-based maintenance provides a platform to explore the opportunities without committing to the future real options. Real options analysis helps to provide estimations on the future resources and outcomes. A major advantage observed from both WestJet Airlines and TFI International analysis is reduced maintenance costs (as the cost of heavy maintenance checks will be saved). However, there is a small initial cost for the implementation of condition-based maintenance. Another vital advantage observed from this analysis is the positive impact on the income, which is a good/high profit-margin associated with the recommended "timing/deferral" option. Therefore, investing in an advanced future technological option will be viewed optimistically by the decision-makers.

4.17 Limitations of the Work

The proposed framework has limitations because of the various assumptions and estimations for the analysis which undermines the quantitative approach of scenario 4. The reliability and validity of the analysis can be questioned by the decision-makers when there are exact accurate values for the real options analysis. A constant value of MARR and WACC values were assumed in the study, assumptions of the value of future technology, expected maintenance costs, the estimate of an upswing, downswing, probability of success, and failure can be argued for an informed and redefined future goal. Due to limited access to data, many associated factors were ignored from the values considered by both the companies. Taxes and inflation, equity, and financial implications were ignored for the calculations. Industry's market and operating environment were considered constant for future calculations. In all the chapters of the study, it was stressed that scenario analysis and real options analysis provide a viewpoint to decision-makers both qualitatively and quantitatively by evaluating the expected benefits and challenges of the proposed option.

The framework does not replace the essential and regulated maintenance checks but provides an alternative view to reduce maintenance costs. With development and innovation, a different technology in the market may provide a competitive approach for the option analyzed, leading to revisit the option selected by the company. An important factor in the development of new technology is its life cycle. Intellectual property licenses and certifications affect the timeline of the building technology. Technology-life cycle and its effects on the valuation of option is not taken into account in the proposed framework. The degree of the potential profits and costs will have a major influence on decision-makers in the future adoption of the evaluated option. Some companies may have other in-house tools for the evaluation of future options.

Chapter 5 Conclusions and Recommendations for Future Work

5.1 Conclusions

The aim of this study was to provide a strategic path that will allow decision-makers to have the flexibility to minimize the cost of maintenance and invest in a profitable future option for the company. The decision-making framework was developed with condition-based maintenance and real options approach. The proposed pathway in the study acts as a decision tool for the industry and is an effective way to reassess the risks, investments, costs, and assets of the company.

The framework follows the steps of the real options analysis with the traditional valuation methods of discounted cash flow and net present value. A sensitivity analysis is also performed to describe the variability in the net present values with changes in the costs, revenue, and MARR. The study shows the importance of condition-based maintenance in the industry to explore real options. The analysis helps decision-makers to make a decision from multiple choices. The important parameters for the decision-making considered in the study were operating income, revenue, technological development costs, risks, and the age of the asset.

The proposed framework was conducted on two different companies from different industries for a comparative viewpoint. The scenario was analyzed quantitatively by dividing into phase 1 and phase 2 for both companies separately. Phase one gave the details of the industry's maintenance practices with a brief introduction to the company. It was followed by the details of revenue and operating income from the public financial records of the company. The records were obtained from the availability of financial records of the companies to streamline a five-year cash flow. A discounted cash flow and net present value analysis were performed on the data obtained from the financial records along with the necessary assumptions. The results obtained from the net present value were positive. However, to provide flexibility and more information for decision-makers, a sensitivity analysis was performed and represented in a Tornado diagram for both companies. Phase 2 discussed the "option to choose" for the companies to decide to buy/lease a new aircraft/truck, retire an aircraft/truck with a good residual value, perform the heavy maintenance checks or invest in new technology. All these conditions involve huge financial and strategic investments for a company's future. A strategic decision to wait for two years to invest in a future technology that is a "timing/deferral option" was further analyzed with an incremental cash flow for both the companies. The importance of condition-based maintenance and corresponding decision-factors, costs and risks were also analyzed qualitatively for both companies in three different maintenance scenarios as well.

Scenario one analyses the condition when no untimely maintenance is performed. The system follows condition-based maintenance and therefore provides a regulated safe operation of the equipment until it breaks. An important advantage of this scenario is no non-regulated maintenance saves the variable expenses and more availability of the aircraft/truck.

Scenario two identifies situations where an immediate replacement is carried out as opposed to scenario one. The replacement with the new part increases the lifespan of the equipment with a better residual value. However, the replacements can lead to an increase in expenses, with the unavailability of the aircraft/truck for operation.

Scenario three describes the case where an unplanned repair or replacement is performed by counterfeit parts or unverified procedures to make the system available for operation. As the system follows condition-based maintenance, the safety and regular monitoring of the equipment is achieved, however, unplanned, and unexpected repairs or replacements increase downtime, maintenance, and labor costs with an increase in the associated operating costs.

Scenario four explores the "timing/deferral" real option when there are new technological opportunities for a company. Due to limited available information for the case studies. Several estimations and assumptions were made to perform the analysis on the incremental cash flow of the industries. The valuation of the real option was analyzed as a probability of success of 65%. The value of the probability of success was decided on the potential of new technology with improved and better capabilities from the decision-makers' point of view. Finally, a positive value of income was generated from the real option calculation presenting a favorable result to wait to invest in new technology.

In conclusion, the proposed framework in the study expresses the value of flexibility to make a decision with condition-based maintenance to minimize maintenance costs and risks. It also provides a potential to explore real options for a company's future. It gives decision-makers a chance to reassess and estimate future growth options for a company. A comparative outlook to implement real options analysis for future technological advancements enhances the flexibility of decision-making. Therefore, a strategic pathway for maintenance decision-making with prospects of future technology investments is demonstrated in the study.

5.2 Recommendations for Future Work

Many improvements can be made to the limitations discussed in the previous chapter. With more information, the qualitative analysis of the scenarios should be further studied with quantitative analysis for a more refined methodology. With the new developments and innovations, other options to reduce maintenance costs can be explored. The relationship and influence of factors like fuel prices, rate of interest, market competition can be further analyzed for more detailed areas of the research. The effects and risks associated with the company's strategic decision during the wait of two years should be discussed. In this study, the real options analysis is performed only on a small part of the fleet for both the companies, a future implementation on a greater part can be conducted. However, it may require extensive detail on the fleet of the company.

The importance of residual value and its relationship with the future opportunity option could be further examined in detail. The probability of success and its associated factors should be studied in detail and a different magnitude could be considered for a more substantial strategic decision. The method can be further developed and used for accurate analysis with the detailed and precise values of MARR, WACC, fleet, operation costs, maintenance costs, type of maintenance performed, model/type of vehicle. Portfolio management and resource allocation are also steps of the real options analysis which are not conducted in this study. With further information about resources and their management from the companies, these steps can also be explored in future research.

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