DEVELOPMENT OF A LIFECYCLE COSTING MODEL FOR CORRECTIVE MAINTENANCE OPERATIONS AT "ALSTOM KAZAKHSTAN"

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Abstract

This capstone project is performed in partnership with "Alstom Kazakhstan". Alstom is the leading international company operating in rail transport markets. "Alstom Kazakhstan" performs both production and maintenance of locomotives. This capstone project aims to develop life-cycle costing (LCC) model for corrective maintenance of locomotives. This LCC model shall process and combine different input factors, such as the WBS structure of locomotives spare parts, purchase prices of spare parts, relevant labour hours and costs needed for repair and replacement operations, and other data. The LCC model shall calculate specific values and metrics required for budgeting and managerial decision making, such as expected total costs for corrective maintenance, breakdown of costs by category, expected labour hours, and others. The model shall also contain dashboards and visual reports to facilitate managerial decision making.

The company has previously developed an LCC model based on Microsoft Excel, however, this existing model has several drawbacks. In the capstone project, we analyze the existing model, identify areas for improvement, redesign the LCC model concept considering current leading industry practices, and reimplement the LCC model from scratch using Power BI software. We have used Microsoft Power BI software in our technical implementation and its embedded languages, including M (for data processing) and DAX (for business logic and calculations). Furthermore, in our model, we have implemented several key improvements, which were not present in the original (legacy) LCC model from the company: (i) incorporation of concepts of financial modelling, such as time value of money, and (ii) incorporation of inventory management calculations, such as calculation of Economic Order Quantity (EOQ). We have also developed dashboards for the end-users and implemented several additional improvements.

The new LCC model developed in this capstone project offers several advantages for the company, such as: (i) it has better data structure based on the relational data model, (ii) it is more maintainable and updatable, (iii) it is more understandable for the users, (iv) it is more modern (being based on more modern software like Microsoft Power BI), and (v) it has better computational performance. The methodology and toolset used in this capstone project can be relevant for other research problems in engineering and business modelling.

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Table of Contents

List of Tables

List of Figures

List of Appendices

1. Introduction

Structure of the report

The outline of the report is 3-level based content. The structure of the report consists of the following chapters:

Chapter 1 – Introduction:

The report starts with an introduction to the main topic of the work. It discusses life cycle costing models, company description, problem background, description of the existing LCC model developed by the company, and problem formulation. Apart from that, it tells the motivation for the project, challenges, expected outcomes.

Chapter 2 – Literature Review:

The literature review is the part of the report that reflects the application of LCC in spare part management in transportation media, best practices that are implemented in the existing model. Description of models, methodologies, and approaches. Apart from that, the literature review distinguishes between preventive and corrective maintenance.

Chapter 3 – Methodology:

In the methodology section, the report discusses a general approach for developing the LCC model concept, tools, and software used during the work like MS Excel, Power Suite, Power BI. It describes the Power BI modelling.

Chapter 4 – Results:

The principal part of the whole work is in the results section of the report. The results section shows the critical improvements for the existing LCC model like financial modelling and forecasting, inventory management applications, a crucial evaluation of underlying model assumptions. It details how Power Suite and Power BI were used to improve the existing model and technical and operational improvements to the LCC model, such as change management.

Chapter 5 – Discussion:

In the discussion section, the report discusses the advantages and disadvantages of the team's model. Also, it assesses how Alstom Kazakhstan has benefitted from the work that was done by the team and how the developed model can be improved further.

Chapter 6 – Conclusions:

Highlights the summary of the findings and conclusions.

1.1. Life-cycle Costing Models

Lifecycle cost (LCC) analysis integrates cost information from all stages of a product or project, from inception to disposal. LCC is a more comprehensive analysis compared to short- and medium-term financial budgets. Using LCC analysis is justified from the viewpoint of the corporate finance theory. In general, companies should aim to maximise shareholder wealth related to the company's long-term performance rather than short-term profitability. Therefore, it is desirable to have a detailed understanding of factors that influence overall cost over the project's duration, especially strategic decision-making.

Companies use LCC analysis to get a comprehensive analysis of costs, e.g. to include all relevant categories of the expenses into the calculation. In practice, certain charges are omitted or understated in the investigation, which negatively affects managerial decision-making, e.g. companies start projects that should not be undertaken. For example, many subsoil use contracts (such as oil, coal, and other minerals) are often signed with an asset retirement obligation. The company is legally obliged to restore operations to ecologically acceptable condition after completing the work under contract. Such costs are often difficult to estimate because they will be undertaken far in the future, and the exact scope of restoration works is unknown. Such types of expenses are often neglected in the costing analysis and budgeting.

LCC analysis is aimed to eliminate such drawbacks. Companies use LCC analysis for long-term forecasting of project performance, e.g., tracking the current and expected profitability of the project. LCC analysis is also used for managerial decision-making to identify the most optimal alternatives considering total costs.

1.2. Company Description

1.2.1. Brief History and Operations in Kazakhstan

This capstone project focuses on developing an LCC model for Alstom's locomotive maintenance operations in Kazakhstan. Alstom is the leading global company in the railway industry, producing different types of railway equipment. Company headquarters are located in France. The company's subsidiary in Kazakhstan ("Alstom Kazakhstan") is one of the leading producers of locomotives and locomotive equipment on the local market and has more than 800 employees and performs both production and maintenance of locomotives.

The company has worked in Kazakhstan since 2010, and the main office of "Alstom Kazakhstan" is located in Nur-Sultan. It also has an electric locomotive assembly plant and maintenance workshops located next to Nur-Sultan. The main client of "Alstom Kazakhstan" is "Kazakhstan Temir Zholy", the national railway operator in Kazakhstan.

1.2.2. Notes on Confidentiality

Alstom group has strict confidentiality policies and does not disclose business information to third parties. To undertake this capstone project, the student team and the supervisors had to sign non-disclosure agreements (NDAs) with Alstom, stating that any information received from Alstom during this capstone project will not be disclosed to third parties.

Also, in terms of the work and calculations performed during the project, specific confidentiality procedures were followed. The company has provided a draft template of the LCC calculations previously developed as an Excel file. However, the actual data was not provided. Instead, the company has provided a limited number of randomly generated data points as an example calculation. Accordingly, the capstone student team's ability to undertake in-depth business analysis of the project and test the LCC model on actual data was restricted.

Thus, this project was focused more on the software application side and aimed to develop an improved LCC model for Alstom, however, the team did not perform detailed tests of the model on the accurate business data. To assess a model's functionality and performance, the team has used a simulated dataset generated by the students team (details will be discussed in the "Results" section below).

1.3. Problem Background

The company is currently facing challenges in developing a proper lifecycle costing (LCC) model for spare parts for locomotives. An LCC model is a model which integrates data from all product's lifecycle stages coherently and comprehensively and facilitates managerial decision-making.

The current LCC model of the company is reasonably functional and performs its job, but has some drawbacks and limitations, e.g.:

- Simplified concept: not all relevant factors are included,

- Data form of tables is not normal in the sense of database theory: there is data redundancy and problems with data integrity,
- Done using Excel formulae that are difficult to trace (developed over several years) and have computing performance issues,
- Problems with change management,
- No reports/dashboards for end-users.

The problem statement: to improve the LCC model concept and make the model more usable for the end-users. This work will consist of two parts. The first part is the theoretical part on refining and improving the existing LCC model by incorporating additional factors. The second part is the practical part, where a new Excel implementation of the LCC model using the Power Suite of Excel and Power BI software is created.

1.3.1. Description of the Locomotives Maintenance Project

Alstom has an active agreement with "Kazakhstan Temir Zholy" to produce two locomotives: KZ8A and KZ4AT. KZ8A locomotives are aimed at cargo trains, while KZ4AT locomotives – at passenger trains. The contract also includes provisions for the maintenance of both locomotives for 25 years from the production date, i.e. company performs periodic checks of locomotives. Suppose any failures and breakages are responsible for the repair or replacement of the affected parts of the locomotives equipment. The LCC model for this capstone project will be focused on this corrective maintenance scope of the contract. This model will aim to include all the relevant corrective maintenance costs for the whole duration of the contract.

1.3.2. Objectives of the LCC Model at Alstom

The objectives of this LCC model at Alstom are two-fold. Firstly, the company needs cost assessment for short-term budgeting (e.g., providing adequate financial resources for the upcoming quarter or year) and, for the long-term financial evaluation of the project (e.g. to assess current and expected profitability of the project for the whole project duration, and whether it is in line with budgeted profitability). Accordingly, the company needs to make managerial decision-making for short- and long-term financial budgeting.

Secondly, the company needs to know the expected requirements for spare parts for inventory management and maintenance planning, such as knowing how many spare parts of a particular type to order for the upcoming period.

1.3.3. Main Challenges and Proposed Solutions

There were a few challenges encountered during the work, such as:

1. Due to confidentiality requirements, in almost all matters, the company does not provide their actual data related to the LCC model, such as a list of parts, prices, labour hours, reliability rates, etc. Similarly, the team could not request additional information to understand further or get source data to incorporate into the model.

The team was dealing with this limitation as follows: the team have agreed with the company represents that it is possible to obtain additional information in truncated form, i.e. he is willing to provide a format of specific existing source (such as SAP report, Excel table, etc.) with table column names, and several (very few) example rows, however, complete information will not be provided. Such an approach is considered suitable for the work's goal because the work is implemented only on the model concept, structure and calculation formulas. There is no need to see complete information, which is confidential. Such an approach seems reasonable, and the limitation is not expected to impede the work progress.

2. The second challenge is the intricate structure and formulae in the existing Alstom’s LCC model. The Excel tool was developed over several years by several people, and the structure and inner workings are not very organised. There are inconsistent Excel calculations and errors on many occasions, e.g. in some cases, and total amounts do not agree with related category breakdowns. Also, the tool is not documented, i.e. there is no guide or reference for users on how the model works. This all complicates the analysis of the existing model and makes its reperformance in Power Suite quite challenging.

The team dealt with this challenge: the team had quite rigorously traced all formulae in the existing model and understood the model calculation logic. On a few occasions, errors were identified, communicated to the company representative, and corrected in the spreadsheet. In some cases, the team had to address additional questions to the company representative, and he has clarified some unclear moments. Overall, this challenge is also currently almost overcome.

3. The third challenge is organizationally related to the student team, in that team members are located in different cities. Two team members (Iskander and

Shynggyskhan) are located in Astana and can meet the company representative from time to time in person. Also, they can meet in person to work together on the model. However, two other team members are located in different cities (Almaty and Shymkent). Accordingly, they do not have direct access to the company representative because online communication is not as good as in-person communication.

The team dealt with this challenge by sharing information across all team members and having team meetings to discuss the current status and recommendations received from Abzal. The unit does not expect this limitation to impede work progress significantly. However, it does have some negative effect on the efficiency and effectiveness of communication with the company and communication within the team.

1.3.4. Division of Responsibilities across Departments

Several company departments have responsibilities relevant to the LCC model calculation and providing the necessary input information. Mr Abzal Baikenov is the Project Engineering Manager, the primary contact person from the company for this capstone project. He is primarily responsible for performing LCC calculations and maintenance of the LCC model.

Also, the procurement department periodically provides information about the prices of spare parts. The procurement department is responsible for choosing the optimal suppliers for different spare parts and negotiating costs, and in case of any changes, it notifies the Project Engineering Manager.

1.3.5. Users of the LCC Model

Users of the LCC model include the Project Engineering manager and the financial department, who are interested in the forecast information from the model regarding future costs, quantities of spare parts, and expected labour hours. This output information from the LCC model is used in other financial models and budgets of the company. Besides the corrective maintenance project, the company has numerous other projects, and this information needs to be consolidated.

1.4. Description of the Existing LCC Model Developed by the Company

The company has previously developed an LCC model in Microsoft Excel. It has provided this as an example to the students' team to develop an improved LCC model during this capstone project. The existing LCC model in MS Excel has several key input and output variables.

1.4.1. Description of the Main Input and Output Variables

The main input variables that the model takes are:

- List of spare parts – the model has a comprehensive list of spare parts for locomotives, which are in the scope of the maintenance project;
- The corresponding list of prices of spare parts – for each spare part, there is its current purchase price;
- Corresponding labour hours and hourly pay rate information – for each spare part, there is information about how many hours are needed for physical replacement of this part on the locomotive, and also what is the hourly pay rate for the employee(s) responsible for the replacement;
- Corresponding reliability rate – for each spare part, there is information about its reliability rate, namely the company uses a measure known as Mean Distance Between Failures (MDBF), which shows, on average, the expected distance to be travelled by locomotive before the part is expected to break or fail,
- Expected mileage (distance) to be travelled by each locomotive in every period (month).

These are the primary input variables or parameters of the model:

- List of prices
- Part prices
- Labour hours and costs
- Reliability rates, and
- Mileage of locomotives

However, additional minor parameters influence the calculation; they will be discussed in more detail in the section “Results” below.

The existing LCC model of the company takes these input parameters, performs certain calculations using Excel formulas and VBA macros, and outputs several measures:

- The model calculates the expected total maintenance cost, with breakdown by part number and month, i.e., for each given part and month, it is providing the expected monetary forecast of the cost needed for maintenance,

- The model also outputs the expected quantities of the parts to be replaced, also with breakdown by month,
- The model also outputs the expected labour hours needed to replace each part in a given month.

Thus, the main output variables of the model are:

- Monetary forecast of expected recurring maintenance costs.
- Expected quantities of failed parts for each period, and
- Expected labour hours needed for each part for each period.

1.4.2. Description of the Calculation Process

Overall, the provided LCC model estimates the expected number of failures based on the expected mileage of locomotives and the reliability rates of every part (MDBF). Simply put, the expected number of failures is calculated as mileage / MDBF (with certain caveats that will be described in the section “Results”). The number of failures is then combined with:

- information about part prices, to arrive at the expected costs of materials.
- information about labour hours and costs to arrive at the expected costs of labour.

The material costs and the labour costs are the two main categories of expenses that the LCC model estimates.

A detailed description of the calculation process and formulas used in the LCC model will be given in the section “Results” below.

1.4.3. Strengths of the Existing Model

Overall, the existing LCC model of the company, which is based on MS Excel, is adequate and functional. It can combine several types of inputs and calculate the main measures needed for decision-making, forecasting, and budgeting at the company. Our student team considers that the current LCC model of the company has the following strengths:

- Being based on MS Excel, it is understandable and usable by a wide variety of users because MS Excel is a widely known and used software.
- The model has quite a small file size and works reasonably fast (as confirmed with the Company representative). It can do the entire calculation on the real dataset within a few minutes).

1.4.4. Areas for Improvement of the Existing Model

At the same time, the existing LCC model of the company has the following weaknesses or areas for improvement:

- The VBA macros used for calculation are obscure. Their purpose is to copy the needed Excel formulas into different cells and then paste the resulting numbers as values into the same cells (i.e., to replace formulas with values). As explained by the Company representative, this is done to speed up the model performance and decrease the file size. However, this significantly deteriorates the user-friendliness of the model because it becomes impossible to understand how the model values are calculated (in the results, they are displayed simply as “hard” numbers, without formulas, references, or explanation of calculation.
- The formulas used are intricate and not very readable, as they massively use Excel cell references (such as B12, G4:G30, etc.) and do not use named Excel cells and ranges – this also makes the model less user-friendly and understandable.
- Almost all the input data (as described above) is stored in one Excel sheet, which leads to data redundancy and can cause data integrity problems, i.e. the data does not have “normality” in the sense of the database theory;
- Also, because all data is stored together without logical structure or separation, it becomes difficult to maintain the model because the data often need to be updated by different employees, and the file has to be sent by email very frequently, so the users cannot be sure, whether the file they are using is up-to-date or not;
- Overall, the model is not very user-friendly and can be understood well only by employees directly involved. However, the results and logic of calculation are not easily understood by the side users and people who see the model for the first time.

1.4.5. Expected Outcomes

The team is expected to evaluate and refine the existing Company’s LCC model by incorporating features from the up-to-date best practice models for LCC. Specifically, some potential outcomes which will be obtained are:

- To improve, modernise and make more functional the existing Excel application for LCC by
    - Employing the Power suite of Excel (Power Query, Power Pivot, Power View) and Power BI software for automation of data collection and

    - processing using Power Query, development of Data Models using Power Pivot and calculations using DAX language, and presentation using dashboards and reports;
    - Analyzing and improving the existing macros scripts previously developed by the company;
- Implement several improvements to the LCC model:
    - Concepts of financial modellings, such as considering the time value of money;
    - The link to the Inventory Management needs (e.g., safety stock, reorder point, batch size, etc.)
    - EOQ analysis, and accordingly inclusion of the cost of storage and cost of ordering as model parameters;
    - Investigation of procurement strategies;
    - Maintenance planning;
- To implement Information Management functions for the model that are currently missing or not functioning as required by the company:
    - Change tracking mechanism for the reference information used by the model (such as prices of spare parts), i.e. recording who, when and how has changed the information;
    - Assess whether the current change management policy is adequate (currently, one person is responsible for making changes in supporting tables);
    - Improve data consolidation/storage, because currently, different departments have their files with pieces of information from the model;
    - Solve the issue with file versioning, when there are numerous files with different changes made, which need to be manually integrated with the case of discrepancies;
- The examination of the main reliability indices;
- Analysis of the replacement vs repair decision and assumptions;
- Other relevant improvements, taking into account the company's industry best practices and operations.

1.5. Problem Formulation

1.5.1. Company Challenges and Requirements for the New Model

Thus, because of the model weaknesses described above, the existing LCC model in the company has limited usage. Based on the capstone project planning and interviews with the Company representatives, the company requires that the LCC model should be free from such deficiencies and instead have the following characteristics:

- The data structure used by the model should be robust and orderly;
- The LCC model should have improved calculation performance and be able to handle the greater number of input data without computational delays (because the slow performance was one of the reasons for the previous usage of workaround ways, such as VBA macros for updating formulas);
- The LCC model should use novel and up-to-date modelling tools, methodologies and techniques;
- The LCC model should be simple, understandable and robust, e.g. formulas should be understandable and verifiable, there shall be no "cryptic" formulas that nobody understands;
- The LCC model shall allow for different types of input data to be updated by different employees and/or be retrieved from different data sources, rather than be updated manually all in one place.

Hence, considering the requirements set by the company for the updated LCC model that must be developed as the deliverable of this Capstone project, our team has decided that the overall objectives for its conceptual improvement are two-fold.

1.5.2. Objectives for the Conceptual Improvement of the LCC Model

The first part is the theoretical part of assessing the existing LCC model to identify opportunities for improvement based on the up-to-date global best practices in the LCC model development. For example, in this part, the team considered incorporating additional relevant factors into the LCC model, which were not considered previously, such as taking into account the time value of money;

1.5.3. Technical Objectives for the New Implementation

The second part is the practical part, where the team will implement a new version of the LCC model, from scratch, based on the improved tools and methodologies that would satisfy the Company requirements set above. For this part, the team has decided to use the Power Suite of Microsoft Excel and Power BI and re-implement the LCC model using this software. We consider that using this software will allow us to make the LCC model more functional, improve its computational performance, and allow for the future growth (scalability) and future development of the model. This part will be described in detail in the sections “Methodology” and “Results”.

1.5.4. Relevance for Master of Engineering Management (MEM) program

Our student team has used and integrated the majority of skills and knowledge obtained in the Master of Engineering Management (MEM) curriculum when performing this capstone project. Speaking broadly, implementation of the LCC model for Alstom requires both engineering and business understanding, which already justifies the relevance for the MEM program. For example, the team had to understand the work breakdown structure (WBS) of the locomotives maintenance contract from the engineering side, implement and analyze breakdown of locomotives parts into systems and subsystems, and understand technical calculations for the LCC model, such as reliability rates of parts. From the business side, the team had to analyze and implement the relevant financial calculations, such as considering the time value of money and developed business reports (such as Pareto charts) suited for the company's business needs for the purposes of managerial decision making.

In the following Table 1.1, we detail some of the areas of the MEM program relevant for this capstone project.

Table 1. 1 Relevance of project to MEM program

Area/course of MEM program	Relevance for the current project
Big Data and Information Management (course)	Heavily used the technical skills and toolset studied in the course, e.g., development of relational data model, calculations in Power Suite of Excel and Power BI
Project Management (course)	Used the project management skills throughout the project for planning, task allocation and progress tracking
Supply Chain Management (course)	Used the skills and techniques of Supply Chain Management to emphasize relevance and impact of the LCC model on the

	procurement and inventory management decisions, implemented some of the calculations and metrics of SCM, for example, implemented Economic Order Quantity (EOQ) calculation in the LCC model
Finance (course)	Analyzed and evaluated the LCC model from the viewpoint of the finance theory, implemented some of the financial calculations studied in the MEM program, for example, incorporated inflation and time value of money (financial discounting) into the LCC model. Demonstrated how financial calculations are relevant in the engineering costing models, such as LCC models.
Production and Service Operations Management (course)	Considered and implemented in the model different aspects of operations management, for example, considered labour hours and labour costs in the LCC model, emphasized the relevance of the LCC model for human resource planning, recruitment, training (e.g., in the recommendations section).
Business Strategy (course)	Emphasized and implemented calculations and reports relevant for managerial decision-making, such as Pareto charts for cost management and optimization purposes.

Overall, this capstone project has contained sub-problems from different areas of the MEM program, which the student team has identified and solved using the skills and knowledge obtained during our studies.

1.5.5. Motivation for the Project

The motivation for undertaking this capstone project is following:

- There is a clearly defined business problem at Alstom Kazakhstan, i.e. the company has a certain engineering and business modelling problem, which is not currently implemented well in the company. That is, there is a specific need for a new software implementation.
- Alstom Kazakhstan is an established partner of Nazarbayev University and is a leading international company in its industry.
- The expected outcome is likely to be helpful for the company, i.e. it is not purely a theoretical endeavour but a potentially valuable business improvement.

- There are both engineering and business dimensions to the stated problem, as discussed above. This is interesting and appealing to all the student team members, considering diverse backgrounds and future career directions.
- The skillset that needs to be practised and developed during this project is diverse, modern, relevant for the MEM program and the future career development of the student team members.
- The project is doable (in terms of scope and timing), considering the student team composition and available skills.

2. Literature Review

Zoeteman (2001) cites the primary purpose of the structural railway reorganization as upgrading, updating, and modernizing its freight cars, locomotives, and flat cars to enhance resources fortifying economic and financial conditions and augmenting competitiveness in the foreign and domestic economies. Transportation firms focus on conserving the existing and improvement of novel competitive merits, establishing innovation, attaining an optimal mix of quality and price of transport services via the improvement, promotion, and implementation of process and product innovations in the sector. The presence of a comprehensive assessment of design asserts the need to factor the impact derived from all stages and aspects of the life cycle of the object execution, technological, and scientific progress. The latter alleviate the life cycle of different products. High technical complexity and time of system also result in the majority of the above been established by projected production costs parameters at the design phase. Despite its long history, the product life cycle theory lacks a standard methodology for evaluating a product's value. Mainly each administrator establishes a method of calculating LCC. Life cycle cost comprises various methods, categories, different calculation techniques, evaluation types, and factors include. Besides, maintenance indices that impact decision-making also exist, entailing spare parts replacement or repair. In the production and maintenance of electric trains, the life cycle cost model comprises tools that enable Infrastructure Managers to underpin and optimise the budget needs, alleviate required performance level costs, and certify the infrastructure quality in the long run. Overall, the LCC model abounds as relevant in multiple fields as its estimate plays a significant role in determining whether or not to obtain an asset.

This literature review chapter provides an analysis of thirteen researches made by different authors on the topic of life cycle costing and has the subsections as history, methods, performance part costing, categories, analysis types, different calculation methods, discussion and conclusion of literature review.

2.1. History

Lifecycle costing commenced in the United Kingdom in the early 1960s, and up to now, the model has not developed fully. Mainly, LCC abounds as a tool to establish the best cost-effective alternative among varying competing options to own, purchase, maintain, operate, or dispose of. LCC model facilitates determining which of the above competing options features as the best to be adopted on technical grounds. For instance, for a highway pavement, coupled with the one-time construction cost, LCCS factors all the inherent costs such as alleviated capacity at work environments and agency costs associated with prospective activities such as prospective periodic sustenance and rehabilitation. LCC discounts all the costs and rounds them off to a current-day value christened as net present value (NPV). The above example applies to any product, material, or system type. Conducting an LCC model requires considering all the elements necessary to be factored or not. If a scope abounds as too significant, it asserts the tool's bounded nature to facilitate alternatives consideration and decision-making. However, in the instance that a capacity features too tiny, it indicates the skewed nature of the results stemming from the choice aspects considered that contributed to the output becoming more partisan or unreliable. LCCA model depicts the exclusion of environmental costs while LCA and whole-life costing comprises a broader scope such as environmental costs.

2.2. Methods

Tzanakakis (2013) cites that Theodore Levitt played a critical role in founding the product life cycle model in 1965. Currently, no standard methodology for evaluating the value of the product life cycle exists. Shang, Boomen, & Man (2019) and Egamberdiev, Lee, & Lee (1976) aver that a single methodology for assessing the product life cycle lacks since each manager personally establishes the computing LCC techniques. The establishment of a standard computing method engaged multiple scientists such as Rausandu and Kawauchi to develop a model based on five key phases contributing to the theory becoming fundamental to many techniques. People commenced applying the life cycle cost evaluation of industrial products to the rail in the early 20th century. Nissen (2009) considers the product life cycle as comprising of five main stages as per the IEC 60300-3-3, and they include:

- Concept and definition
- Design and development
- Manufacturing and Installation
- Operation and maintenance, and last
- Disposal

Moubray (2001) indicates that LCC theory derives from the summation of various mathematical models utilised to approximate the value of multiple items that cover the total cost of the product LCC entirely.

2.2.1. The Concept Definition and Planning Stage

The primary stage encompasses the initial processes before the development process begins. Moubray (2001) asserts the need to ensure a valid business case for a product and a concrete tactical plan to avail the best chance of survival and success for a start-up. This stage requires market research and competitive evaluation to garner a comprehension of the market and the leading players. The above analysis answers questions such as target audience, need for the product, and the competitors. Besides, the research needs to focus on the production cost and a product's price points. Responding to the above questions informs investors regarding the need for a product and the potential to derive profits from the product. Furch (2016) also cites the need to establish a business case encompassing the writing of a strategic plan and a product roadmap before starting the development process. The above documents focus on the product in the long term based on the premise that the products might shift over time, relying on the competitors, market, and business objectives.

2.2.2. The Developing Phase

This phase entails putting a product in software or hardware and building it. The latter requires breaking down the product into features consisting of user stories and specifications. Galar, Sandborn, & Kumar (2017) asseverate that after establishing a product's characteristics based on user specification and reports, a need arises for ranking the former according to priority and difficulty as it facilitates establishing the features that abound as tricky, time-consuming, and significant to come up with a minimum viable product.

Mokrousov et al. (2013) postulate the need for early feedback to facilitate testing the assumption established during the planning phase. Early testing enables an early product validation or whether the latter requires some tweaking. Leading performance indicators of a product such as revenue, acquisition cost, revenue growth rate, AARRR metrics, acquisition, activation, retention, referral, and revenue avail knowledge concerning product success.

2.2.3. The Launch Stage

The launch phase is the commissioning of an object or a product. The main cost items at this phase are the cost of construction work, the cost of installation work and the cost of commissioning. Basically, these cost items are determined by design project estimates (Kato and Maout, 2016).

2.2.4. Operation and Maintenance

This stage contains cost items that estimate the cost of ownership of the system. This phase is the most expensive and the longest one. Ownership costs are not directly visible and difficult to predict. Cost items of the Operation and Maintenance phase are characterized by their length in time (10–30 years), as a result of which it is necessary to take into account the change in prices for the resources consumed during the operation of facilities due to inflation. However, the costs received at different points in time are not comparable with each other and must necessarily be brought to the initial point in time by discounting. The main items of the cost of this phase are the costs of wages of maintenance personnel, repair costs, electricity costs, depreciation deductions (Kato and Maout, 2016).

2.2.5. Disposal

Kato & Maout (2016) contend that the disposal stage follows the assessment and evaluation of a product and establishes the need for a manufacturer to keep or deal away with some product elements. This phase needs customers' insight and knowledge concerning the features removed or maintained. Iterating and upgrading the supported features ensures the competitiveness of a product. The latter entails commencing the product development cycle once more.

Also, Moubray (2001) indicated that this cost item often neglected due to its insignificance. However, disposed equipment may have some residual value, which can be profitable after disposal.

2.3. Categories

Galar, Sandborn, & Kumar (2017) states that life cycle costs comprise the assumptions and ground rules, cost breakdown structure, work/product breakdown structure, cost categories selection, cost elements selection, cost estimation, and result presentation. LCC abounds as the best technique of establishing cost drivers, permitting comparison of different systems, and convey the necessary information for economic and technical decisions to be made. Both PBS and CBS abound as hierarchical tree structures essential for explaining an LCC model (Galar, Sandborn, & Kumar, 2017). A work breakdown structure plays a critical role in defining the activities vital to the final product.

2.3.1. Ground Rules and Assumptions

Any assumptions made and corresponding rules derive from bounded information indicating the need for limiting them by the constraints, which facilitate estimation. Such restrictions usually follow beliefs that bind the estimate's scope, determining baseline situations that the approximation will derive. Cost analysis needs to select a sequence of statements, which define the conditions the approximation relies upon (Shang, Boomen, & Man, 2019). The arguments abound in the form of ground rules and assumptions. Initial exploration of technical baseline and exploring the ground rules and assumptions facilitate analysts to flush any possible miscomprehensions. Tasks completed during this stage include defining the estimates, establishing the program, and global-specific postulations, such as life cycle and time-phasing. Besides, the above requires selecting any program timetable information by program or phase acquisition tactic, establishing any budget inflation, constraints, and travel costs, specifying the government's equipment, and identifying significant subcontractors and prime contractors. Nissen (2009) indicates that ground rules illustrate a list of agreed standards availing guidance and alleviating conflicts in definitions. Directed conditions become regulations that a team conducts their estimate. Technical baseline prerequisites depict ground rules cost estimates. In the absence of firm ground, analysts establish postulations, which facilitate the estimation to proceed. Postulations stem as necessary in the lack of ground rules as they represent past, present, or prospective judgments advanced as genuine in the absence of an affirmative proof (Moubray, 2001).

2.3.2. The Cost Breakdown Structure

All the costs deriving from every single stage of an asset's LCC are depicted in the cost breakdown structure. The latter's purpose abounds as establishing, defining, and arranging all cost aspects to be factored in an LCC. Cost breakdown structure helps approximate the LCC, as all the costs entailed further breakdown to avail a cost such as labour cost, asset purchase price, or training fees. Cost breakdown comprises four significant cost categories: operating costs, acquisition costs, disposal costs, and maintenance costs. The costs differ depending on the sector where the LCC model features (Kato & Maout, 2016). Acquisition costs abound as the preliminary cost christened as capital cost. People minimise the capital cost to alleviate the total project cost. Operating cost refers to the essential cost for using a system during its practical life. The above associates link to the facility maintenance cost. This category consumes a lot of the total cost. Maintenance cost features are necessary for sustaining an asset or a system during breakdowns (Mokrousov et al., 2013). Two categories of maintenance costs include unscheduled and scheduled maintenance costs. Disposal cost regards the residual value, which also abounds as challenging to establish. The latter abounds as the cost applied in getting or disposing of an asset during its disposal time.

2.3.3. Product Breakdown Structure

The hierarchical structure of things that abound as the outcomes of a project is dealt with in the product breakdown structure. Testing a product breakdown structure for correctness requires the critical review of the PBS ad querying if the PBS contains “work”. Whether all the high-level products broken down comprise sufficient detail level, whether the product identification and sourcing have taken place, and whether all the products abound as couched as outcomes or nouns in the past (Zoeteman, 2001).

2.3.4. Cost Categories

Furch (2016) cites that cost categories facilitate cost definition into a specific group than the CNS code. The most applied cost categories include equipment, labour, materials, and others. Varying cost groups facilitate distinct fields. For instance, labour as a cost category permits the editing of a unit of measure, quantity, labour rate, and production rate. Cost for budget line item comprising cost category equals prediction rate multiplied by amount multiplied by labour rate. Equipment facilitates the editing of the unit rate, quantity, and unit of measure. Materials cost category permits the editing of the division of standard, amount, and unit rate. "Other" abounds as a broad cost group and applies in instances where the costs do not align with equipment, labour, or materials (Furch, 2016). Moubray (2001) indicates that cost elements abound as those elements representing a product's manufacturing cost. The factors include labour, material, and expenses.

The sum cost of a product from beginning to end is a cost estimate. Examples of cost estimates also include the Total Ownership Cost, such as the investment costs, research, development costs, disposal costs, and last, operating and support costs that abound during a product's life cycle. Based on the above, a life cycle cost features the approximated cost of developing, deploying, producing, maintaining, operating, and disposing of a product or system. Milestones present in an estimate include cost estimating categories, work breakdown structure, and cost element structures

LCC formula = C + PV Recurring - PV Residual Value (Mokrousov et al., 2013)

LCC abounds as the life cycle cost, C represents initial construction cost, PV regards the present recurring value of the regular expenses, and PV represents the residual value or the current value and the conclusion of a project.

2.4. Analysis Types

Egamberdiev, Lee, & Lee (2016) cites the presence of four types of assessment in LCC, including scope and goal, overall inventory analysis, effect evaluation, and interpretation. Life cycle evaluation scope and goal definition concern developing a perfect model dealing with simplifications and distortions. Scope and goal abound as the critical choices an individual needs to factor in and describe. The latter also abounds as the primary reason for handling a specific procedure in the first place. Scope and goal definition also facilitates comprehending the general limits of a project. Inventory assessment encompasses considering all the environmental inputs and outputs, which abound as highly linked and related with the product or service applied. The latter includes energy consumption and raw materials, which a firm requires for the production procedure coupled with pollutant emissions and waste streams. This step avails knowledge regarding what takes place with a project and how its environmental impacts. Impact evaluation entails coming up with conclusions, which facilitate the comprehension of the decisions that impact a business. To attain the latter, a firm needs to classify how the procedure affects the environment and assess everything based on significance and what the firm aspires to accomplish in the first LCC phase. Last, the interpretation stage avails the conclusions established throughout the procedure that abound as entirely impacted by the goals and scope outlined in the initial process. Firms need to test whether their findings stem as valid and align with the data utilised throughout the process.

2.5. Different Calculation Methods

LCC abound three significant cost calculation techniques, including the analogous cost technique, parametric cost methods, and the engineering cost method. The identical cost method utilises a similar past project to approximate the cost or duration of the current project explaining the word analogy's origin. Zoeteman (2001) deems the analogous approximation as "top-down" and lacking accuracy compared to other estimating methods. Analogous estimating encompasses the combination of expert judgment and historical content. Parametric estimating derives from establishing the duration unit cost and the number of units necessary for the activity or project. Scalability determines a measurement's accuracy. The engineering cost technique develops the total cost estimate by totalling detailed estimates at lower degrees of the cost breakdown structure. The process encompasses breaking down the system into lower-level aspects, including direct material, direct labour, and other costs.

2.6. Analysis and Summary of Various Literatures

Shang, Boomen, & Man (2019) states that procurement and tenure of sophisticated technical systems, including trains, aircraft, and energy production plants, align with high complexity, substantial investment costs, and actual costs for maintenance and operations over its LCC. The initial decision concerning the ideas, requirements and choice of supplier significantly influences the Total Ownership Cost. Project administrators need to establish the latter findings without the knowledge of the controlling parameters. Kato & Maout (2016) cite the importance of a systematic and efficient decision-making procedure encompassing the application of simulation and modelling tools to evaluate the results of the decisions. Life cycle management abounds as essential to attaining the operational needs at the lowest life cycle cost. One significant factor that influences the decision-making process includes the need. Mokrousov et al. (2013) states the need to weigh the need of a project concerning efficiency. For instance, a company needs to consider the electric train's significance, such as speed and cost-saving.

Egamberdiev, Lee, & Lee (2016) posits that all systems pass through multiple phases beginning with concept definition, specifications, and acquisition, progressing with the system design and development, production, service entry, operations, and maintenance, and last disposal. Managers need to make many decisions regarding the technical system's care, procedures, and logistic support. Consequences of the conclusions arrived at emerge years later. The latter affirms that an individual's potential to influence the total ownership cost alleviates during the system's life cycle. If decisions abound in the later stages of a project without exploring the probable consequences on life cycle cost and operational performance, a business can encounter future cost increases.

Galar, Sandborn, & Kumar (2017) touches on the system's analytical approach to LCM and indicates that it raises questions such as when should a firm replace its fleet of systems, the necessities to be included in a new system, system to purchase, and the investments in logistic aid, spares and other resources to be selected. Besides, the above approach touches on the necessary enhancements that abound as cost-effective to facilitate the enhancement operations. Systecon applies a mixture of tools to evaluate distinct elements of a decision. For instance, the OPUS10 optimisation tool enables identifying the excellent logistic aid solution from a cost-effective viewpoint and fastening the spares assortment. SIMLOX features a simulation essential for validating ability and sustainability to take care of distinct scenarios and dimension personnel, fleet size, and repair requirements. Cost calculation tool CATLOC facilitates LCC comparisons, budgeting, establishing of cost drivers, and cost evaluations. The above tools play a significant role in availing decision aid for each decision type and aids in showing the optimal trade-off between availability and cost.

When working with the LCM evaluation procedure, the firm should define their system and scope, including the immediate decisions and the options available, prerequisites and boundaries for maintenance and operations, describe influencing parameters and establishing their model, acquire input data commencing with the rough data framework, and validating the model, data quality, and enhance data that comprises essential effect on the decision. Besides, a firm needs to conduct evaluations, assess the results, carry out sensitivity evaluations, establish motivators of effectiveness and cost, and, last, iterate to develop the best solution (Curran, Chou, & Trappey, 2008).

Kianian & Kurdve (2019) deems the LCC purpose as aiding higher manufacturing and management personnel with their decisions associated with activities in manufacturing systems such as the decision support system. A need arises for the PPC model to comprise the potential to analyse and define the present manufacturing situation and scheduled decisions. LCC base varies from that of PPC. Despite the premise that LCC endeavours to function as a DSS, it also targets to augment the dynamics of factors including the evaluation of total costs associated with making, buying, or owing, and the disposal of a system or product that abound as essential in both PPC and LCC for maintenance planning. PPC also differs from LCC as it focuses on the current production activities present in the production systems.

In contrast, the latter focuses on two varying vital types associated with timing, including ex-post LCC and ex-ante LCC. The above abounds as a prospective approach grounded in assessments and judgements. The above significantly features in the initial decision-making stages, such as the planning phase before the acquisition stages. PPC abounds as a modular model comprising the ability to feature in distinct manufacturing contexts that consists of varying process support prices such as quality assurance, IT support, and inbound logistics with the potential to be added on the direct manufacturing costs and their impacts on the sum manufacturing cost can be assessed (Kianian & Kurdve, 2019).

Shang, Boomen, & Man (2019) recommends a company initially consider the decisions that commit most of the prospective life cycle costs. Besides, managers need to decide systematically throughout the entire life cycle to deal with instances of suffering from uncontrollable augmenting costs. The early LCM tasks for adopting in the conceptual stage include defining high degree operational requirements and needs, assessing optional tactics and system ideas and their LCC's outcomes, and defining an LCM tactic. During the acquisition phase, a company should interpret operational needs into balanced specific requirements based on availability, logistic support, maintenance, and LCC. Other significant actions include specifying support tactics and acquisition prerequisites, assessing tenders, and negotiating contract terms. During the development and production stages, managers need to conduct tasks such as verifying requirements, performing trade-off analyses, designing logistic support systems, and optimising the logistic support resources. The above functions abound as essential considering that they guide managers regarding decision points and the necessary tasks.

2.6. Conclusion of Literature Review

In conclusion, the literature review established lifecycle costing as comprising a significant history since its emergence in early 1960. LCC abounds as a tool to develop the best cost-effective alternative among varying competing options to own, purchase, maintain, operate, and dispose of. LCC model facilitates determining which of the above competing options features as the best to be adopted on technical grounds. A product's life cycle consists of five primary stages: design and development, concept and definition, manufacturing and installation, operation and maintenance, and last disposal. Mainly, LCC plays a significant role in influencing a firm's purchases, which is essential to Alstom Company considering its new investment in the Electric Railway industry. It plays an important role in the building industry based on its three main steps, including how it's clearly, structured cost evaluation that facilitates seeing the inherent costs influencing the cumulative cost of ownership, identifying hotspots for enhancement in the baseline design and testing distinct solutions for the present objectives after the main expenditure depict clearly, and establishing options, which facilitate the comparison between benefits and reassign the costs to derive maximum value from the project. Most LCC models employ parametric techniques in the aerospace industry that depend on historical information and associate the cost with attributes such as design parameters mass and the maximum speed. However, the premise that parametric models engineering information does not determine LCC fails to represent the impact of technology on LCC. However, constant research resulted in the emergence of “hybrid” lifecycle costing techniques that usually utilise engineering data to enhance the primary parametric models. Overall, LCC comprises significance if a firm employs it accurately. However, to obtain maximum merits, a firm needs the expertise to foretell the associated expenses related to the product, asset, investment, or project.

3. Methodology

3.1. General Approach for the Development of Life Cycle Costing Model

The first thing that needs to be noted is that there are many approaches to developing life cycle costing. But this work describes the method that is used in NATO. Even though the report discusses the improvement in the life cycle costing model in the railway industry, the approach used in NATO depicts a transparent and structured process that might be useful for any industry.

Before any costing activity is performed, it is sufficient to determine what should be assessed and identify the assessments utilized (e.g., identifying budgets, versions assessments, pricing, etc.). The model which is going to be developed can range from a big turnkey project (e.g., primary capital investment including buildings and infrastructure), a self-contained structure (e.g., separate platforms like an aeroplane, boat or tank), or an application on a global scale (e.g., theatre (s) of action and use). The approach that will be implemented should be adapted to the questions that will be asked, the requirements of cost, and the available data (Methods and models for life cycle costing, 2007).

With some modification (depends on the level of detail), regardless of the project's features, the same basic approach to life cycle costing can be applied to all projects. That approach consists of the following phases that are depicted in the subsequent sections more widely (Methods and models for life cycle costing, 2007):

- Determine the objectives and goals of the project.
- Set the content of the system, the boundary of costing and the hypothesis for the project.
- Elaborate the structure of the life cycle cost framework.
- Set the data and populate the cost framework for the life cycle costing model.

As soon as the project's scope and size have been determined, the general cost estimation method will begin, as seen in Figure 3. 1. Due to the availability of additional data, the definition of the hypotheses, or simply overall refinement. It might be reasonable to carry out multiple iterations after the first collection of results is obtained. The phase ends with the analysis of findings, conclusions, and financial implications. (Methods and models for life cycle costing, 2007).

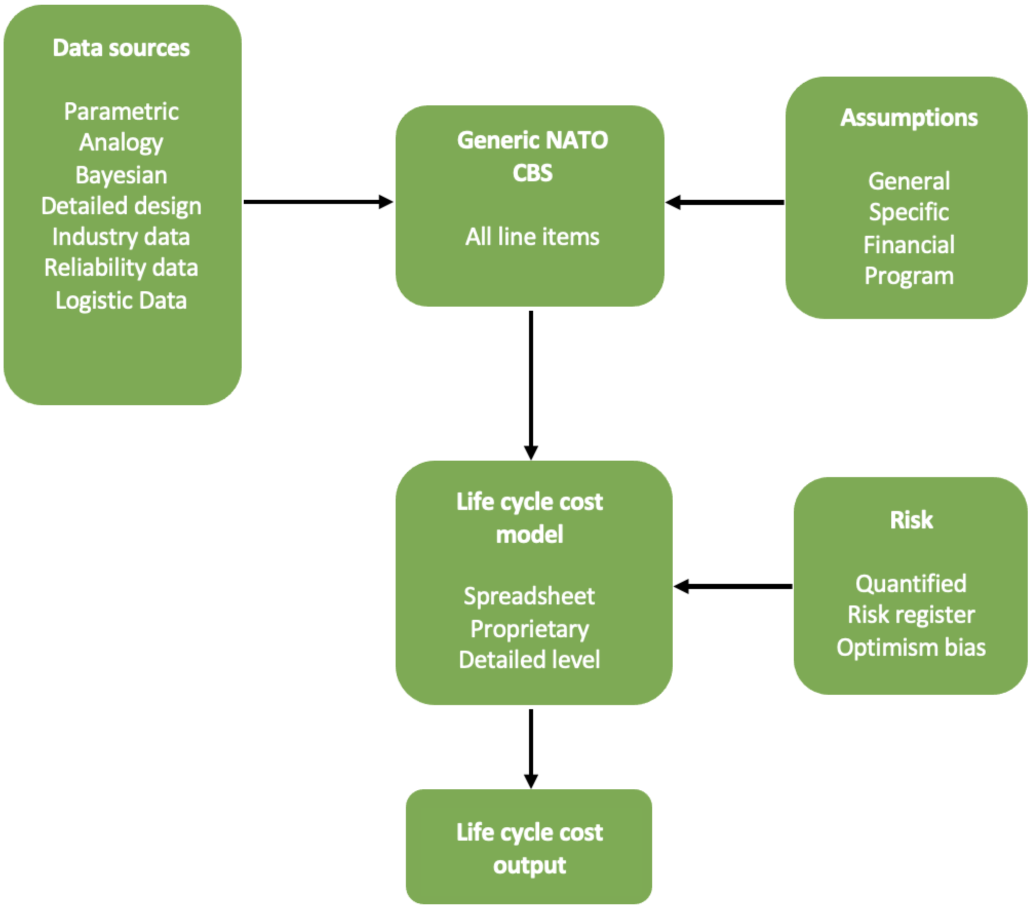


Figure 3. 1 Generic Life Cycle Cost Estimating Process.

3.1.1. Determination of the Goals and Objectives

The goal and the project's targets have a primary influence on the way a project is performed. A wide range of issues can lead to a wide range of approaches to completing the project. It will frequently be hidden in terms of the form project being undertaken, but this has to be evidently and unequivocally determined if the life cycle cost project will give useful and informative results. Beforehand procurement stages will focus on estimating affordability, selection analysis, etc. when the available data that supports the life cycle cost analysis is scattered. This is substantial to carry a few iterations of the process because of the specification of assumptions and overall refinement of the data. This stage would also include determining the models and/or variants to be explored (Methods and models for life cycle costing, 2007).

3.1.2. Setting the Boundary of Costing and Hypothesis

The boundary of costing determines precisely what cost items will be contained in the project and to what extent they will be analysed. Apart from that, the degree of detail of the project depends on external factors such as the maximum length of the project, the financial remedies affordable to perform the project, the accessibility of eligible personnel to execute the project, the accessibility of professionals to give information and the accessibility of data (Methods and models for life cycle costing, 2007).

Three boundaries exist to examine. The first of them refers to the determination of the model itself, specifically the items of cost. This is better to describe the whole system and, after the description, establish an agreement with the stakeholders regarding those items that are out of the framework of the project. A distinct understanding is obtained that helps avoid any misunderstanding during the whole timeline of the project (Methods and models for life cycle costing, 2007).

The second of the boundaries relate to the timescale facets to set what program stages should be included, e.g., staged procurement, staged implementation, additional construction guidelines, in-service date, and the probable suggested model's operational life (Methods and models for life cycle costing, 2007).

The third boundary approval determines what will be embedded within the framework of the project. It can range from the plain cost of buying a spare part of the equipment to the overall cost to the government or industry of mastering, provision, operating, supporting and disposing of a final range of such equipment (Methods and models for life cycle costing, 2007).

The first thing to do to guarantee completeness is that a complete list of all probable cost elements must be composed, which encompasses all stages in the project life cycle. Following that, identified cost elements have to be decreased by eliminating those failing outside the determined cost element boundary (Methods and models for life cycle costing, 2007).

If the aim is to include a forecast of potential cost spending over the program's existence, additional costs such as capability enhancements are included. Each country's requirements determine the price of the final element. Typically, the parties settle on an apportionment based on planned usage, which is then added to the cost estimates for completeness (Methods and models for life cycle costing, 2007).

It is essential to construct a set of statements that specify the conditions under which the estimate will be based before an appraisal is undertaken. When constraints are imposed on the estimator, they become the law by which the measurement is carried out. In the absence of a solid ground rule, the estimator will define assumptions. Since main beliefs and ground rules can have significant cost consequences, it's good to run a sensitivity analysis on them (Methods and models for life cycle costing, 2007).

All details, assumptions and ground rules must be collected and reported for the estimate to have an entire audit trail. The following subsections explain how the United Kingdom and the United States collect and record this information (Methods and models for life cycle costing, 2007).

3.1.3. Elaboration of the Structure of Life Cycle Cost Framework

The criteria for the life cycle cost system will be determined once the costing boundary has been established (e.g., spreadsheet or more sophisticated modelling methods may be used in the implementation). The costing system should account for both the immediate requirements of the current process as well as the evolving needs of subsequent phases (Methods and models for life cycle costing, 2007).

The framework's structure will be determined by the conditions addressed in Subsections 3.1.1 and 3.1.2. Figure 3. 2 depicts a standard outline for a standardised life cycle cost model (Methods and models for life cycle costing, 2007).

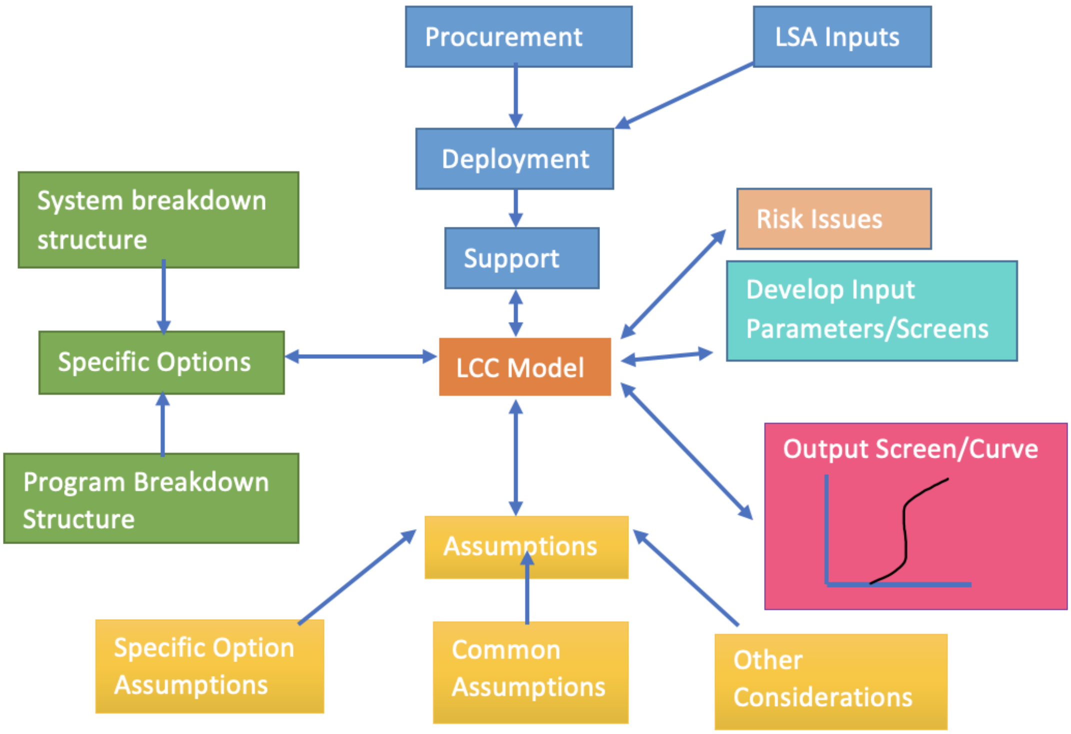


Figure 3. 2 Example of a Typical Life Cycle Cost Framework Structure.

The structure is broken down into many sections in the diagram. The cost breakdown structure representing the system, any particular system choices, and specifics of the program timescale will be left (in green). The software report pertaining to procurement planning, how the device would be used in organisational and peacetime use, and how it would be maintained in these surroundings will be at the top (blue). The LSA (Logistic Support Analysis) and ILS (Integrated Logistic Support) inputs would aid in the interpretation of the suggested implementation. The ground rules and assumptions will be at the bottom (in yellow). These would be written down in a journal, and the material would be used to fill in the blanks in the model where there was no complex data. On the right, risk concerns could be incorporated into the model to achieve a "risk-balanced" cost. It might be advisable to create specific appropriate input and output displays to assist the user in order to prevent an overly complex implementation (Methods and models for life cycle costing, 2007).

To ensure the proper application of the calculations in relation to the input attributes, all life cycle cost models must be thoroughly checked and validated (Methods and models for life cycle costing, 2007).

3.1.4. Setting the Data and Populating the Life Cycle Cost Framework

The cost breakdown mechanism must be filled until the life cycle cost framework structure has been defined. A selection of cost factors may be used in the cost breakdown structure. These expenses would have to be estimated. The data's availability would determine the formula for calculating the approximation (Methods and models for life cycle costing, 2007).

The following are some of the more popular data collection methods (Methods and models for life cycle costing, 2007):

- Survey of the Market

This is typically useful for collecting technological information, but it is constrained in terms of acquiring rates. Any costs obtained would almost certainly have a wide margin of error and little or no support.

- Visit a Factory

This will yield commodity details and statistics, but it is doubtful that the firms will offer anything more than a large order cost with little supporting evidence.

- Inside the Study, Data for Direct Use

These will be real or estimated costs specifically related to the system's failure. Actual equipment acquisition prices, publicly available records for facilities and facilities, and so on could all come under this heading. A significant portion of these expenses may depend on existing data and could be kept by cost accounting agencies or consultancies.

- Analogous Systems Data

This may include low-level, mathematical, and other details about the device in question, which could be used in parametric or other modelling approaches to extract the necessary information. This type of data could include things like size, weight, complexity, and reliability.

- Data Derived from the Logistic Analysis

This will be evidence and knowledge from ILS (Integrated Logistic Support) research on the reliability of components, maintainability, and details on the supply chain. To help life cycle costing, the cost estimator has to be mindful of the following basic ILS facts (considering that some of these would be unavailable in the program's early stages).

An ISP defines the ILS program’s work frame and interfaces for a general defence framework (Integrated Support Plan). It is the most important ILS management strategy.

Certain plans, such as (but not limited to) the following, are applicable to the ILS Program (Methods and models for life cycle costing, 2007):

- LSAP (Logistic Support Analysis Plan).
- Plan for Reliability and Maintainability program.
- LCC (Life Cycle Cost) Plan.
- MANPRINT (Manpower and Personnel Integration) Plan.
- LORA (Level of Repair Analysis) Plan.

The LSA (Logistic Support Analysis) is a continuous iterative analytical procedure that is used to (Methods and models for life cycle costing, 2007):

- Examine the intrinsic supportability properties of a given or presumed configuration.
- Determine the configuration's last support criteria.

It is important to note that the LSA's findings lead to life cycle expense in two ways (Methods and models for life cycle costing, 2007):

1) The operation of the study provides evidence from which life cycle costs can be calculated; and

2) LSA findings lead to life cycle cost reduction by showing the system's support cost drivers and providing input to the ILS design effect.

The life cycle cost assessment (see Figure 3. 3) is based on the life cycle cost modelling effort, which uses the Use Study to determine the full set of operating criteria used to calculate reasonable costs (Methods and models for life cycle costing, 2007).

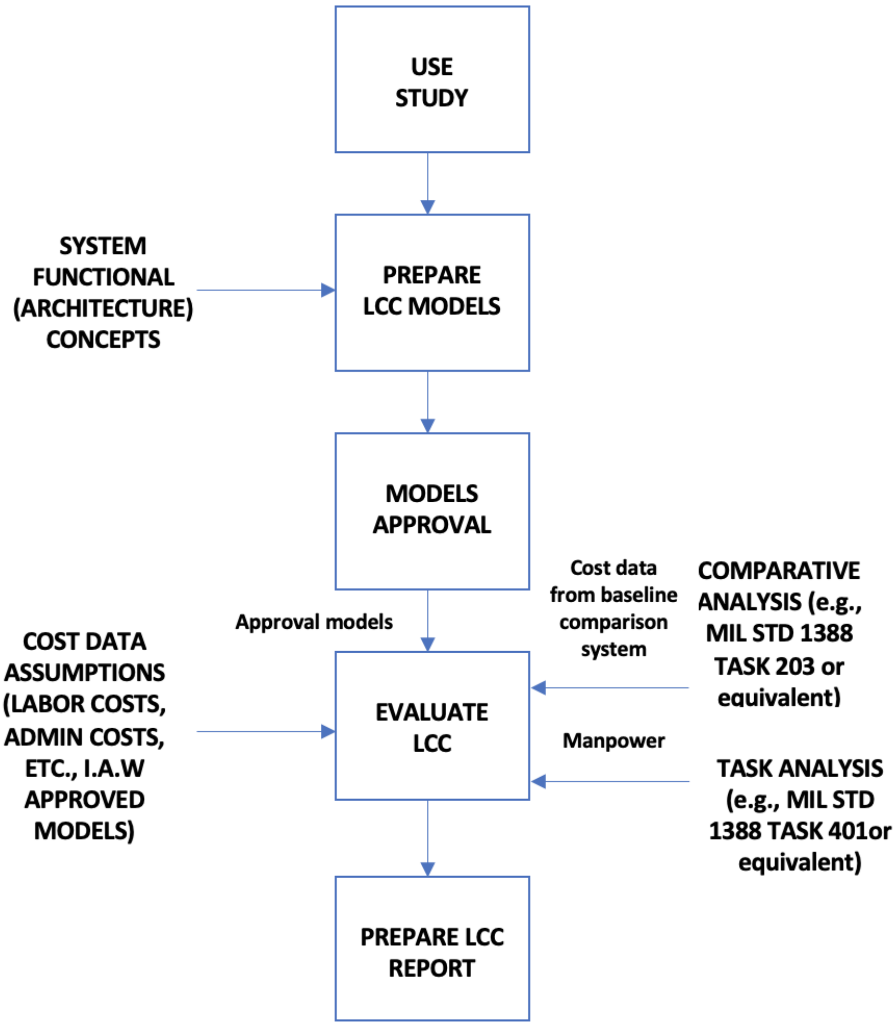


Figure 3. 3 Process Flow for Determining LCC Support to Logistic Analysis.

The completion of LSA Task 203 (Comparative Analysis) and Task 401 will contribute to the life cycle cost analysis (Task Analysis) (Methods and models for life cycle costing, 2007).

The aim of Task 203 is to recognise supportability issues that have arisen through the use of systems that are already in operation using comparative elements, as well as to determine the drivers of supportability, cost, and readiness that must be considered in the comparative device architecture (Methods and models for life cycle costing, 2007).

Task 401's goal is to concentrate on possible essential support items and has an impact on system design to lessen their effect (Methods and models for life cycle costing, 2007).

The LSAR (Logistic Support Analysis Record) is used to monitor and improve logistic support services based on the results of the LSA mission (Methods and models for life cycle costing, 2007).

Early in a program, the LSAR database is developed to catch logistic specifications, define functional logistic breakdown structure, and record the original effects of LSA activities. The LSAR database is used to define the final logistic breakdown structure, monitor the logistic output of the system, and identify the complete logistic breakdown structure before the development process (Methods and models for life cycle costing, 2007).

Determine the operational and maintenance functions, logistic support services, and transportability characteristics. The LSAR archive is used in the development process to update identity data related to configuration modifications, record LSA mission updates, and document the outcomes of technical documentation review (Methods and models for life cycle costing, 2007).

When the in-service process is being implemented, the LSAR database is used to collect R&M (Reliability and Maintainability) data about the system's usage and help, amending logistic data due to configuration modifications, to handle obsolescence, and to assess the impact of any maintenance organisation changes (Methods and models for life cycle costing, 2007).

The knowledge flow from different papers and research are integrated in Figure X to include the life cycle cost to fund logistic analysis studies (Methods and models for life cycle costing, 2007).

3.2. Tools and Software used

As it was mentioned in the preface section, the problem statement of the project is to improve the LCC model concept and to make the model more usable for the end-users. To achieve this objective, the team decided to use the following software and tools:

- MS Excel and VBA
- Power Suite (Power Query, Power Pivot)
- Power BI

3.2.1. MS Excel and VBA

Developing the life cycle costing model is possible in various tools. The life cycle costing model was previously developed by Alstom using Microsoft Excel. The model also used macros (programming scripts) in Visual Basic for Applications (VBA) language.

MS Excel is a spreadsheet application for storing and analyzing numerical and statistical data. This tool is deemed to be one of the popular tools that enable easy and fast use. MS Excel includes a variety of resources for performing tasks such as equations, graphing tools, pivot tables, macros, and more. It works for a variety of operating systems, including Windows, Mac OS, IOS, and Android. An Excel spreadsheet may be perceived as a series of columns and rows that construct a table. Columns are typically assigned alphabetical characters, and rows are typically assigned numbers. A cell is the intersection of two columns and rows. A cell's address is determined by the letter that represents a column and the number that represents a row (Introduction to Microsoft Excel 101: Notes About MS Excel, 2021).

The complex formulas, formatting, various functions, conditioning formatting, and coding in MS Excel and VBA enable creating a functional and informative life cycle costing model.

3.2.2. Power Suite (Power Query, Power Pivot)

Power Suite is the set of add-ons (additional helper modules) for MS Excel to create an informative and functional life cycle costing model. Without them, it would be hard, if not impossible, to develop or improve the life cycle costing model. Among the Microsoft Power Suite plug-ins, the team decided to use Power Query, Power Pivot, and Power BI add-ons. Power BI will be described in 3.2.3. subsection.

Power Query (named Get and Transform Data in earlier versions of Excel) enables to import and connect to external data, and after this change, the shape of that data, e.g., delete a column, modify a data type, or unite tables, in forms that are tailored to your requirements. After that, Query can be loaded into Excel to generate reports and charts. On a regular basis, the data should be updated to keep it in its current state. Power Query has four stages to use (Connect Make connections to data in the cloud, Transform Shape data to meet your needs, data and it., 2021):

- Connect – Link to data in the cloud, on a service, or on a local machine.
- Transform – Form data to be tailored to your requirements while original source intact.
- Combine – Integrate data from a variety of origins in order to provide a new perspective on the data.
- Load – Finish the Query and save it to a worksheet or Data Model, then update it on a regular basis.

Let us take a closer look at each point.

Connect

Power Query may be used for importing to a single data source, like an Excel Workbook, or to various source or cloud services. Web Data, Azure, Databases, files, along with these Excel tables in the present workbook, are all examples of Data Sources. Power Query enables to combine all these data sets, applying any liked style of transformations and variations to find information, probably, would not be possible to notice otherwise (Connect Make connections to data in the cloud, Transform Shape data to meet your needs, data and it., 2021).

As all data are imported, data should be updated in order to all changes are brought from external sources (Connect Make connections to data in the cloud, Transform Shape data to meet your needs, data and it., 2021).

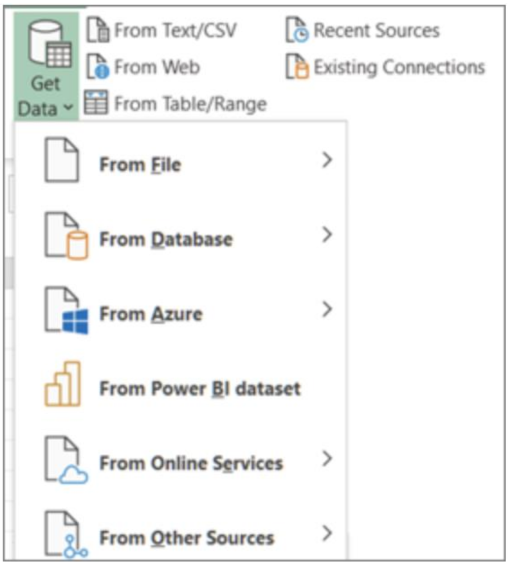


Figure 3. 4 Importing data from external sources.

Transform

To transform data means changing it in order to meet needed requirements. For instance, columns can be deleted, the data type can be modified, or rows may be filtered. These operations are called data transformation (Connect Make connections to data in the cloud, Transform Shape data to meet your needs, data and it., 2021).

It can be explained in this way. A vase is made from a lump of clay that is shaped into a useful and attractive version. Data remains the same. Data must be shaped into a table that meets the requirements and allows for visually appealing presentations and dashboards (Connect Make connections to data in the cloud, Transform Shape data to meet your needs, data and it., 2021).

Power Query utilizes a devoted window named the Power Query Editor to contribute and display data transformations. Power Query Editor can be launched by taking Launch Query Editor from the Get Data command in the Get and Transform Data group, apart from that, it can be launched at the time of connecting to a data source, generate a new query, or load a new query (Connect Make connections to data in the cloud, Transform Shape data to meet your needs, data and it., 2021).

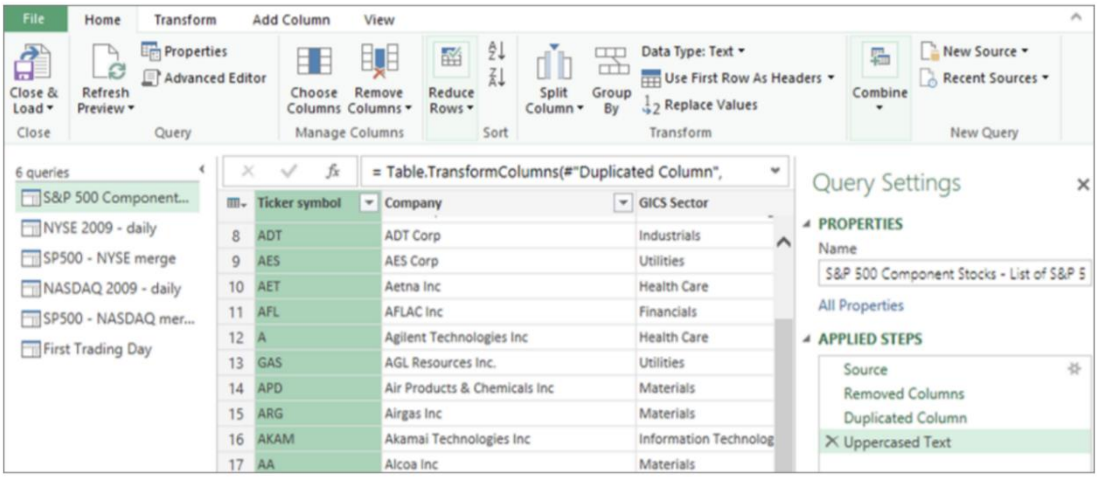


Figure 3. 5 Power Query Editor.

The Power Query Editor traces everything that is happening with data reporting and tagging every transformation or phase that is applied to data. It might be a data connection, a deletion of the column, an integration, or modification of data type, it is possible to look and change every transformation in the Applied Steps section of the Query Settings panel (Connect Make connections to data in the cloud, Transform Shape data to meet your needs, data and it., 2021).

A lot of transformation is available in the user interface. Every transformation is registered as a phase in the context. There is an opportunity to write and change phases utilizing the Power Query M Language in the Advanced Editor (Connect Make connections to data in the cloud, Transform Shape data to meet your needs, data and it., 2021).

Entire transformations of data connections as a group compose a query that is an updated view of the actual (and unmodified) data source. At the time of updating a query, every phase operates by itself. Queries substitute the necessity to manually unite and form data in Excel (Connect Make connections to data in the cloud, Transform Shape data to meet your needs, data and it., 2021).

Combine

There is an opportunity to combine several queries in the Excel workbook by appending or merging them. The append and merge functions can be made within any query with a tabular shape. Also, they are irrespective of the data sources that the data obtained from (Connect Make connections to data in the cloud, Transform Shape data to meet your needs, data and it., 2021).

- Append – This operation generates a new query that keep entire rows of a first query followed by entire rows of a second query. It is possible to make two kinds of append operations (Connect Make connections to data in the cloud, Transform Shape data to meet your needs, data and it., 2021):
    - Intermediate Append – Generates a new query for every append operation.
    - Inline Append – Adds data to the present query before the final result is reached.

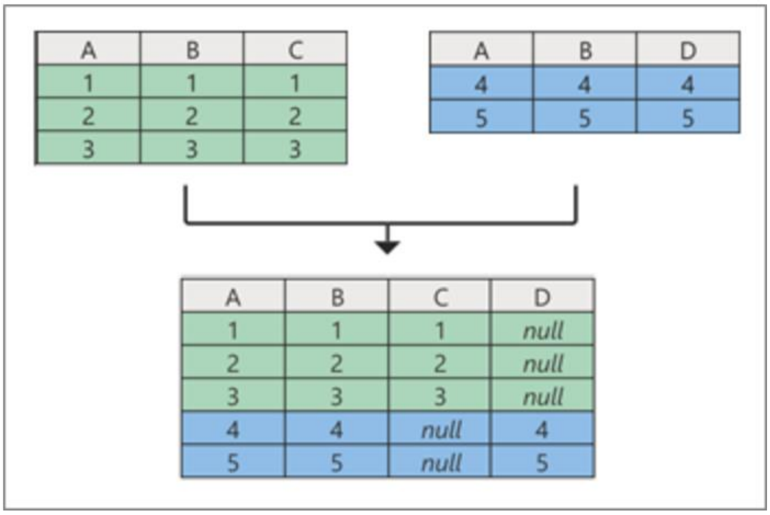


Figure 3. 6 Append Operation.

- Merge - A merge operation generates a new query of two present queries. That one query keeps the entire columns from the main table. One column is serving as a navigation link to a referred table. The referred table keeps entire rows that match every row of a common column value in the main table. Moreover, it is possible to extend or append columns from a referred table into the main table (Connect Make connections to data in the cloud, Transform Shape data to meet your needs, data and it., 2021).

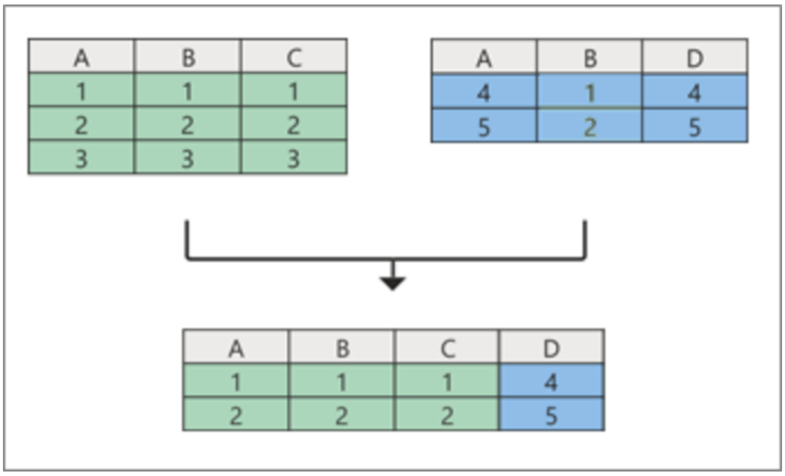


Figure 3. 7 Merge Operation.

Load

Two primary options to load queries into the workbook (Connect Make connections to data in the cloud, Transform Shape data to meet your needs, data and it., 2021):

- Close and Load orders are performed in the Close group within the Home tab. It is loaded from the Power Query Editor.
- Right-click a query and choose Load to from the Excel Workbook Queries panel (Choose Queries and Connections).

Load options can be customized by exploiting the Query Options dialogue box (Choose File – Options and Settings – Query Options) to choose in what way the data is willing to be looked at and where the data is willing to be loaded, in a Worksheet or a Data Model (which is relative data origin of several tables which is located in a workbook) (Connect Make connections to data in the cloud, Transform Shape data to meet your needs, data and it., 2021).

Another add-on is Power Pivot. Power Pivot is a data modelling mechanism that enables to generate data models, set interrelations and generate computations. With this add-on, it is possible to operate with a large set of data, construct comprehensive interrelations and generate complicated (or elementary) computations, everything within the high-performance ambience and everything within the well-known experience of Excel (Power Pivot - Overview and Learning, 2021).

At the time of Power Pivot add-on is turned on, in the ribbon, the Power Pivot tab become accessible. It is shown in Figure 3. 8 (Power Pivot - Overview and Learning, 2021).

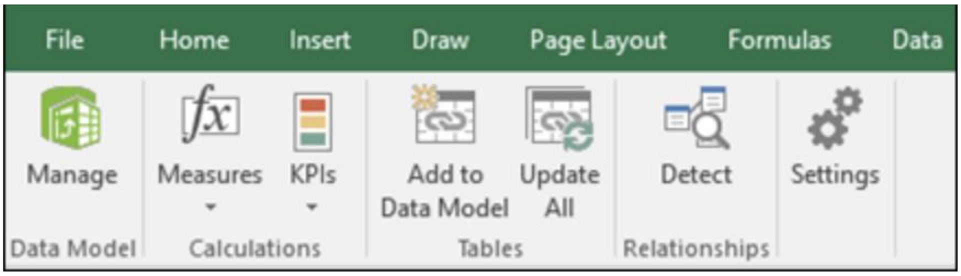


Figure 3. 8 Power Pivot tab.

Using the Power Pivot ribbon tab, choose Manage inside the Data Model section (Power Pivot - Overview and Learning, 2021).

At the time of choosing Manage, the Power Pivot Window shows up. Here, the Data Model may be looked at and managed. Apart from that, it is possible to append computations, set interrelations, and see items of the Power Pivot Data Model. A Data Model is the assemblage of tables or any other data, frequently with established interrelations between them. Figure 3. 9 depicts the Power Pivot Window with a table showed (Power Pivot - Overview and Learning, 2021).

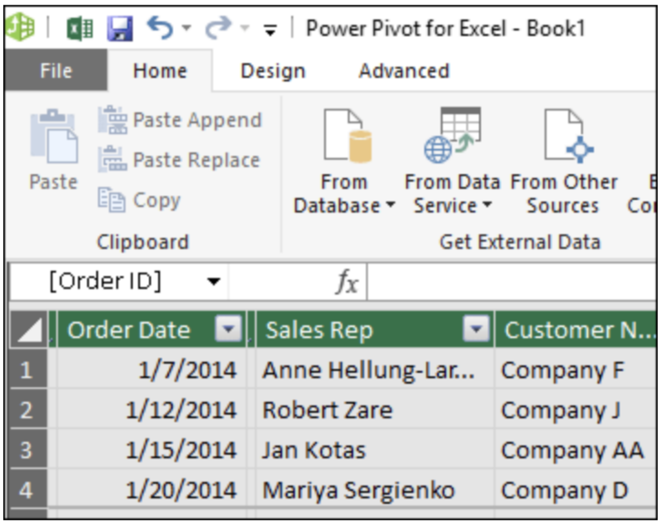


Figure 3. 9 Power Pivot Window.

Also, the Power Pivot Window may be used to create, visualize interrelations between the data within the model. Current interrelations may be seen in the Power Pivot Data Model by clicking the Diagram View Icon, which is on the bottom right side of the Power Pivot Window. The Power Pivot Window in the Diagram View is depicted in Figure 3. 10 (Power Pivot - Overview and Learning, 2021).

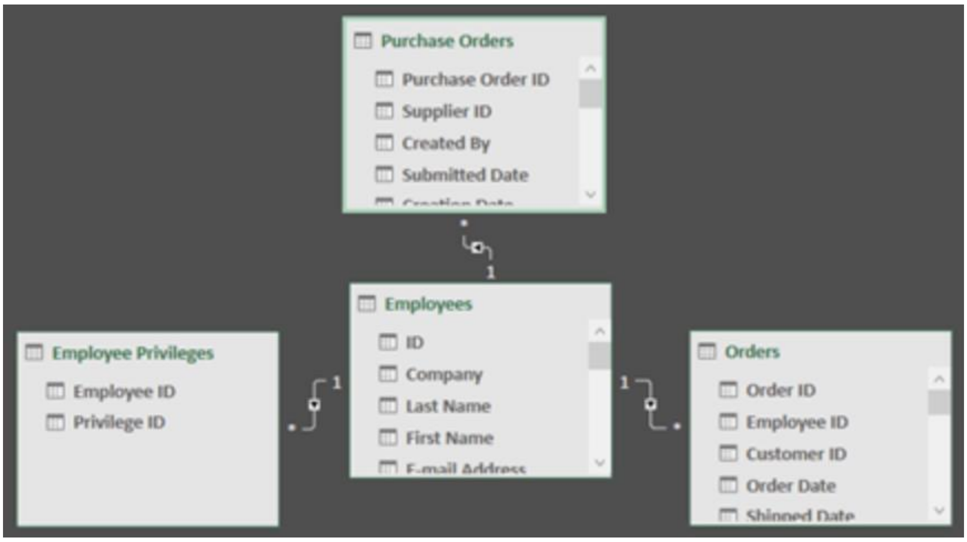


Figure 3. 10 Power Pivot Window in the Diagram View.

3.2.3. Power BI

Power BI is a Business Intelligence and Data Visualization application that transforms data from various sources into dynamic dashboards and BI reports. The team aimed to improve the life cycle costing model in the way of functionality and adding a variety of factors that help better identify costs of the spare parts and understandable and pictorial form.

The life cycle costing model considers thousands of data and should be packaged in a well-visualized form that the end-user could understand the data and use them when needed. Since deliverables of the work should be concise and clear, visualization graphs have been generated using Power BI. It helps to see the overall picture of the model and helps the decision-making process.

The tool is considered one of the tops among data analytics tools. It has many advantages for managing the data and presents them appealingly and clearly. Here are a couple of Microsoft Power BI's most valuable capabilities:

- Easily integrates with current applications:
  Power BI blends seamlessly into the current market environment, helping you to implement analytics and reporting quickly.
- Dashboards with a lot of customization:
  The knowledge dashboards, which can be personalized to suit the exact needs of any project, are Power BI's crowning quality. To have a cohesive user interface, you can conveniently embed dashboards, and BI reports in the applications.
- Securely publish reports:

The tool allows you to set up automated data refresh and post reports so that all users have access to the most up-to-date information.

- No memory or speed limitations:

  Moving an existing BI infrastructure to a robust cloud environment with Power BI embedded removes memory and speed constraints, allowing data to be retrieved and analyzed quickly.

- There is no need for advanced professional assistance:

  Without the need for advanced technological assistance, Power BI allows for quick inquiry and study. It includes a versatile natural language interface as well as easy-to-use graphical design tools.

- Extracting business intelligence quickly and accurately:

  It aids in transforming the company's data into rich graphics, allowing you to extract business intelligence for better decision-making.

- Simplicity and success in balance:

  Both the in-memory analysis technology and the DAX scripting language are excellent examples of a delicate combination of convenience and accuracy.

- Supports Specialized Data Platforms:

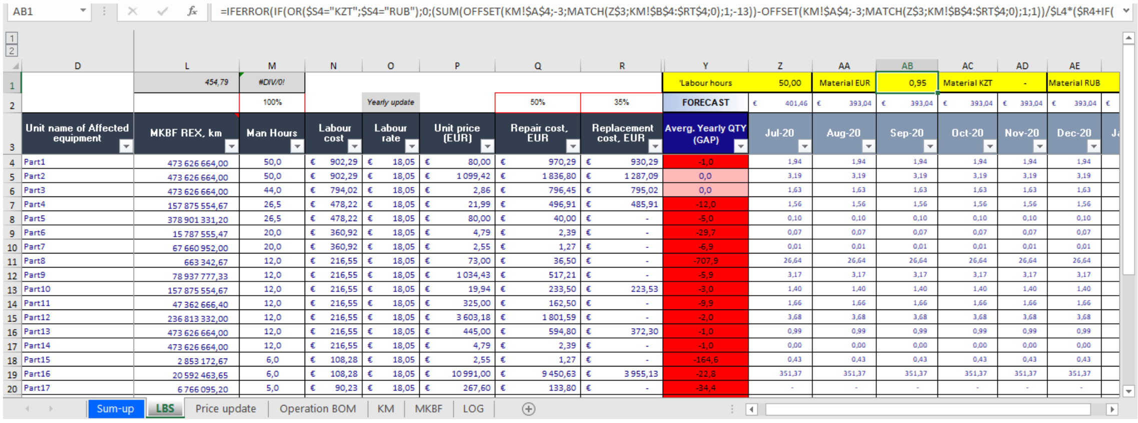
  Microsoft Power BI software teams will assist in the smooth integration of the environment with advanced cloud technologies such as Cognitive resources, Cortana, and the Bot platform. Consequently, results for the verbal data query given in natural language are provided (8 Major benefits of Microsoft Power BI you must know, 2021).

4. Results

4.1. LCC Implementation using Power Suite

4.1.1. Analysis of Existing Model of Alstom

Before the development of a new LCC model by our team, the existing model was critically assessed and analyzed in order to understand the algorithm, identify opportunities for improvement and plan the implementation of a new LCC model. The existing LCC model has been developed very thoroughly by Alstom over several years and uses a Microsoft Excel spreadsheet. The existing model satisfies most of the company needs, however, there are some notable drawbacks that will be discussed later. Below, the snapshot of the existing model is provided as an example, and it is only part of the whole LCC table (Figure 4.1).



	D	L	M	N	O	P	Q	R	Y	Z	AA	AB	AC	AD	AE
1		454,79	#DIV/0!						'Labour hours	50,00	Material EUR	0,95	Material KZT	-	Material RUB
2			100%		Yearly update		50%	35%	FORECAST	€ 401,46	€ 393,04	€ 393,04	€ 393,04	€ 393,04	€ 393,04
3	Unit name of Affected equipment	MKBF REX, km	Man Hours	Labour cost	Labour rate	Unit price (EUR)	Repair cost, EUR	Replacement cost, EUR	Averg. Yearly QTY (GAP)	Jul-20	Aug-20	Sep-20	Oct-20	Nov-20	Dec-20
4	Part1	473 626 664,00	50,0	€ 902,29	€ 18,05	€ 80,00	€ 970,29	€ 930,29	-1,0	1,94	1,94	1,94	1,94	1,94	1,94
5	Part2	473 626 664,00	50,0	€ 902,29	€ 18,05	€ 1 099,42	€ 1 836,80	€ 1 287,09	0,0	3,19	3,19	3,19	3,19	3,19	3,19
6	Part3	473 626 664,00	44,0	€ 794,02	€ 18,05	€ 2,86	€ 796,45	€ 795,02	0,0	1,63	1,63	1,63	1,63	1,63	1,63
7	Part4	157 875 554,67	26,5	€ 478,22	€ 18,05	€ 21,99	€ 496,91	€ 485,91	-12,0	1,56	1,56	1,56	1,56	1,56	1,56
8	Part5	378 901 331,20	26,5	€ 478,22	€ 18,05	€ 80,00	€ 40,00	€ -	-5,0	0,10	0,10	0,10	0,10	0,10	0,10
9	Part6	15 787 555,47	20,0	€ 360,92	€ 18,05	€ 4,79	€ 2,39	€ -	-29,7	0,07	0,07	0,07	0,07	0,07	0,07
10	Part7	67 660 952,00	20,0	€ 360,92	€ 18,05	€ 2,55	€ 1,27	€ -	-6,9	0,01	0,01	0,01	0,01	0,01	0,01
11	Part8	663 342,67	12,0	€ 216,55	€ 18,05	€ 73,00	€ 36,50	€ -	-707,9	26,64	26,64	26,64	26,64	26,64	26,64
12	Part9	78 937 777,33	12,0	€ 216,55	€ 18,05	€ 1 034,43	€ 517,21	€ -	-5,9	3,17	3,17	3,17	3,17	3,17	3,17
13	Part10	157 875 554,67	12,0	€ 216,55	€ 18,05	€ 19,94	€ 233,50	€ 223,53	-3,0	1,40	1,40	1,40	1,40	1,40	1,40
14	Part11	47 362 666,40	12,0	€ 216,55	€ 18,05	€ 325,00	€ 162,50	€ -	-9,9	1,66	1,66	1,66	1,66	1,66	1,66
15	Part12	236 813 332,00	12,0	€ 216,55	€ 18,05	€ 3 603,18	€ 1 801,59	€ -	-2,0	3,68	3,68	3,68	3,68	3,68	3,68
16	Part13	473 626 664,00	12,0	€ 216,55	€ 18,05	€ 445,00	€ 594,80	€ 372,30	-1,0	0,99	0,99	0,99	0,99	0,99	0,99
17	Part14	473 626 664,00	12,0	€ 216,55	€ 18,05	€ 4,79	€ 2,39	€ -	-1,0	0,00	0,00	0,00	0,00	0,00	0,00
18	Part15	2 853 172,67	6,0	€ 108,28	€ 18,05	€ 2,55	€ 1,27	€ -	-164,6	0,43	0,43	0,43	0,43	0,43	0,43
19	Part16	20 592 463,65	6,0	€ 108,28	€ 18,05	€ 10 991,00	€ 9 450,63	€ 3 955,13	-22,8	351,37	351,37	351,37	351,37	351,37	351,37
20	Part17	6 766 095,20	5,0	€ 90,23	€ 18,05	€ 267,60	€ 133,80	€ -	-34,4	-	-	-	-	-	-

Figure 4. 1 The existing model snapshot

Because of Company confidentiality considerations discussed above, the Company has provided the student team with a generated (random) dataset of 25 spare parts, parameters of which were generated randomly by the Company representative. The real business data on the Company spare parts and their characteristics were not provided. The model formulas were provided with no changes, keeping the overall structure and formulas of the model intact.

The provided Excel model file consists of 4 active sheets: (i) LBS (sheet consisting of main model calculations, where all variable inputs are converted to lifecycle cost per part), (ii) Sum-up (the overall figures of estimated costs of project derived from main model sheet "LBS" with breakdown by cost category), (iii) Price update (prices of parts in three different currencies), (iv) KM (actual and planned kilometres travelled by locomotives per month). The data in sheets "Price update" and "KM" are updated by corresponding departments of Alstom company. The “LBS” sheet has 25 core column headings, where 11 out of 25 are of descriptive nature, filled with text below, and the remaining 14 are of numerical nature consisting of inputs and calculated fields below (Appendix 8.1).

The core columns followed by date headings in months starting from November 2020 till the end of the project lifespan, which is December 2047. In the columns under each month heading, there is a calculated total lifecycle cost per part derived from the “main formula”, which will be explained further. In addition, the cost breakdown by category and labour costs are calculated automatically using the VBA macro (script) that was written by the Company representative to automate the calculation. The main purpose for using VBA macros is to speed up the computational performance of the Excel spreadsheet so that certain LCC calculations would be performed only once (upon the manual run of the macro) and not automatically updated with each change in the values (which was slowing down the calculations). Also, based on the inquiry of the Company representative, the VBA macro is used to decrease the file size because the resulting numbers are inserted into the spreadsheet as values (constants) instead of Excel formulas, which significantly decreases the file size of the spreadsheet. Overall, the use of the VBA macro is not justified, as it was not created to perform certain custom calculations (all calculations even in the VBA macro are performed using standard Excel formulas), but on the other hand, it was only done as a workaround to solve computational performance and file size problems. This already indicates that the structure of the old LCC model is not optimal.

So, it is clear from above that rows are filled by unique parts used in the maintenance process. In addition to the table, there are some figures located out of the table, like “Total mileage”, “assumptive percentages”, “exchange rate” of tenge to euro. These figures are used in intermediate (supportive) calculations.

The existing model has several key input variables: (i) list of spare parts with their attributes, (ii) prices of parts, (iii) labour hours, (iv) reliability rates of spare parts and (v) mileage of locomotives. Parts and prices are periodically updated by the procurement department using email notices to the Company representative. Based on such notices, the Company representative manually updates the corresponding figures in the LCC model. Based on inquiry, this makes the process of input data updates slow, inconvenient and prone to errors.

Furthermore, the spare parts prices differ in currencies, which make the data import a little more complicated. Moreover, the unit price is the most sensitive data, which can have a big impact on the LCC model. Labour hours represent the time duration needed to repair or replace the failed part or parts. This data is estimated by engineers and HR specialists who allocate the hours for certain activities required by failure type. Besides the labour hours, the HR department assigns the labour rates (pay rates), which are periodically changed. The reliability rate, mean kilometres between failures (MKBF), is the result of statistical analysis of historical records used to forecast the need for maintenance session when calculated mean kilometres are travelled by locomotives. The mileage data is acquired from Company's database, which contains the actual and planned kilometres passed by locomotives.

The main outputs of the LCC model are: (i) forecast number of parts breakages for each period, (ii) forecast costs with breakdown by category, (iii) estimated labour hours by period. The cost categories are the cost breakdown elements, such as service costs, material costs and labour costs needed for corrective maintenance for each spare part per month. These outputs are used for decision-making, forecasting, and budgeting at the Company.

The "main formula" (as referred to by the Company in the LCC model) that calculates the total forecast cost for a given part and for a given month is following:

```
=IFERROR(IF($I4="YES";(SUM(OFFSET(KM!$A$4;-
3;MATCH(Z$3;KM!$B$4:$RT$4;0);1;-13))-OFFSET(KM!$A$4;
3;MATCH(Z$3;KM!$B$4:$RT$4;0);1;1))/$L4*($R4);IF($K4="YES";(SUM(O
FFSET(KM!$A$4;-3;MATCH(Z$3;KM!$B$4:$RT$4;0);1;-13))-
OFFSET(KM!$A$4;-
3;MATCH(Z$3;KM!$B$4:$RT$4;0);1;1))/$L4*($Q4+$R4);(SUM(OFFSET(KM!
$A$4;-3;MATCH(Z$3;KM!$B$4:$RT$4;0);1;-13))-OFFSET(KM!$A$4;-
3;MATCH(Z$3;KM!$B$4:$RT$4;0);1;1))/$L4*($R4+$P4)));0)/12
```

The structure of many other formulas in the LCC model, such as formulas for cost categories (material costs, service costs), is very similar to the above formula. It can be noted that such formulas use standard Excel formulas, such as OFFSET, MATCH, which are prone to errors in case the location of input data ranges changes. Also, the formulas use cell references, such as $I4, etc., instead of named ranges and columns, which make the formulas less readable and understandable. We have performed a detailed study of such formulas in order to understand the calculation algorithm and identify the main inputs and outputs of the formulas.

For example, the formula calculating the total cost of the part for July 2020 can be represented using the below flowchart in Figure 4.2.

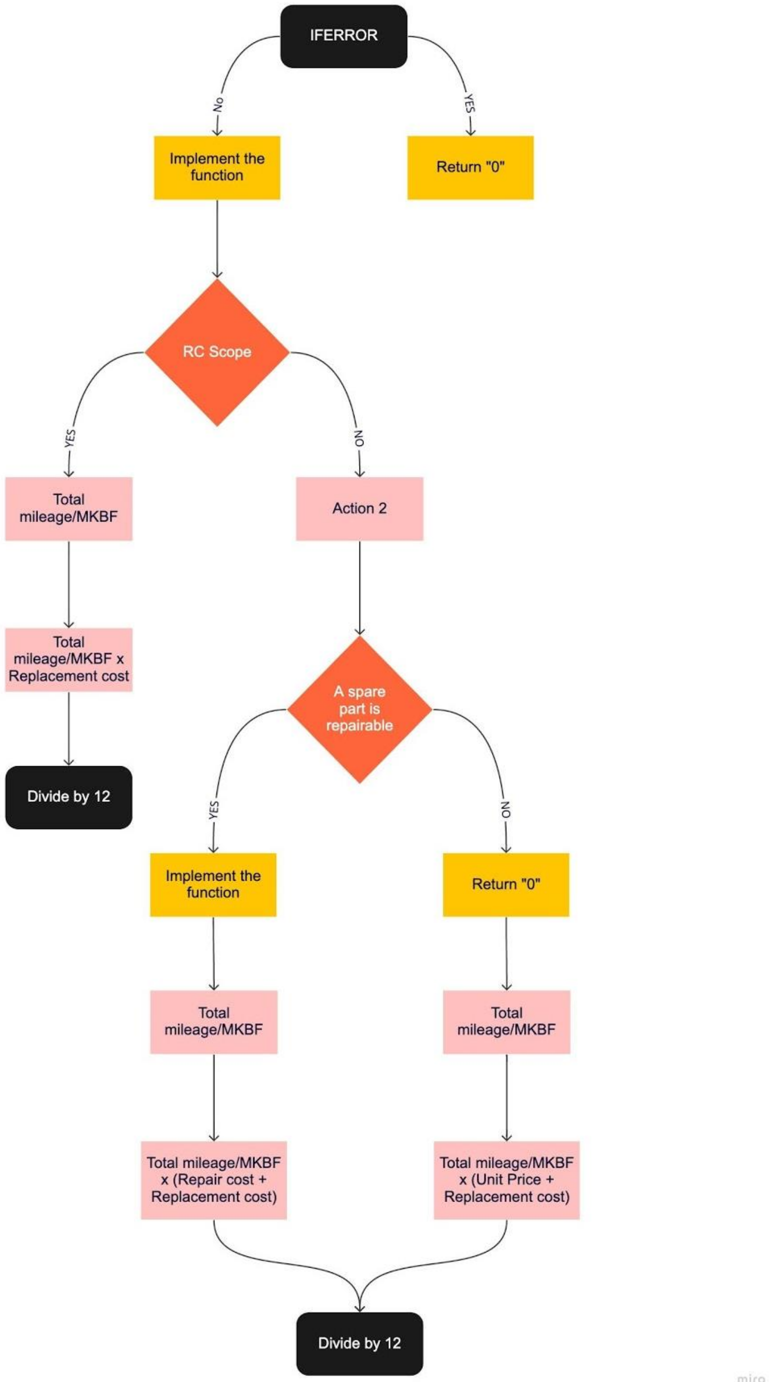


Figure 4. 2 Algorithm of main calculation formula.

1. The first formula used is the "IFERROR" function. This function identifies if there is an error in the calculation of the total forecast cost. In case if there are errors, the formula will return a "0" value, otherwise, it will display the correct value.

2. The second stage in this formula is to use the "IF" function. It says if in the "RC Scope" column the "I4" cell contains the word "Yes", meaning that the Alstom has an agreement with a third party for repairing the spare parts then implement the "SUM" function and subtract "OFFSET" function. This phase calculates the Total mileage for all locomotives for 12 months.

3. "SUM" function contains the "OFFSET" function. Which means that the values that are within the "OFFSET" function should be summed. "OFFSET" function contains the following:

   1. It says to go to the "KM" sheet (this sheet displays the total km per locomotive per month)
   2. Refer to "A4" cell
   3. Catch up the third row "Total mileage" that is above this cell and catch up with a column that should match the "Z3" cell that is in the "LBS" sheet. Height is "1", which means catch only one row and width is "-13" which means catch 13 columns from the right.
   4. What we have done up to this point is we took a sum of the Total Mileage for all locomotives for the previous 13 months.

4. Now, the formula subtracts the total mileage of one redundant (current) month from the previous 13 months by using the "OFFSET" function again in order to get mileage for the previous 12 months, i.e. not taking into account the current month itself.

5. The obtained value is divided by the "L4" cell, which represents the Mean Km Between Failure per part.

6. Following that, the obtained value is multiplied by the "R4" cell, which contains the replacement cost per part.

By now Total cost for a given part is calculated. But this process is implemented only if Alstom has an agreement with a third party for repairing the spare parts.

In case if the Company doesn't have the agreement that is "I4" cell contains the word "No" or whatever that differs from "Yes", then the following part of the formula is implemented:

```
IF($K4="YES";(SUM(OFFSET(KM!$A$4;-
3;MATCH(Z$3;KM!$B$4:$RT$4;0);1;-13))-OFFSET(KM!$A$4;-
3;MATCH(Z$3;KM!$B$4:$RT$4;0);1;1))/$L4*($Q4+$R4);(SUM(OFFSET(KM!
```

```
$A$4;-3;MATCH(Z$3;KM!$B$4:$RT$4;0);1;-13))-OFFSET(KM!$A$4;-
3;MATCH(Z$3;KM!$B$4:$RT$4;0);1;1))/$L4*($R4+$P4))
```

7. It says if the cell "K4" contains the word "Yes", that is, the spare part is repairable, then implement the "SUM" function and subtract the "OFFSET" function.

8. Next steps are identical to the third, fourth, and fifth paragraphs.

9. The obtained value is multiplied by the sum of Repair cost and Replacement cost that are contained in "Q4" and "R4" cells, respectively.

10. In case if "K4" contains the word "No" or whatever that is different from "Yes", then implement the "SUM" function again. Also, these steps are identical to the third, fourth, and fifth paragraphs. The only distinction is that obtained value is multiplied by the sum of Replacement cost and Unit price that are contained in "R4" and "P4" cells, respectively.

11. The final step is the obtained value from the calculation is divided by 12 to get the monthly forecast cost.

Besides the main calculation formula, there are some calculated inputs:

- MKBF - MKBF stands for Mean Km Between Failures. The value depends on whether the Replacement quantity is equal to "0" or not and calculated by the following formula:

  =IF(X4=0;($F$1*J4)/1;($F$1*J4)/X4)

  Where "X4" stands for replacement quantity, it says If there is no replacement quantity, then multiply "F1", that is Total mileage, by "J4", which is Unit quantity per locomotive. Unit quantity per locomotive means how many spare parts are used in one locomotive. The obtained value is divided by 1. If there is a replacement quantity, then the obtained value should be divided by the replacement quantity.

- Repair cost - The repair cost depends on whether a spare part is replaced or not and calculated by the following formula:

  =IF(H4="replacement";0;P4*$Q$2+R4)

It says if “H4”, that is, Activity mode is equal to “replacement”, meaning that a spare part is replaced, then the cost is equal to “0”. If it has an activity meaning that a spare part should be repaired, then multiply the Unit price by “Q2” that represents the 50% (assumed percentage) and add Replacement cost.

- Replacement cost - Replacement cost is calculated by the following formula: =P4*$R$2+N4

Where “P4” is Unit price, “R2” is 35% (assumed percentage), and “N4” is a Labor cost.

In the process of analysis of the existing LCC model, we have also identified some errors, which will be detailed in one of the below sections. We have also identified some of the disadvantages of the existing model:

- Using complicated Excel formulas and cell references often makes it difficult to read, understand, and interpret the formula. The LCC model calculations become not transparent, which makes the model prone to errors.
- Furthermore, the use of VBA macros (detailed above) leads to the fact that certain values in the spreadsheet are kept as fixed numbers instead of formulas, and therefore it is very cumbersome to track the calculation logic, especially for less experienced users.
- The input and output values of the model are not well structured and stored together in one large spreadsheet, such as the “LBS” sheet. This leads to numerous problems of data redundancy and data integrity. For example, many of the identified errors were because not all values in a certain column were considered (only part of the column was referred to in the formula). The calculation approach is very complicated and tends to be easily disrupted upon data manipulation.
- In addition, such a structure makes data updates very difficult because different parts of the spreadsheet need to be updated by different responsible employees. Because of such difficulty, almost all update operations are done manually by the Company representative, which is not very effective and efficient.
- Because of the suboptimal structure of the calculation spreadsheets, there are different problems leading to the slow performance of the model.

The drawbacks identified and summarized above were considered further when developing the new structure for the LCC model.

4.1.2. New Data Model Development

Although the existing LCC model satisfied some of the Company's needs, it fell behind the new era of business tools and was assessed inefficient in terms of use, modification, and analysis. It was not able to meet some of the arising Company's requirements, such as the need to automatically update input data in a structured manner. Consequently, in our project, the existing LCC model based on an Excel spreadsheet was entirely reorganized, implemented from scratch using different software (Power BI) and improved to yield higher efficiency and compatibility. The new model was developed using the integration of Power Query, Power Pivot and Power BI tools. The development of a new model followed the step-by-step implementation of Excel Power Suite (Figure 4.3).

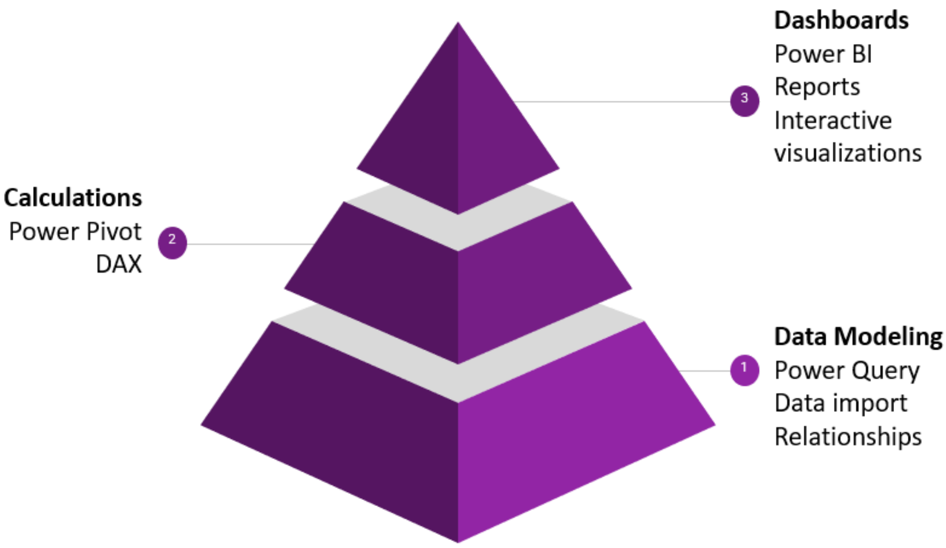


Figure 4. 3 Implementation of Excel Power Suite.

1. In the first step, Power Query and M language were used to create the new data model, analogous to the functioning of a relational database management system (RDMBS). Also, import operations were automated using Power Query in order to facilitate the transition from the old Excel-based spreadsheets to the new LCC model.
2. In the second step, Power Pivot and DAX language were used to create flexible and powerful LCC calculations. Also, several key improvements to the LCC model were implemented in this step.

3. In the third and final step, Power BI Desktop software was integrated into the developed model to provide users with an easy and simple approach to exploring data and different reports with highly interactive visualizations.

After following these three steps, the new LCC model was developed. The new LCC model is a modern business tool that calculates the lifecycle cost of maintenance of locomotives and gives all relevant report figures with highly interactive visualizations.

4.1.3. Data Modelling and Data Import

Development of new Data Model

Data modelling is the first step consisting of structuring the data model and automating data import operations. In order to come up with a suitable data model, a database normalization process was followed. Database normalization includes the reorganization of a data structure according to the so-called normal forms in order to reduce data redundancy and improve data integrity. The Power Query was primarily used in this step. Before processing the existing model to data model, the diagram of a proposed data model (in Appendix 8.2), including new structural composition, relationships and input and output flow, was conceptualized. This diagram is the heart of the implementation process and guidance in building the data model. In the diagram, rows and columns in Excel were transformed into database tables to give the model a dynamic character and to establish relationships and make it behave like a relational database management system (RDBMS).

To establish relationships between the tables, primary and foreign keys were created for lookup operations and to facilitate update with new information and to track changes. During creating the new structural composition of the model, the main large-sized table in the LBS sheet of the existing LCC model was broken into several sub-components representing new data tables. The construction of new tables was like any breakdown structure where the main object is divided into many elements grouped together by dependence relationships. The development of a new model resulted in 15 data and lookup tables, which were connected with each other in a logical way.

Most of the data tables are based on data from the existing LCC model of the company, while some of the following tables were added as part of restructuring and improvement, such as (i) users, (ii) countries, (iii) inflation, (iv) forex rates and (v) inventory management. In the beginning, these additional tables had no operational value before they were connected and calculated by formulas (in the second step).

As depicted in the diagram, the tables were connected by creating relationships in order to combine data on key fields. It was essential to generate consistent relationships between data and lookup tables. In most cases, the one-to-many relationship was used, where there was one data table with unique records (for example, list of spare parts), and one lookup table with multiple items that relate to the main table (for example, spare parts prices that can be updated multiple times on different dates).

After applying the Power Query data modelling based on the developed concept model, the digital form of the drawn data model diagram was created, first in MS Excel. In Appendix 8.3, the diagram view of the newly developed model in Power Pivot is demonstrated. The developed data model was fully structured and connected, considering relationship directions and hierarchies to reflect the multiple levels of granularity.

As a result of the first step, the data model was given a new form and environmental infrastructure and became convenient for storing data in a structured way and implementing the formula and measures to be developed in the following implementation steps.

Data Import operations

In the developed model, some tables were designed and created based on the new structural composition offered by the project team. Other tables consisting of initial input data were imported from the existing model using Power Query. In order to facilitate data transfer from the old MS Excel spreadsheet into the new data structure, numerous data import operations were automated using Power Query and M language.

The data import process for the new data model needed many steps on imported old data from the current data model. Each imported table was preprocessed, and Power Query saved the steps for the automation of loading and shaping new data in the future. The most common operations applied in importing input data from existing data model are: (i) deleting redundant rows and columns, (ii) adding an index and conditional columns (such as Boolean values instead of strings “Yes” and “No”), (iii) renaming columns, (iv) unpivoting operations, and (v) additional formatting of values (such as currencies and percentages formats).

For example, one step used during data import was the Unpivot operation. Unpivoting transforms two-dimensional tables into the plain columnar format. In the old Excel spreadsheet, complicated MATCH and OFFSET formulas were used to extract relevant values from the two-dimensional table, such as the mileage table (where the locomotives list was in rows and months – in columns). On the other hand, using the plain columnar format, where each attribute is stored in columns (in the RDBMS way), allows extracting relevant data effortlessly using simple DAX formulas. In this example, it was needed to unclutter the information in the mileage data table, and unpivoting and other operations transformed the mileage data to a more manageable format.

So, the main objective of data import by Power Query was obtaining a clear and concise set of data for further convenient use, leaving behind the need for repeatable complex query procedures upon loading additional new inputs.

4.1.4. Calculations Using Power Pivot and DAX language

In the second step, formula implementation turned the developed data model into the fully functioning new LCC database model. In the old data model, calculations are written with basic arithmetic and additional Excel functions. As discussed, most formulas in the old model look very complex and cannot be easily interpreted by an inexperienced user. Moreover, any data modification could disrupt the integrity of the model.

Instead of this, in order to develop new LCC calculations, DAX language was used. DAX stands for Data Analysis Expressions; it is a simple and easy to learn language developed by Microsoft to interact with data in their data analysis platforms. DAX because the latter goes beyond the capabilities of traditional grid-style formulas, with powerful functions explicitly built to work with relational data. The DAX calculated fields and measures were primarily applied in calculation data tables, mainly in the lcc_calculation and inventory_management table.

In the lcc_calculation table of the developed model, calculated columns and measures based on DAX were added using intuitive syntax. Below in Table 4.1, all columns of the lcc_calculation table are listed.

Table 4. 1 Calculation elements of lcc_calculation table.

Input columns	Output columns	Assisting columns
kms_prev_year	Total Cost	Latest Reliability Rate Type
Latest Price Per Unit	Material Cost	Forex_Rate
Latest Reliability Rate	Repair/Service Cost	Currency
Latest Labour Cost Per Unit	Labour Cost	
Latest Labour Hours Per Unit	Labour Hours	
Replacement Cost Per Unit		
Repair Cost Per Unit		
Expected Failures Quantity		

To give an illustration of a DAX formula, the calculated column for the total forecast cost for a given part and for a given month is as follows:

```
Total Cost (KZT) = if(RELATED(q_parts[is_outsourced]),
    [Expected failures QTY]*[Replacement Cost Per Unit],
    if(RELATED(q_parts[is_repairable]),
        [Expected failures QTY]*([Repair Cost Per Unit]+[Replacement Cost Per Unit]),
            [Expected failures QTY]*([Replacement Cost Per Unit]+[Latest Price Per Unit])
    )
) / (( ( 1 + [discount_rate] ) ^ ( [n_per]/12 ) ))
```

As can be observed, formulas in DAX language are easy to understand. The calculation above means that:

1. If part repair is outsourced, only replacement cost for all quantities of expected failed parts is calculated.

2. If the part is not outsourced, there comes another condition, which checks if the part is repairable or not.

3. If the part is repairable, the sum of repair and replacement costs for all quantities of expected failed parts is calculated.

4. If the part is not repairable, the sum of replacement and price costs for all quantities of expected failed parts is calculated.

Thus, there is no need for complex formula as it was in Excel since all required for calculation columns are included by the common function “RELATED”, which retrieves data from related lookup tables. Moreover, there is no need for Excel “OFFSET” function to retrieve the mileage and quantity of failed parts for one year period since it is calculated by simpler DAX common expressions, such as “CALCULATE” and “FILTER”, which are included in the calculation of mileage of previous year and expected failure quantity in the following way:

```
kms_prev_year = CALCULATE(sum(q_mileage[mileage_km]),FILTER(q_mileage,and(q_mileage[mon]>=
[start_month],q_mileage[mon]<=[end_month])))
```

```
Expected failures QTY = if([Latest Rel Rate Type]="D", ([kms_prev_year]/[Latest Rel Rate])/12 ,
 (1/[Latest Rel Rate])*COUNTROWS(q_locomotives)*RELATED(q_parts[Unit QTY per Loco]) )
```

For additional reference, common DAX functions that are used and LCC calculations used in the developed model are listed in Appendix 8.4.

4.1.5. Developed Dashboards, Reports, and Visualizations.

In the third and final step, the developed model was fully migrated from MS Excel to the Power BI Desktop software in order to deliver dynamic reports with highly interactive visualizations (Appendix 8.5).

Dashboards are very powerful visualizations of the various type, which turn the numerous data outputs to gathered and digested information for the end-user. Power BI Desktop not only gives good reports and reviews but also makes it easy and simple to create convenient and easy-to-understand reports with interactive features.

First, the project team designed the sum-up report requested by the company in a way analogous to the old MS Excel model. The sum-up report provides the total cost and cost breakdown structure per part, including cost breakdown by currencies. This report can be used as a periodical update document to be shared within the company and to analyses the overall figures, which give quick information to assess the project performance in general and in detail. This sum-up report table is supported with the stacked column chart of total cost breakdown by material and service cost with the project implementation period manipulation slicer.

Secondly, the Economic Order Quantity (EOQ) report table is added to suggest quantity forecasts of spare parts for the use of the procurement department. The procurement department can analyze the results of the EOQ report to adjust their purchase plans and estimate the corresponding budget.

Also, the cost driving parts described by the Waterfall chart and Pareto chart are included in dashboards. The Pareto chart represents the total forecast maintenance cost with breakdown by parts, sorting the costs by part from largest to smallest, and displaying the total cumulative cost for parts. This allows the Company to identify those spare parts which contribute the most to the cumulative maintenance costs and to focus their optimization and procurement efforts on those parts. Such charts can be used for further financial, operational analysis of part prices and for decision-making related to inventory management and procurement.

Thirdly, there is the visualization is an analytical interactive dashboard that allows the user to see the factors affecting the total cost and how different inputs affect the total cost to increase or decrease.

4.1.6. New LCC Model Testing

As discussed above, because of confidentiality reasons, the Company has only provided a limited dataset of 25 generated items in order to demonstrate the calculation logic of the model. This dataset is not sufficient in order to assess the performance of the newly created model based on Power BI.

Based on the inquiry of the Company representative, the real business dataset of the Company consists of slightly less than 1,000 spare parts. For the purposes of testing, information about 2,000 spare parts was generated randomly by the student team. The model's calculation was checked and determined to be reasonably accurate. Computational performance and file size were assessed to be appropriate for the Company business needs. For example, for the generated dataset, full model recalculation together with data import operations took approximately 3 minutes.

4.2. Key Improvements for the LCC model

4.2.1. Financial Modelling and Forecasting

The Company's existing LCC model lacked the time value of money (TVM) in its calculations used. The student team has assessed that it is critical to allows time value of money calculations in the project of such a long duration (25+ years) because incorporation of the time value of money can significantly affect LCC cost estimates and therefore affect the decision making.

The time value of money is the concept that money considered in the current moment in time is worth more than the identical amount in the future due to its potential earning capacity. In other words, this core principle of finance holds that provided money can earn interest, and any amount of money is worth more the sooner it is received. Apparently, for this capstone project, it is highly recommended to include consideration of the time value of money, especially for a company whose project duration is more than 30 years.

The new LCC model developed by the student team implements financial modelling of the LCC from different perspectives. The essence of financial forecasting is the consideration of currency inflation and discount rate to show dynamic financial modelling, therefore inflation and discount rates were added into the LCC model as additional parameters.

Formula 4.1 below describes how the present value can be calculated, considering the time value of money.

$$PV = \frac{FV}{(1+r)^n} \quad (4.1)$$

PV	=	present time value
FV	=	future value
r	=	rate of interest
n	=	number of periods

First, the base year was established for all costs to be discounted back to consider the time value of money. Then, the calculations in the LCC model were adjusted by taking into account forecast inflation and discount rates. In the developed LCC model, also monthly compounding was implemented because the base period of the LCC model is 1 month.

Using the adjustments above is a conceptually required practice in finance. Consequently, the financial report of the LCC model will be more accurate and sensitive in further analysis and decision-making processes.

4.2.2. Inventory Management Applications

The part price and its quantity used per locomotive maintenance session are core figures in the existing LCC model which can be used as input data for a further application like inventory management. The old model based on MS Excel did not consider any inventory management applications.

In the developed LCC model, calculation of the economic order quantity (EOQ) was incorporated. EOQ is the concept from inventory management and is such ordering quantity, which minimizes the total holding costs and ordering costs. The newly developed model is provided with EOQ calculation for each part over the whole project duration. The estimation Formula 4.2 is:

$$EOQ = \sqrt{\frac{2 \times D \times S}{H}} \quad (4.2)$$

D	=	Annual demand (units)
S	=	Cost per order ($)
H	=	Holding cost ($)

Annual demand is calculated from the sum of expected failures quantity filtered per year and part type. Whether the company will be interested in relying on developed EOQ, the functional baseline is offered, and by further modification of data, it can become a useful tool for collaboration with the procurement department and can assist procurement decisions.

4.2.3. Critical Evaluation of Underlying Model Assumptions

The replacement and repair costs in the existing model are calculated based on assumptions. These costs are estimated by the following Formula 4.3 and Formula 4.4:

$Replacement\ cost = 0.35 \times Part\ price + Labour\ cost$ (4.3)

$Repair\ cost = 0.5\ \times Part\ price + Replacement\ cost$ (4.4)

The 35% and 50% multipliers are the assumptions used in determining corresponding costs. These assumptions can influence the accuracy of the whole model, resulting in bigger deviations in comparison of the actual total costs with planned. The critical evaluation of underlying model assumptions was performed to emphasize the need for alternative solutions or other improvements, increasing the reliability of the assumption and the accuracy of results.

The most basic concerns regarding assumptions are the high variance of failures and the complex system of the locomotive. Some spare parts are easily replaced, incurring less than projected cost, and other spare parts can cost very cheap. Still, it can be in the deepest part of the system resulting in a much higher incurred cost for replacement operations. Currently, the company is dealing with assumptions by using the simplified assumptions described above. Because of the confidentiality reasons described above, the Company did not provide any historical data that could facilitate the student team in the refinement of these assumptions, thus in the developed LCC model, the same assumptions as above were used.

The replacement and repair processes are the collections of activities of technical specialists. It is recommended in the future to refine these assumptions and to construct a more detailed estimate of the cost for every activity and step operated by a specialist. The sum of all activities conducted in the maintenance process will result in the final cost of the process. Such an approach requires massive inspections, observations, and recordings as well as costs. The company needs to conduct a cost-benefit analysis to make sure that the efforts put will result in appropriate results.

4.3. Technical and operational improvements to the LCC model

4.3.1. Change Management

A significant challenge for the Company when maintaining the LCC model is caused by the necessity for periodic update of the model’s input information, such as spare part prices, reliability rates, labour hours and rates, locomotives mileages, etc. This information is often provided by different responsible employees and departments. Because of the unstructured design of the old LCC model based on MS Excel, most of such information update operations were done manually and required significant time and effort.

In this capstone project, a new data model for all LCC data is offered. This model allows storing different types of input information separately from each other in an organized way in different lookup tables. Therefore, such information can be easily updated automatically independently from each other and not affect other unrelated parts of the calculation. This represents a good solution and way forward for the Company to solve its challenge with updating the input data.

In this project, such an automatic update operation was implemented and demonstrated for spare parts prices. As of the time of report writing, the Company is in the process of automating certain parts of data exchange and business processes using the Microsoft Lists platform. The Company has created a Microsoft Lists table with information regarding spare parts prices. The LCC model demonstrates how to automatically import such spare parts information, which is periodically updates, using Power Query import operations. As of the time of report writing, the Company is in the process of implementing analogous tables for other input information, however, they are not finalized, therefore, they were not included in the LCC model implementation.

During the project implementation, the project team elaborately studied the LCC modelling. The investigation for useful information started by exploring the railway industry and elements of its infrastructure. Consequently, the maintenance operations related to rolling stock held in the railway industry become the project team's focus. In parallel, the company activity and its business processes related to the LCC model were inspected. Several meetings with the company representative revealed differences in the LCC model practised in the company from the LCC models practiced in the corresponding industry. For example, The LCC model designed for locomotive maintenance operations of Alstom excluded many costs like depot maintenance costs, consumables cost and support equipment cost, which are essential in LCC. In addition to the model, the users and the LCC model flow through the departments of the Alstom company were discussed, resulting in ineffective and poor data update and modification. The key problem was a need to update input parameters, such as part prices, labour costs, reliability rates, in an effective way considering the updates of different departments. For example, the price updates were mailed to the LCC model manager and entering the updates was time-consuming and double work. Thus, in the first plays, separate tables in the data model were created to solve the problem, implying that each table will be imported automatically from a different source location. Moreover, each table has fields such as update_date and updated_by, and fields can be updated multiple times, but in the calculations, only the latest updated data is taken. In further discussions with the representative of Alstom, all possible alternative solutions offered by the project team were analyzed and filtered to apply the most convenient solutions to the model.

Regarding the data updates, the following solution was agreed. The data update will be processed by using the Microsoft Lists product. All changes and updates in input data will be filled in Microsoft Lists by responsible users. The updated data will be inspected and approved in the same Microsoft Lists resulting in a final data table designed for the developed LCC model. The final procedure will include the creation of links to the sources of corresponding input data tables.

This and other improvements and changes that will deliver the developed model will need some time and adaptation period for the company. So, the change management will require the project team to prepare, support and help Alstom employees to master the new LCC model.

4.3.2. Other Improvements and Their Effect

During the new model development, many other minor improvements were made. At the beginning of the project, the existing LCC model had some little mistakes in formulas, and not all relevant fields were included to be calculated. All identified and corrected mistakes made the source LCC data model more decent for further usage to develop the new model. In the remodelling process of the existing LCC file, many new columns were added to the developed model to make the model more vulnerable to the access of new users and data modification procedures. The same columns help to create more vivid reports and dashboards. For example, the input data tables were designed to have the update dates and users columns which consequently were used in calculations to include the latest updated input data. The other improvements that cannot be easily recognized are hidden in the systemic structure composition. For example, simple and short namings were used for the simplicity of data modification.

4.3.3. Errors Identified in the Existing LCC Model

While working on the LCC model calculations, we have identified and investigated some discrepancies in the calculations contained in the old LCC model provided by the Company. Specifically, on the sheet "Sum-up", the total forecast cost in the cell A3 = €92,663 did not agree with the total costs per breakdown (range A5:A10) = €145,308. It was discussed with the Company representative that in the correct implementation, they should agree, and the difference is due to unknown errors in Excel formulas. While implementing the calculation logic, we have traced the following.

Some denotations that are used:

- Key two parameters for parts are:
  col. I → RC scope (outsource)
  col. K → repairable or not
- The main part values/costs are:
  col. P → price of new part
  col. Q → repair cost
  col. R → replacement cost

Next, using these column names, the logic in the "Main formula" for the overall cost can be represented as:

```
If I (RC outsource): then only R (only replacement cost)
    If not I (not RC outsource):
        If K (repairable): Q+R
        If not K (not repairable): P+R
```

The costs are classified as:

R and P → go to material cost

Q → go to repair cost

Therefore, correct formulae for cost breakdown should be:

Repair: **`If (not I and K) then Q else 0`** (4.5)

Materials:

```
If I: R
If not I:
If K: R
If not, K: P+R
```

or the same in a more simplified way **(for materials):** **`R + IF(not I and not K then P else 0)`** (4.6)

So, the main changes that shall be made in the calculations are: on sheet "LBS", cells AB1, AD1, AF1, AH1 were updated in accordance with the above logic of Formulae 4.5 and 4.6.

In addition to that, cells AA2:MQ2 and T1 had errors in that they did not include all available rows, hence some total values also did not agree. Similarly, some other cells also had missing or inconsistent formulas of their respective column, e.g. when copying formulas across the column, some cells were simply skipped or old values were kept instead of the correct formula. We have identified and corrected such artefacts in several calculation cells and communicated these facts to the Company representative.

Also, in the process of implementation, we removed rounding for some cells in order to trace formulae more accurately because rounding also gave some (small) differences.

For all the changed cells, cell comments were added, and the updated calculation file was shared with the Company representative.

After making these changes and pressing the "Update" button on the sheet "Sum-up", it was noted that the total cost amount agrees with the cost breakdown.

Overall, all the identified errors are not considered critical for the LCC calculations, however, the fact that our student team has identified such discrepancies demonstrates that using complex Excel formulas and keeping input data in an unstructured manner (in one large spreadsheet) is prone to errors. Such calculations errors can go unnoticed for a long time. Our new proposed implementation based on Power BI is free from such disadvantages because all data are stored in a structured way in the relational data model, and furthermore, all calculations are also done in step-by-step and structured calculation style using DAX language (i.e. no named cell references are used, only specifically named columns and measures). This was discussed in the previous sections.

4.3.4. Improvements and Contributions Summary

The key contribution of our capstone project is the new LCC model, which was developed by our team from scratch using Microsoft Power BI. This new LCC model represents the main added value for the Company. The benefits of the LCC model based on Power BI were discussed above. Our LCC model consists of three main novelties:

1. New relational data model, which allows storing all input and output data in the structured and connected way. Our data model eliminates the possibility of errors caused by data duplication and data integrity.
2. New LCC calculations implemented in DAX language, instead of old-style Excel formulas – this brings better readability and maintainability of the LCC model, decreases the risk of human errors and improves computational performance.
3. Custom dashboards developed for managerial decision making at the Company, such as the Pareto chart for spare parts.

Major accompanying contributions are:

- We have implemented several LCC model improvements that were not present before, specifically: financial modelling (incorporation of inflation and time value of money into calculations) and inventory management calculations, such as Economic Order Quantity (EOQ) calculation.
- In the process of developing the new LCC model, we have scrutinized and reverse-engineered the Company's old LCC model based on Excel and have identified and corrected several calculation errors that went unnoticed for a long time. Details of such errors were provided in the section above. We have communicated such identified errors to the Company representative.
- We have also prepared and presented several recommendations for the Company for the future development of the model.

5. Discussion

In this capstone project, we have successfully implemented the LCC model for Alstom based on Power Suite and Power BI software and met the objectives set at the beginning of the project.

5.1. Advantages and Disadvantages of the Developed Model

The developed LCC model has the following advantages, as compared to the legacy model based on Excel:

- It has a better data structure because it uses a relational data model;
- It is more maintainable because it is more structured;
- It is more understandable for the users because the formulas do not use cell references and many levels of nesting (as in Excel), but instead use named tables, field names, and accordingly, DAX formulas are very readable and straightforward to understand;
- It is more modern, as it uses up-to-date tools and software, such as Power BI;
- It has better computational performance – calculations in the old model in MS Excel were relatively slow, and the company had to use workarounds to temporarily improve performance, such as the use of VBA macros to recalculate formulas, while the new model in Power BI is speedy;
- It is more scalable because the Power BI model can handle more information (in terms of quantity and diversity of data) in case the company needs it in the future;
- It is very updatable in terms of the input data of the model – because of the logical data structure used, it is possible to automatically update different tables (using Power Query) based on almost any data source (not necessarily Excel files) and to get most recent information about input parameters;

In order to be more objective and balanced, we can also think of some potential disadvantages of the model, although we think they are much outweighed by the advantages:

- Some users might be less familiar with Microsoft Power BI software. While MS Excel software is quite old, widely adopted in the corporate world and well known by the vast majority of users, Microsoft Power BI software is relatively new and not all users might know how to use the software. We think that this disadvantage is relative, because regardless of our model, Power BI software is becoming the leading software in data analytics globally, and companies will be gradually adopting it in the few coming years, so Alstom will have a change to start this adoption with our model;

- In order to share the model across different users in the company, they will need this additional software (Power BI) to be installed on their software.

Besides these relatively minor disadvantages, we do not see any negative sides to the adoption of the Power BI model because it can do any of the calculations done in the MS Excel model previously and has many other current and potential improvements.

5.2. Company Benefits from the Project

We consider that this project is beneficial for the partner company (Alstom) for the following reasons:

1. We have reverse-engineered and scrutinized the old LCC model in Excel, raised multiple questions to the company regarding its operation, and identified and corrected several substantial errors in formulas. Because the legacy model was previously developed over numerous years, even company representatives could not immediately recall some aspects of its functionality, as some formulas were quite obscure. Because of our work, the company has undergone through additional review of the existing model;
2. The company representative also gained exposure to the Power BI software and modelling methodology, started learning this software, and his department became interested in broader adoption of Power BI software in Alstom Kazakhstan and possible replacement of other Excel calculations;
3. The company will perform LCC calculations more effectively and efficiently using the new LCC model. Calculations can be more effective because Power BI offers better reports, dashboards, and other functionality, which can help build tailored calculations suitable for the business task. Calculations can be more efficient because the model is faster computationally, but also because the data structure allows for faster and automatic update of input data from different sources. Thus, it will be instantly connected instead of sending multiple emails with data updates or communicating otherwise across departments.

4. The model can facilitate better collaboration across departments and better, more transparent data exchange, because data input and updates can be customized in the data model (using Power Query), instead of existing and often bureaucratic procedures, such as email communications.
5. The LCC model developed by our team will support decision making at the Company. The model presents calculation data in visual way using interactive reports and dashboards, while the old model based on MS Excel lacked such capabilities. This allows faster and more convenient decision-making in many areas. For example, conveniently presents forecast total cost and cost breakdown (by period), and this information can be used for financial budgeting at the Company.

   Also, the LCC model contains inventory management calculations, such as Economic Order Quantity (EOQ), which make it relevant for purchasing and inventory management decisions, such as decision on how many items of particular spare part to order in the current period. Similarly, the Pareto chart of spare parts presents the major spare parts in terms of their contribution to the total cost, this allows Company to focus procurement and negotiation efforts on those spare parts that are the most costly.

5.3. Recommendations for the Company

The model that we have developed is fully functional and performs the tasks of LCC calculations. In the future, we suggest that the Company can work in the following directions to improve further and extend the model:

- The company can extend the model to better integrate with other business tasks and functions. For example, in our project, we have demonstrated how the model can be used for inventory management planning, using calculations, such as Economic Order Quantity (EOQ), which can be helpful for the Procurement Department. Such functionality can be extended, for example, by offering additional tools and calculations for the Procurement department, and also other departments, for example, the Labour Hours estimates for each future period that the model calculates, can be used by Human Resources Department for staff planning, recruitment and training purposes. Such better integration of business tasks and functions can offer additional insights and efficiencies for the company, based on the suggested model, which can serve as a platform for processing and sharing different kinds of information across departments and decision making.

- The Company can also add more business data to the model and not limit it to the input parameters currently present in the data model. The power of data analytics comes not merely from the quantity of the data but also by their diversity and integration because integration and co-processing of different types of data often lead to emergent effects, i.e. it is possible to extract some features from the combined dataset, which was not possible by analyzing each of the component datasets separately. Thus, the company can identify additional input data in the company which can be relevant for the LCC calculations or accompanying calculations and include them into the existing data model;
- The Company should continue the current work of the integration of data exchange with Company's IT platforms. For example, Alstom Kazakhstan is widely using Microsoft tools and platforms for data exchange, communication, and team collaboration, proving valuable and helpful, especially in the current quarantine situation due to COVID-19 and restrictions. Alstom Kazakhstan is using tools such as Microsoft Lists to facilitate shared data storage and automation of some parts of the business processes within the Company. The model developed in our capstone project can be an integral part of such an IT ecosystem because Power BI can import and integrate data from a wide variety of software and formats, including Microsoft Lists;
- Model migration and deployment into cloud: we have developed and tested our model using the Power BI Desktop version, which works on a single computer. However, after testing and adopting the Company, the model can be deployed to the Power BI cloud version for a real production environment because it will offer additional computational performance and larger data storage. Also, the model will be readily accessible by any person in the company, who will be granted access rights to the cloud model.

5.4. Future Work Suggestions

The research work on the locomotives maintenance project at Alstom Kazakhstan can be continued in different ways, because it is a large and long-term project (over 25 years duration), so it offers a wide range of data and business tasks/problems, which can be looked at from different angles.

This project focused on the corrective maintenance side of the project. However, it is worthwhile to consider and further research predictive maintenance operations at Alstom and to combine the approach and methodology with the current capstone project model to generalize the model and have it to include both corrective and predictive maintenance analysis. The motivation for such potential project is that there might be specific patterns in the spare part failures/breakages, which can be revealed using proper data analysis and machine learning techniques so that it would be possible to identify potential problems within locomotives in advance, rather than to repair in case of breakages. Such an approach can also be more economical. However, a much greater quantity of input data for analysis will be required for such tasks, and as was discussed above, due to confidentiality reasons, Alstom does not readily provide such business data, however, it would be a useful and interesting project in case data access limitation would be resolved.

5.5. Next Steps

Sections 5.3 and 5.4 above present general directions for the future development of LCC model. This section presents specific next steps that can be undertaken in order to advance in this direction.

1. Integration of input data from SAP with Power BI LCC model.

   The Company uses SAP as its ERP system, so most of its business data is stored in SAP. As discussed above, different aspects of accounting and other data from SAP system can be relevant and useful for the LCC model. For example, the data on actual corrective maintenance costs (by period) can be extracted from SAP and compared with planned costs calculated by the LCC model, thus identifying any under/over budgets. The data from SAP system can be extracted automatically using Power Query and loaded into the LCC model in the same way, as other input data was loaded. However, due to specifics of SAP ERP system, certain custom reports, such as export into XML or CSV reports, might be needed, as well as custom modules for data export from SAP. For these tasks, assistance of qualified SAP professionals might be required.
2. Analysis of existence of data for predictive maintenance analysis.

Similarly, using the existing historic data, such as accounting and corrective maintenance data on actual spare parts breakages, the Company should assess whether it has adequate and sufficient data in order to undertake a potential research project on the predictive maintenance. When analyzing the existing data, the Company can consider availability of detailed information by: (i) spare part id, such as inventory number, (ii) period of breakage, (iii) locomotive of breakage, (iv) character of breakage, such as repairable or non-repairable, and other relevant engineering characteristics, (v) cause of breakage, and other information. In case such information is not readily available, the Company can assess opportunity of collecting such information, and estimate the costs and potential benefits associated with such data collection effort.

3. Integration with Microsoft Lists.

   As discussed previously, the Company uses Microsoft Lists for data exchange across departments and automation of certain parts of business processes. Specific efforts in this direction related to the LCC model should be continued. For example, as of the time of completion of this capstone project, the Company has achieved significant progress in automation of collection of information regarding locomotives spare parts, for example periodic updates of parts prices are performed automatically by the Procurement Department using Microsoft Lists portal. Conveniently, Microsoft Lists allows export of the data in table form into query file, similar to a simple Excel or CSV file.

   Thus, it shall be tested in detail, how this information regarding spare parts can be automatically loaded into the LCC model developed by our team. An example data import operation using Power Query is demonstrated in our project, however it might need to be customized, depending on specific format and columns used in the Microsoft Lists portal.

   Furthermore, upon completion of data import from Microsoft Lists on the spare parts prices, the Company should automate in similar manner input information regarding other key input parameters of the LCC model, such as: reliability rates, labour hours and costs, mileage, and other data. This will greatly improve convenience and performance of the LCC model, because instead of Excel or CSV files, the data would be automatically loaded from the most current version located in Microsoft Lists portal.

4. Purchase of cloud version of Microsoft Power BI

Finally, to prepare for the next step of the LCC model deployment into the Microsoft Power BI cloud version, the Company should consider purchasing the respective subscription. Using the cloud version will offer several advantages for the Company, such as ability to use the model by multiple users, greater computational speed and larger storage capacity. Based on the cloud version, the Company will be able to develop other engineering and financial models in the future. When considering purchase of the cloud version, the Company should plan its budget and estimate how many users will be regularly using the software.

5.6. How the Project Contributes to the Next Steps

The potential further research, such as the predictive maintenance problem, and the specific next steps suggested in the previous section, can be organically continued based on the LCC model delivered in this capstone project. The developed LCC model has implemented the structured relational data model, which contains and connects the key parameters of the LCC model. More information can be added into the model by creating additional tables and relationships. Because the model is structured quite well, adding new tables and relationships should not significantly undermine existing calculations, if carried accurately. The developed model presents a finished, yet expandable, canvas, on which further work on LCC modelling can be undertaken. The data import queries using Power Query can be updated to accommodate different input sources, whether it be Excel files, CSV files or Microsoft Lists tables. Again, if updated accurately, change in the data import should not affect calculation formulas used in the model. In this way, the model data, as presented in the relational data model of Power Query, are structured, scalable and expandable.

Also, in this manner using Microsoft Power BI, all information regarding the Company’s maintenance project can be stored, processed, and analyzed (interpreted in terms of business problems) in one place. This provides good opportunity, for example, for the future integration of the corrective maintenance model with the predictive maintenance model, because significant part of the input data will be shared, although some data will need to be added using Power Query, as described above.

Overall, we consider that the LCC model developed and shared by our team in this project can be improved and expanded in many ways, which is facilitated by the fact that we have completely shared the model with the company and made all our steps and calculations open and transparent. Therefore, the Company can tweak and customize any step or component of our LCC model, depending on the arising business task.

6. Conclusions

In the capstone project report, the project of developing an LLC model designed for corrective maintenance operations at “Alstom Kazakhstan" was delivered. The project was conveyed by the project team consisting of NU students and the Alstom company. The project duration was equivalent to the academic semester period. Despite the various challenges, the project was completed and delivered in time and scope. Summarizing all sections above, the new developed LCC model proves itself a practical and valuable business tool. All activities and processes described in the report suggest that the project team made a significant contribution to make the developed LCC model worth to be integrated not only in Alstom but also in any other relevant companies.

In the beginning of the project, the student team focused on understanding the existing LCC model of Alstom, which was based on an Excel spreadsheet. After exploring all attributes and functions of the model, the company needs and problems were identified in discussions with company representatives. After understanding the scope of the project, the planning and research phases were initiated. Firstly, the existing model was broken into many elements and restructured into a new data model using Power Query and Power Pivot. In parallel, the literature review and methods of constructing the LCC model were studied. After acquiring some knowledge and creating methodology, the basic LCC model was developed by applying DAX functions in Power Pivot.

Further, the developed LCC model was tested and evaluated to assess its efficiency and performance. In this stage, the developed model proved itself efficient and easy to use and to modify. The next stage required improvements and solutions integration to the model. The research conducted and further discussions resulted in using Power BI and adding a list of improvements to the developed model. The final version of the new developed LCC model became an attractive business tool for use by the Alstom company.

As for Alstom, the developed LCC model, besides solving some certain problems within the company's operations, offers several critical improvements such as financial forecasting considering the time value of money, economic order quantity, dynamic data modelling and highly interactive visualizations. Moreover, the developed model is created with the integration of the latest business tool solutions of Power Excel and Power BI. The approach taken by the project team makes the developed LCC model attractive and modern. That is why Alstom is highly recommended to change its legacy LCC model with the innovative one in order to stay in the competition of the business environment. Although the developed model is better than the existing model in many aspects, the former is far from perfection. Since the project was constrained in time and scope, the developed model was designed to address the company's specific needs. Only several possible improvements were included in the model. Thus, there is a big opportunity window to improve the developed LCC model and design for other areas in the company or industry. The most important thing to conclude with is the experience and knowledge gained by the project team and the company. The project team acquired must-have skills in several modern software tools that can help them build any business tool for request. Moreover, the experience gained in the “walls” of Alstom is assumed to be priceless and necessary for most engineering managers.

This capstone project demonstrates the applicability of financial and engineering modelling to wide range of business problems. Combined with proper software data processing and analytics tools, such as Microsoft Power BI, the example of our methodology can lead to successful applications for different business tasks and problems, for example in:

- Sales analysis and forecasting for the retail and trading companies,
- Inventory management applications, such as for production and logistics companies,
- General financial modelling and applications such as financial reporting, management accounting, budgeting, etc.,
- Business prediction and forecasting.

To conclude, the project of developing the LCC model brought many challenges as well as opportunities. The challenges addressed to the project team made the team members experienced and more skilled. The team believes that the company will also enjoy the developed model and can expect its benefits shortly.

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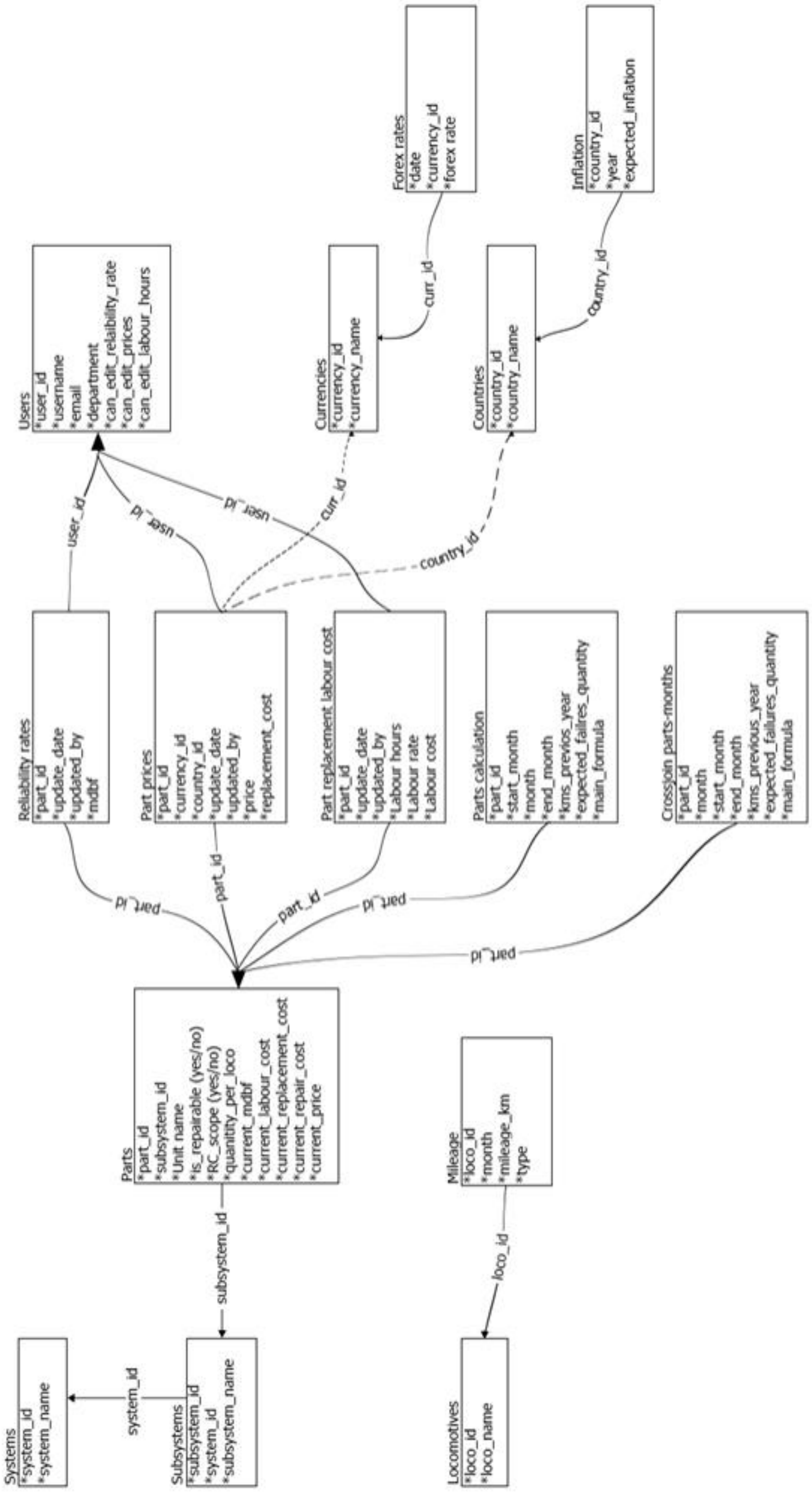
8. Appendices

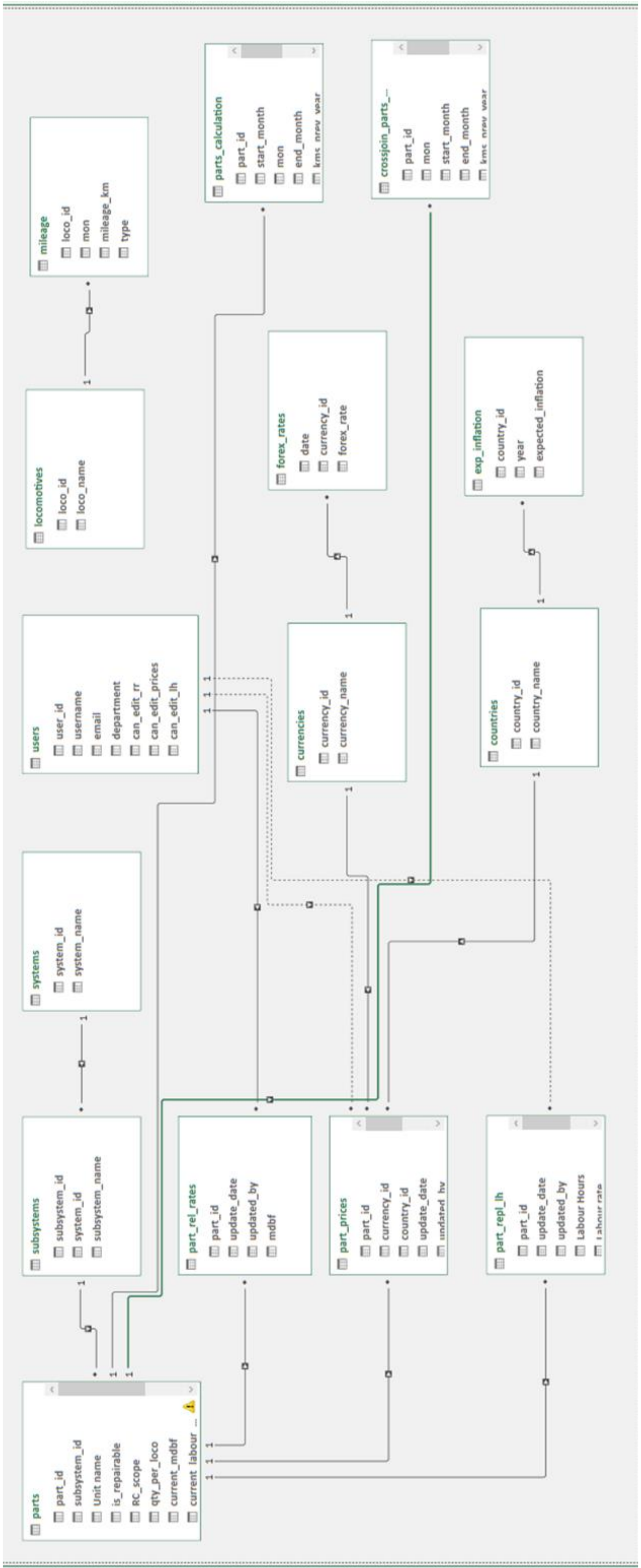
Appendix 8. 1 Columns in LBS sheet

1. # - ordinal number
2. System – part reference to a certain system
3. Subsystem – part reference to a certain subsystem
4. Unit name of Affected equipment – name of part
5. Part number – inherent ID number of parts
6. Part number GSI – ID number of parts given by company in the central GSI database
7. Failure mode – type of failure
8. Activity mode – type of activity held to deal with failure
9. RC scope – availability of outsource for activities (YES/NO)
10. Unit QTY per Loco – quantity of parts required by each locomotive
11. Repairable – Is part repairable or not (YES/NO)
12. MKBF REX, km – Mean kilometers between failures
13. Man Hours – man hours needed to accomplish the activity
14. Labour cost – the cost of activity (Man hours * Labour rate)
15. Labour rate – cost of per man hour
16. Unit price (EUR) – cost of unit part
17. Repair cost, EUR – cost of repair if part is repairable
18. Replacement cost, EUR – cost of replacement if part is not repairable
19. Currency – currency in which part is bought
20. Labour hours till the end of project – forecast calculation
21. Project End Final Cost (Forecast) – the sum of costs forecasted till the end of project
22. Project End QTY (Forecast) – quantity of parts needed till the end of project
23. Averg. Yearly QTY (Forecast) – quantity of parts needed per year
24. replacement QTY (Actual) – Quantity of replaced parts per year
25. Averg. Yearly QTY (GAP) – difference of column 24 and 25 (forecast-actual)

Appendix 8. 2 Data model structure before development



Appendix 8. 3 Diagram view of developed data model



Appendix 8. 4 List of used DAX functions and calculations

CALCULATE - Evaluates a given expression or formula under a set of defined filters

FILTER - Returns a table that represents a subset of another table or expression

SUM - Evaluates the sum of a column

MAX - Returns the largest value in a column or between two scalar expressions

EARLIER - Returns the current value of the specified column in an outer evaluation pass of the mentioned column

RELATED - Returns related values in each row of a table using relationships with other tables

IF - Checks if a given condition is met, and returns one value if the condition is TRUE, and another if the condition is FALSE

AND - Checks whether both arguments are TRUE, and returns TRUE if both arguments are TRUE, otherwise returns FALSE

COUNTROWS - Counts the number of rows in the specified table, or a table defined by an expression

FIRSTNONBLANK - returns the first value in the column, filtered by the current context, where the expression is not blank

DAY/MONTH/YEAR - Returns the day of the month (1-31), month of the year (1-12), or year of a given date

DATEDIFF - Returns the difference between two dates, based on a selected interval

EOMONTH - Returns the date of the last day of the month, +/-a specified number of months

```
kms_prev_year = CALCULATE(sum(q_mileage[mileage_km]),FILTER(q_mileage,
and(q_mileage[mon]>=[start_month],q_mileage[mon]<=[end_month])))
```

```
Latest Price Per Unit =
CALCULATE (
    SUM ( part_prices[price] ) ,
    FILTER (
        part_prices,
        part_prices[update_date]
            = CALCULATE (
                MAX ( part_prices[update_date] ),
                FILTER ( part_prices, part_prices[part_id] = EARLIER ( part_prices[part_id] ) )
            )
            && [part_id] = EARLIER ( [part_id] )
    )
) * RELATED(forex_rates[fx_rate]) * ( 1 + [inflation_rate] ) ^ ( [n_per] / 12 )
```

```
Latest Rel Rate =
CALCULATE (
    SUM ( q_part_rel_rates[Reliability Rate] ),
    FILTER (
        q_part_rel_rates,
        q_part_rel_rates[update_date]
            = CALCULATE (
                MAX ( q_part_rel_rates[update_date] ),
                FILTER ( q_part_rel_rates, q_part_rel_rates[part_id] = EARLIER ( q_part_rel_rates[part_id] ) )
            )
            && [part_id] = EARLIER ( [part_id] )
    )
)
```

```
Latest Labour Cost Per Unit =
CALCULATE (
    SUM ( part_repl_lh[Labour Cost] ),
    FILTER (
        part_repl_lh,
        part_repl_lh[update_date]
            = CALCULATE (
                MAX ( part_repl_lh[update_date] ),
                FILTER ( part_repl_lh, part_repl_lh[part_id] = EARLIER ( part_repl_lh[part_id] ) )
            )
            && [part_id] = EARLIER ( [part_id] )
    )
) * ( 1 + [inflation_rate] ) ^ ( [n_per] / 12 )
```

```
Latest Labour Hours Per Unit =
CALCULATE (
    SUM ( part_repl_lh[Labour Hours] ),
    FILTER (
        part_repl_lh,
        part_repl_lh[update_date]
            = CALCULATE (
                MAX ( part_repl_lh[update_date] ),
                FILTER ( part_repl_lh, part_repl_lh[part_id] = EARLIER (
part_repl_lh[part_id] ) )
            )
            && [part_id] = EARLIER ( [part_id] )
    )
)
```

```
Replacement Cost Per Unit = [Latest Price Per Unit]*0.35+[Latest Labour Cost Per Unit]
```

```
Repair Cost Per Unit = [Latest Price Per Unit]*0.5+[Replacement Cost Per Unit]
```

```
Expected failures QTY = if([Latest Rel Rate Type]="D", ([kms_prev_year]/[Latest
Rel Rate])/12 , (1/[Latest Rel Rate])*COUNTROWS(q_locomotives)*RELATED(q_parts
[Unit QTY per Loco]) )
```

```
Total Cost (KZT) = if(RELATED(q_parts[is_outsourced]),
    [Expected failures QTY]*[Replacement Cost Per Unit],
    if(RELATED(q_parts[is_repairable]),
        [Expected failures QTY]*([Repair Cost Per Unit]+[Replacement Cost Per
Unit]),
            [Expected failures QTY]*([Replacement Cost Per Unit]+[Latest Price
Per Unit])
    )
) / ( ( 1 + [discount_rate] ) ^ ( [n_per]/12 ) )
```

```
Material Cost (KZT) = [Expected failures QTY] *
(
    [Replacement Cost Per Unit] +
    if( and(not(RELATED(q_parts[is_outsourced])),not(RELATED(q_parts
[is_repairable]))),
        [Latest Price Per Unit],
        0
    )
) / ( ( 1 + [discount_rate] ) ^ ( [n_per]/12 ) )
```

```
Repair/Service Cost (KZT) = [Expected failures QTY] *
(
    if( and(not(RELATED(q_parts[is_outsourced])),RELATED(q_parts[is_repairable])
),
        [Repair Cost Per Unit],
        0
    )
) / ( ( 1 + [discount_rate] ) ^ ( [n_per]/12 ) )
```

```
Labour Cost (KZT) = [Expected failures QTY] * [Latest Labour Cost Per Unit] / (
( 1 + [discount_rate] ) ^ ( [n_per]/12 ) )
```

```
Labour Hours = [Expected failures QTY] * [Latest Labour Hours Per Unit]
```

```
Latest Rel Rate Type =
CALCULATE (
    FIRSTNONBLANK( q_part_rel_rates[RR_type], q_part_rel_rates[RR_type]),
    FILTER (
        q_part_rel_rates,
        q_part_rel_rates[update_date]
            = CALCULATE (
                MAX ( q_part_rel_rates[update_date] ),
                FILTER ( q_part_rel_rates, q_part_rel_rates[part_id] = EARLIER
( q_part_rel_rates[part_id] ) )
            )
            && [part_id] = EARLIER ( [part_id] )
    )
)
```

Appendix 8. 5 Power BI Desktop Dashboards

Cost breakdown by category and part

part_id	part_name	Total Cost (KZT)	Material Cost (KZT)	Repair/Service Cost (KZT)	Labour (
1	Part1	228 979,53 ₸	112 080,20 ₸	116 899,33 ₸	10
2	Part2	217 731,52 ₸	108 799,53 ₸	108 931,99 ₸	10
3	Part3	191 324,81 ₸	95 662,23 ₸	95 662,58 ₸	9
4	Part4	172 865,29 ₸	172 865,29 ₸	0,00 ₸	17
5	Part5	88 282,82 ₸	88 282,82 ₸	0,00 ₸	7
6	Part6	2 609 004,96 ₸	1 304 493,83 ₸	1 304 511,13 ₸	1 30
7	Part7	608 763,30 ₸	304 380,57 ₸	304 382,72 ₸	30
8	Part8	37 271 069,31 ₸	18 632 394,81 ₸	18 638 674,51 ₸	18 62
9	Part9	322 048,67 ₸	159 154,95 ₸	162 893,72 ₸	15
10	Part10	156 555,10 ₸	78 273,95 ₸	78 281,15 ₸	7
11	Part11	991 657,64 ₸	397 940,29 ₸	593 717,35 ₸	26
12	Part12	1 146 209,62 ₸	356 052,50 ₸	790 157,12 ₸	5
13	Part13	116 514,62 ₸	44 854,11 ₸	71 660,51 ₸	2
14	Part14	52 180,65 ₸	26 090,04 ₸	26 090,61 ₸	2
15	Part15	2 165 577,29 ₸	2 165 577,29 ₸	0,00 ₸	2 16
16	Part16	41 415 690,20 ₸	41 415 690,20 ₸	0,00 ₸	30
17	Part17	762 527,42 ₸	762 527,42 ₸	0,00 ₸	76
18	Part18	43 500,48 ₸	43 500,48 ₸	0,00 ₸	4
19	Part19	184 051,06 ₸	184 051,06 ₸	0,00 ₸	17
20	Part20	236 702,04 ₸	236 702,04 ₸	0,00 ₸	4
21	Part21	270 258,16 ₸	270 258,16 ₸	0,00 ₸	15
Total		**2 507 752 025,94 ₸**	**1 779 319 901,73 ₸**	**728 432 124,21 ₸**	**818 591**

Material cost for EUR
1,29bn₸

Material cost for KZT
448,78M₸

Material cost for RUR parts:
38,97M₸

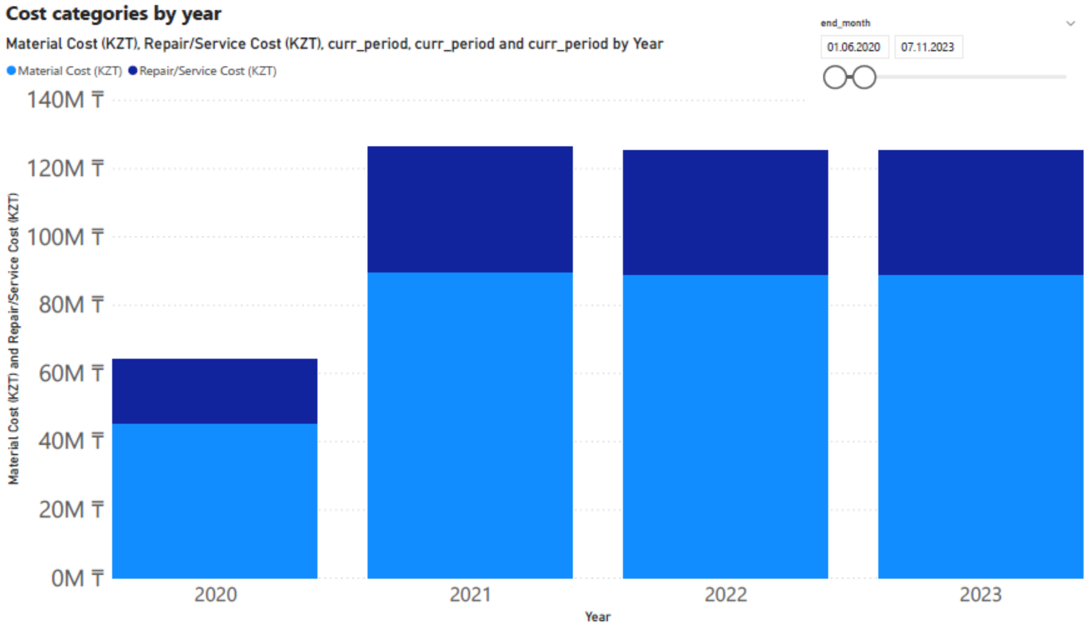
Repair/service cost for EUR parts:
446,58M₸

Repair/service cost for KZT parts:
242,23M₸

Repair/service cost for RUR parts:
39,62M₸

Cost categories by year

Material Cost (KZT), Repair/Service Cost (KZT), curr_period, curr_period and curr_period by Year



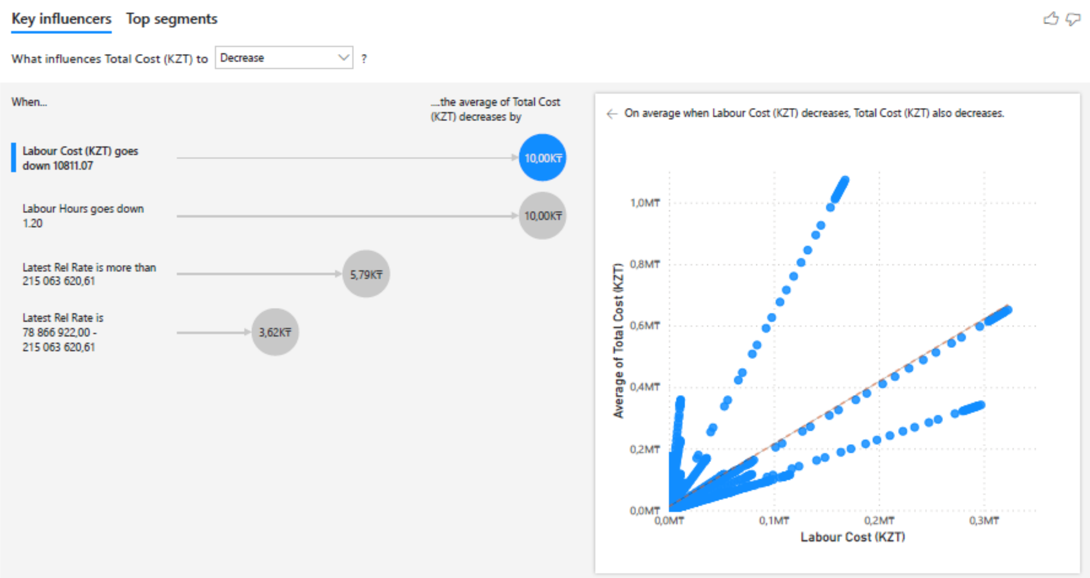
EOQ by part (in units) for 2021

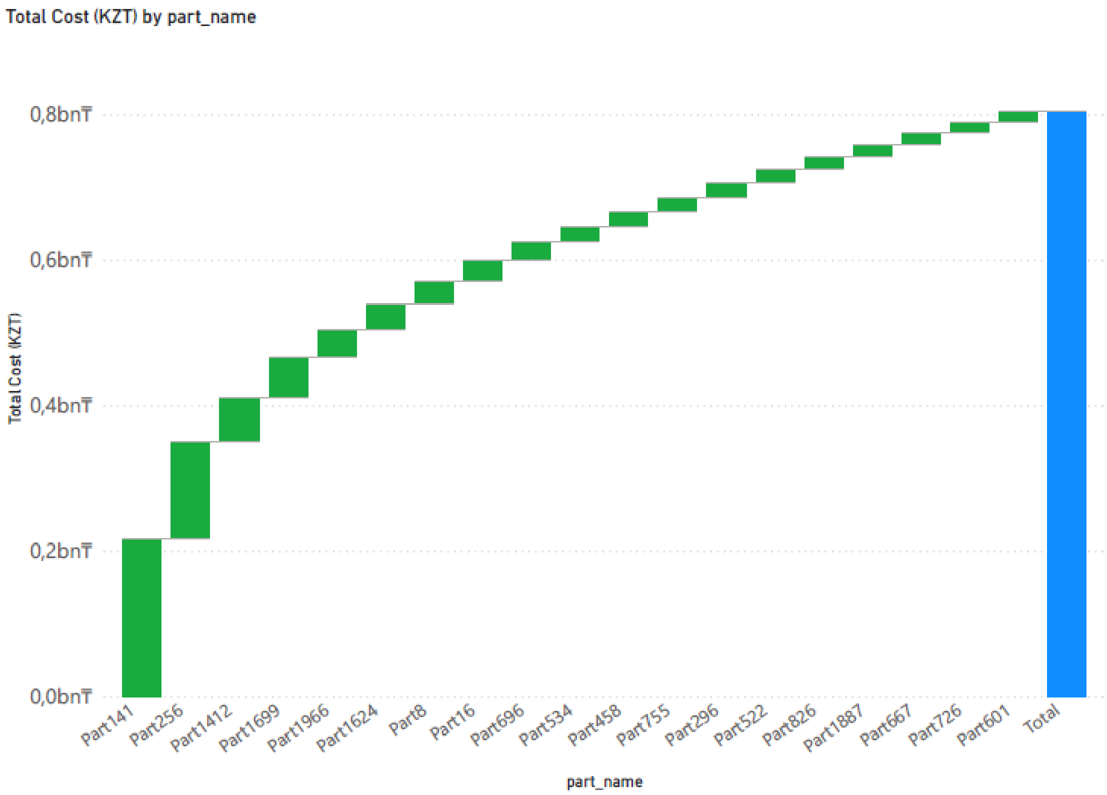
Economic order quantity (rounded)

part_id	2021	Total
256	19,00	**19,00**
1699	14,00	**14,00**
141	13,00	**13,00**
377	10,00	**10,00**
8	9,00	**9,00**
497	8,00	**8,00**
165	7,00	**7,00**
522	7,00	**7,00**
667	7,00	**7,00**
696	6,00	**6,00**
1624	6,00	**6,00**
1679	6,00	**6,00**
1760	6,00	**6,00**

Frequency of ordering (in months)

T	Count of part_id
0,00	1941
6,00	1
9,00	2
12,00	1
13,00	1
16,00	2
17,00	1
18,00	1
19,00	1
20,00	1
21,00	1
22,00	1
24,00	2
25,00	2
26,00	1
27,00	1
Total	**2000**





Pareto chart: Total Cost