A digitisation method for paper-based systems using critical success factors

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Thesis submitted in fulfilment of the requirements for the degree *Master of Engineering in Computer and Electronic Engineering* at the North-West University

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Graduation: August 2021

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Abstract

Title:	A digitisation method for paper-based systems using critical success factors
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Degree:	Master of Engineering in Computer and Electronic Engineering
Keywords:	digitising, paper-based, efficiency, availability, scalability, modernisation, web technologies, critical success factor

Companies are compelled to improve efficiency in order to remain competitive. However, companies often have paper-based systems that reduce their efficiency. Literature has proved that digital transformation can contribute towards improving paper-based systems.

Digitisation frameworks do exist, although they are generic and lack the detailed requirements for implementation. Related studies were reviewed to identify the Critical Success Factors (CSF) of digitisation, although none of the existing frameworks address all CSFs. Once CSFs have been identified, a methodology can be formalised to address digitisation.

Based on literature and identified shortcomings, the methodology adopts the Agile Framework that promotes stakeholder collaboration to guide project implementation through prioritisation and evaluation of quantified CSFs. CSFs are quantified by using the methods found within literature to ensure successful implementation. This method is explained by two case studies.

Case Study A involves 100 engineers who produce weekly reimbursement documents. Digital transformation of the system saved an average of 33.16 minutes per employee per week. The futile time avoided resulted in estimated cost savings of R620 000 per annum.

In Case Study B diesel rebate assistance is provided by means of a paper-based log system. Digital transformation resulted in an estimated diesel rebate request valued at R5 million. The availability and security of digital data proved to be extremely valuable since those involved were able to analyse various other systems affected by diesel usage according to given data.

Both case studies proved that by evaluating CSFs of systems, digitisation can be successful and stakeholder priorities satisfactorily addressed. Furthermore, both case studies have shown that digital transformation promotes efficiency.

Acknowledgements

To my parents, Deon and Lynette Wilken, thank you for your love and support throughout my life. Thank you for always believing in me and for making me believe in myself. Without your support in helping me through this, it would not have been possible to complete my Dissertation.

To my grandparents, Gideon and Ina Wilken as well as Rina de Kock, thank you for your constant encouragement to pursue Higher Education. You have always been the wind in my sails.

To Dr. Jan Vosloo, thank you for all your valuable time, endless patience and input during the writing of this dissertation. Without your valuable knowledge, the Dissertation would not have been possible.

To Prof. E. H. Mathews, thank you for the opportunity to do my Masters at CRCED Pretoria. Also to TEMM International (Pty) Ltd and ETA Operations for funding my research.

To Jano de Meyer and Dr. Pieter Goosen, thank you for your mentorship. Without your guidance and encouragement, it would not have been possible. Your guidance and encouragement enabled me to complete this huge task successfully.

Lastly, thank you to all my friends.

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Nomenclature

Abbreviations:

AAI	Architecture Adaptability Index
AHP	Analytic Hierarchy Process
CIO	Chief Information Officer
CSF	Critical Success Factor
DBMS	Database management system
EAI	Element Adaptability Index
GDM	Group Decision Making
JSON	JavaScript Object Notation
NFR	Non-Functional Requirements
SAI	Software Adaptability Index
SARS	South African Revenue Services
SOA	Service-Oriented Architecture

Units:

h	Hours
min	Minutes
ms	Milliseconds
ZAR (R)	Official currency of South Africa

Chapter 1

Introduction

1.1 Background

In an ever-growing world of interconnection, companies need to be constantly efficient in order to remain competitive [1]. These improvements are not limited to specific sectors but can be implemented on various company systems. Chief Information Officers (CIOs) concerned with this have in recent years explored the use of digitisation to make improvements to systems [2] by examining several different ways in available literature [3]. Digital transformation surveys were sent to 302 CIOs and senior IT executives with varying backgrounds and industries worldwide to evaluate their perception on the challenges involved with digital transformation [2]. Results of the investigation, as discussed below, give an indication of patterns identified by participating CIOs.

Digital transformation, digitalisation and digitisation are crucial and therefore it is important to fully understand the meanings of each concept [3]. Digitisation is the process of transforming analogue to digital format, which is also known as digital enablement. Digitalisation is the process of using digital technologies to enable or improve systems. Digital transformation is the effect of using digital technologies.

Figure 1.1 shows an expected change in digital transformation pace as perceived by CIOs and IT executives. According to the graph it is the expectation of 91% of respondents that the rate of digital transformation change will increase over the next year (52% indicated significant increase and 39% somewhat increase).

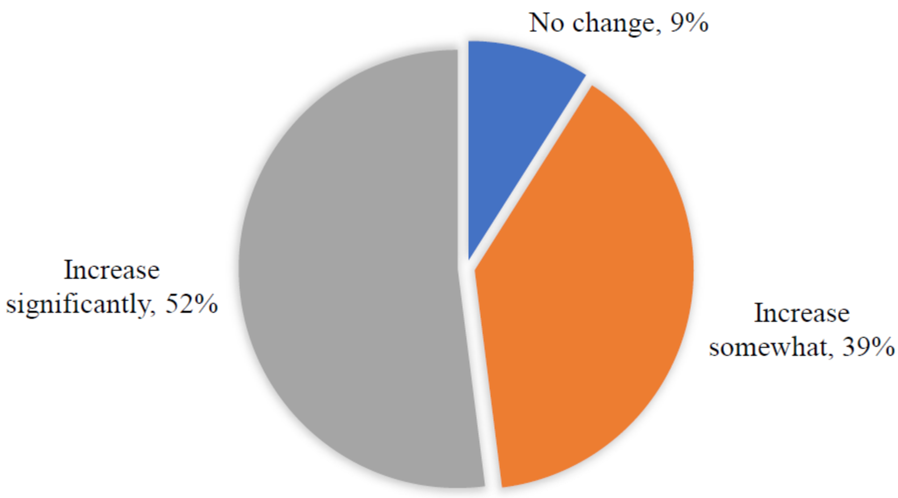


Figure 1.1: Expected change in digital transformation pace

Furthermore, companies are more willing to apply digitisation due to increasing market competition as well as customers' expectations to obtain modern products and services [1]. According to the relevant survey respondents' views are based on the most important values when undertaking digital transformation. The values are listed in order of increasing importance:

- **Partner relationship**: Alliance with other commercial entities by contractual or by other arrangements [4]. According to the survey, 31% of the respondents considered partner relationship very important [2].
- **Workforce re-skilling**: Investing in the time and resources of companies to provide training to employees to be better equipped for their job or to reaffirm existing skills [5]. According to the survey, 40% of the respondents considered workforce re-skilling very important [2].
- **Increasing efficiency and cost savings**: Evaluation of current company systems in order to identify opportunities to improve efficiency and cut expenses [6]. According to the survey, 52% of the respondents considered increased efficiency and cost savings very important [2].
- **Researching new technology**: Investing in company resources and funds to explore opportunities for newer technologies [7]. According to the survey, 52% of the respondents considered new technology research very important [2].
- **Growing new markets**: Exploring new opportunities in order to expand the consumer and product market [8]. According to the survey, 53% of the respondents considered the expansion of new markets very important [2].
- **New products and services**: Exploring new products and services that a company can offer [8]. According to the survey, 53% of the respondents considered new products and services very important [2].
- **Improving existing products and services**: Exploring existing products and services that can be improved [7]. According to the survey, 57% of the respondents considered improvement of existing products and services very important [2].
- **Customer experience**: Determining the current satisfaction of customers as well as ways to improve it [9]. According to the survey, 69% of the respondents considered new customer experience very important[2].

According to the survey respondents, customer experience is the most important factor during digital transformation. However, growing new markets, new products and services as well as improving existing products and services all have an impact on customer experience. Therefore, the four main factors are customer centered.

Improving existing products and services is considered as the second most important factor that impacts customer experience. Improvement of products and services by modernised systems increases a company's efficiency.

The maturity level indicates the progress made to digital transformation as viewed by the survey respondents. The CIOs view improving existing products and services as not a mature process, as only 41% of the respondents are satisfied with the maturity level [2].

Due to this lack in the mature process, it is difficult to identify candidate systems for digitisation. CIOs have commonly followed the Aristotle's Nicomachean Ethics by asking: "who, what, where, why, how and when" in the identification process [3]. However, an easier way to identify candidate systems is to determine the system's efficiency within a company [2].

1.2 Paper-based systems

Paper-based systems use paper as an analogue medium to transfer information or store data permanently [10]. Paper is manually processed to retain information for future use. If paper is not stored properly, the printed content may fade, leading to the loss of information [11].

Paper-based systems are one of the oldest and most outdated systems [10], and have minimal means for checking other than tedious manual inspections. The complete life cycle of information exchange through paper-based systems is time-consuming.

Paper-based systems reduce the overall efficiency of information exchange and pose high environmental and economic costs [10]. In 1999 South Africa had an estimated three trillion pages or 1,95 million ton printed [12]. In 2019 Peters Papers reported that South Africa produced 2,3 million ton of paper in 2013 [13]. According to Figure 1.2, paper production has increased by 18% over the past 14 years.

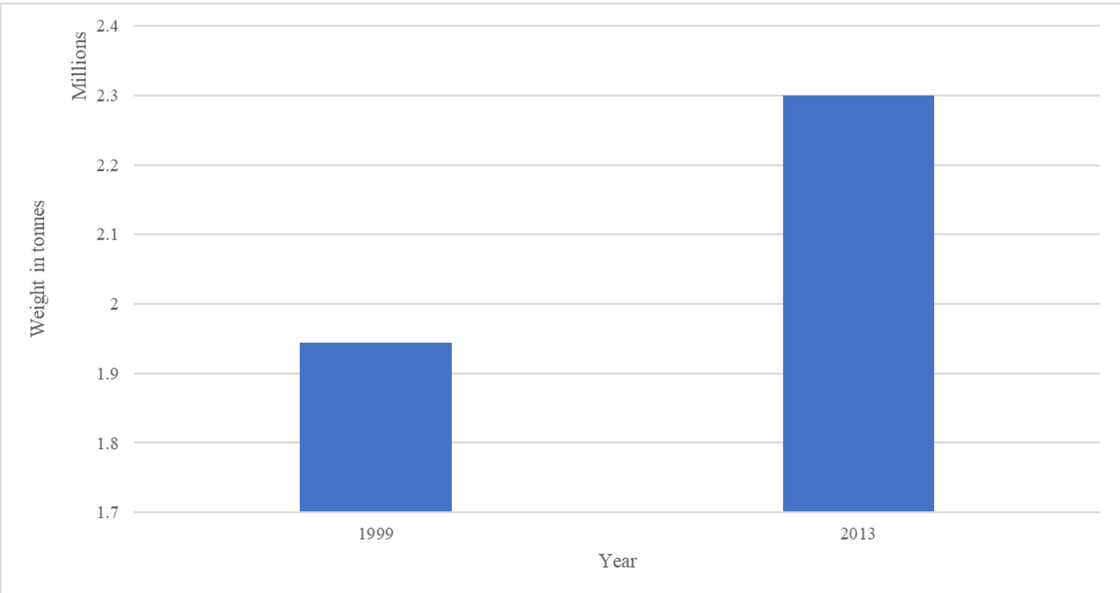


Figure 1.2: Paper usage increase

Paper as a medium for the exchange and recording of human information dates as far back as 220 CE [11]. The use of paper has been popular throughout the centuries. However, the need for alternatives has emerged more in recent years due to increasing demand as well as the threat of deforestation and global warming.

Companies try to reduce their overall paper dependence by replacing the conventional way of storing information with storage on computers [12]. This led to a significantly lower paper demand, and thus declining deforestation.

Paper-based systems in companies can be referred to as administrative paper-based systems [10]. Administrative paper-based systems consist of data collected in a specific page format suitable for delivery and processing by company systems. This logical structure of administrative paper-based systems is particularly useful during the implementation of modern techniques.

1.3 Digitisation implementation

The common method followed by industries, consists of phases described as [3, 14, 15, 16],

- **Phase 1** - Project justification
- **Phase 2** - Site assessment
- **Phase 3** - Project planning
- **Phase 4** - Digitisation activities
- **Phase 5** - Processes in the care of records
- **Phase 6** - Evaluation

These phases are executed in sequential order by using the Waterfall Framework, as depicted in Figure 1.3 [3]. However, this particular framework has no feedback mechanisms to revisit or to confirm previous phases.

Phase 1 focuses on the value obtained from digital transformation in the proposed system [3, 14, 15, 16]. This phase emphasises the identification of goals to be achieved as well as potential benefits obtained in a particular project. The justification of the project also requires an analysis of potential costs and the expected revenue gain. The project justification is presented with a risk analysis accompanied by mitigation plans. Ultimately, the project justification should make it clear what the value of the project will be based on the benefits and risks.

Phase 2 evaluates the full range of affected systems and the feedback contains information that can be used in the digitisation process [3, 14, 15, 16]. The site assessment should set

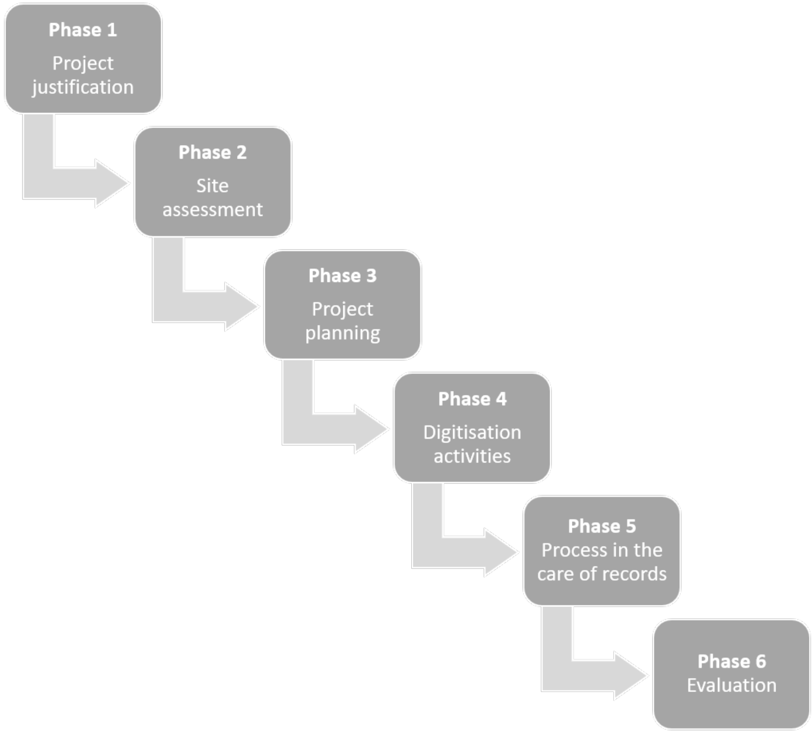


Figure 1.3: Industry digitisation process

boundaries for systems that will be affected and those that will not be affected. The context should include any physical infrastructure required as well as any human resources assigned to the maintenance of the system.

Phase 3 involves a project plan consisting of a selected digitisation approach, an incorporated project management strategy, resource management, clear technical specifications, and an indication of risk management [3, 14, 15, 16]. The project plan requires a scope of business drivers, requirements and constraints. Apart from that, the purpose as well as the objectives of the project must be clearly defined. Expected benefits identified in Phase 2 should also be set out in the project plan.

Phase 4 entails the actual digitalisation process [3, 14, 15, 16]. The industry methodology does not specify a specific approach and the process can be affected by disciplinary background, proprietary technology or a particular nature of the system. Regardless of the process there are fundamental issues that need to be addressed, such as acceptable file formats and quality, key identifiers and validation of the method.

Phase 5 provides a general overview of system usage and maintenance responsibilities [3, 14, 15, 16]. The system administrator receives a duty statement in order to maintain the digital system.

Phase 6 deals with the estimation of net value gain due to system digitilisation and criteria for estimated objectives [3, 14, 15, 16]. Reflection on digital transformation contributes to the elimination of future mistakes.

The requirements of each phase, except those in Phase 4, are precisely followed by industries, which can be expected due to the changing nature of candidate systems. This general approach can be validated by evaluating key performance indicators from successful projects in the past. Evaluation of systems – Phase 4 – ensures that any efforts in this regard are successful.

With regard to Phase 6, it is essential that digitisation efforts meet the set requirements.

1.4 Critical Success Factors of digitisation

Critical Success Factors (CSF) are used in the construction of a framework consisting of the most important elements responsible for successful implementation of digitisation [17]. Proper evaluation of Success Factors can increase the chance of successful delivery [17].

CSFs are treated as measurable, manageable and verifiable variables [17]. Literature regarding digitisation of legacy systems is obtained by means of a critical review. Key phrases as the following are used for this purpose:

- Digitisation,
- Legacy systems,
- Process of digitisation,
- Digitisation benefits,
- System improvements through digitisation,
- Paper-based system digitisation
- Digitisation implementation.

The following are the most common CSFs of such an in-depth literature review related to legacy systems:

- Ease of information **availability** [17, 18, 19, 20, 21].
- Capability for **expansion** [20, 22, 23, 24, 25].
- Ease of system **maintenance** [17, 18, 23, 26, 27, 28, 29, 30].
- System **adaptability** [19, 20, 26, 27].
- Capacity to function as a **web-based** system [19, 31, 32].
- Ease of system **migration** [17, 32, 33, 34].

These CSFs are quantifiable, not only with regard to the criteria they represent, but also as metrics for the successful implementation of digitisation.

Ease of information availability

The need for large amounts of information is the main driving force behind the global increase in internet usage [21]. Especially the current generation desires more and more information. Therefore, it should be available everywhere, anytime and on any device [21].

In order to meet the huge demand for information, the capacity of systems must be carefully planned [17, 19, 20, 21]. Once the system is implemented, its availability can be measured against storage system availability, system data availability, user-perceived data availability, data loss rate and data loss ratio [17, 18, 19, 20].

- **Storage system availability** is measured as the steady state probability that storage systems work flawlessly. This probability is negatively affected by a storage system that is off.
- **System data availability** is measured as the steady state probability that data can be accessed from the storage. The probability is negatively affected when storage is running but with faults.
- **User-perceived data availability** is measured as the steady state probability that data is accessible for users. The probability is negatively affected by services that are off or under maintenance.
- **Data loss rate** is measured as transactions lost per hour. If data storage fails and is not recorded, transactions between two backup points are lost.
- **Data loss ratio** is measured as the number of lost transactions per total number of transactions.

Capability for expansion

Capability for expansion describes a system's ability to increase or perform under increasing loads [20, 23, 25]. Software systems with excellent extensibility do not suffer from overload.

The ability to expand prevents system design or duplication of systems [20, 23, 25]. Extensibility characteristics are usually context related [20, 23, 25]. However, systems can be analysed by evaluating the structural and load scalability. Structural scalability refers to the ease of system expansion. Load scalability refers to the performance of a system under varying loads.

Systems with high structural scalability are the result of the framework used to implement the system [24]. An analysis of the various frameworks for project implementation is therefore important in order to ensure that framework implementations comply with structural scalability. Quantifying the structural scalability is a process that measures the time to implement software [25].

In order to quantify load scalability of a system, the demand load on a system is varied and the delivery time is measured [20, 23, 25]. Consequently, load scalability can be expressed as a linear or exponential series where systems with exponential scaling are not desirable [25].

Ease of system maintenance

System maintenance describes the maintenance of software and the system that stores data [17, 18, 23, 26, 27]. It is related to development requests while a system is in the maintenance cycle. Such requests may include resolving existing bugs or installing newer features [35].

Software should be developed according to a development framework that includes continuous integration testing. It is possible to evaluate the ease of maintenance on software according to existing criteria, which have shown to be reliable, by following such a framework [17, 23, 26, 27, 28]. One of the most popular criteria used by companies is the Maintainability Index (MI), which is based on the Halstead's Volume, McCabe's Cyclomatic Complexity and lines of source code with a revised version that includes a code to comment on ratio [29, 30].

Data backup is a crucial aspect of maintenance [18, 26]. The policy governing this aspect needs to specify the frequency of partial and complete backups as the frequency of backups can affect the system up-time with consequences for data availability.

In order to select the best data backup policy for a system, use must be made of the data availability calculations, as set out under Availability of Information, that substitute the frequency of backups specified in the policy.

System adaptability

Modern systems today are increasingly relying on collaborative collections of systems, also known as systems of systems (SoS) [19, 20, 27]. In order to ensure the successful introduction of sub-systems, adaptability must be taken into account by the system design. System adaptability is the extent to which a software system adapts to change in its environment [19, 20, 26], and should not be confused with system robustness.

System adaptability is often associated with the Non-Functional Requirements (NFR) [19, 20, 26]. It is difficult to measure NFRs, because their nature is not easy to understand.

However, by measuring the architecture and software adaptability index over the system cycle, a broad system adaptability criteria can be quantified [19, 20, 26].

In order to calculate the system adaptability criteria, the lowest level or unit must be defined. An adaptable element of architecture has a unit element adaptability index (EAI). Architecture adaptability index (AAI) is the total EAI for all elements of architecture per total number of elements. Software adaptability index (SAI) is the total AAI for all architectures of the software per total number of architectures [19, 20, 26].

Figure 1.4 gives an overview of the quantification of the system adaptability index. According to the example, the lowest level or units are System request handler, System request finaliser, Sub-system 1, 2 and 3. Each unit has an assigned EAI that describes the number of adaptable elements within that process. The total number of elements within the system is calculated by counting all non-adaptable elements and adaptable elements.

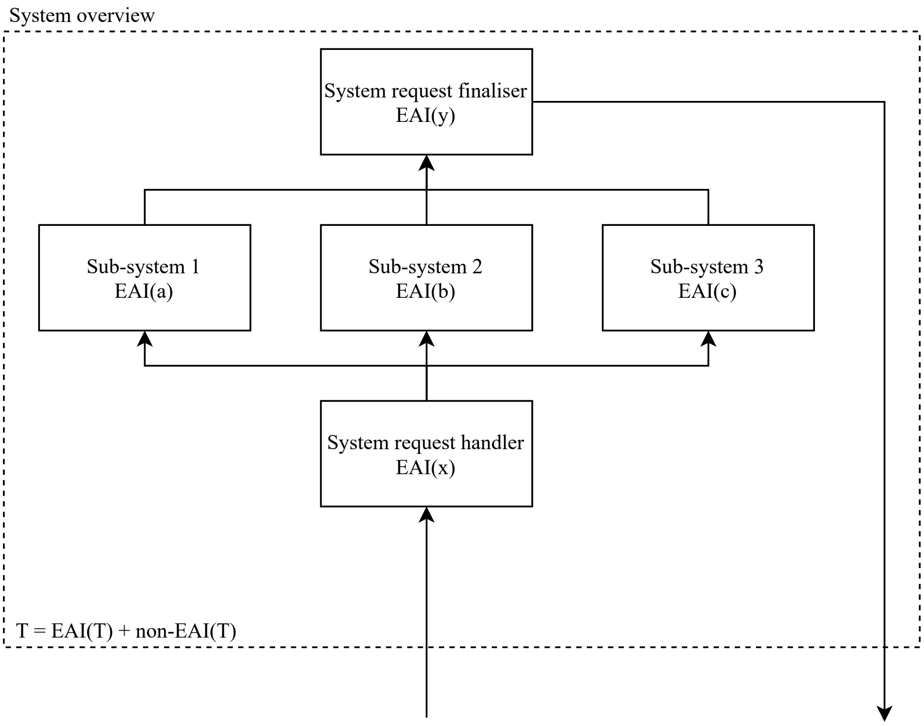


Figure 1.4: System adaptability illustration

According to Figure 1.4 the AAI can be calculated as:

$$AAI = \frac{x + y + a + b + c}{T} \tag{1.1}$$

where x, y, a, b and c are the EAIs and T is the total number of elements within a system. Therefore, SAI can then be calculated as:

$$SAI = \frac{AAI}{A} \tag{1.2}$$

where A is the total number of architectures. From the example shown in Figure 1.4 it can be seen that A would be 4.

Capacity to function as a web-based system

As already mentioned, the availability of data anywhere, anytime and on any device is an increasing requirement [21]. Web-connected or web-based systems allow data access by means of the internet [31].

According to Chen et al. [36], systems that do not support data access through the web are classified as legacy. Legacy systems can be prevented by designing and planning a project for the web [36].

Accessible systems due to standard communication channels usually have the capacity to function as a web-connected system [31, 32, 37]. Standard communication channels include, but are not limited to, ethernet connection through cables, cellular network or Wi-Fi access points [38].

Ease of system migration

System migration is the move from one software environment to another [17, 32, 33]. Typical software migration is moving legacy systems to cloud-based platforms [17, 32, 33]. However, the system being moved can pose several challenges.

Migration to cloud-based platforms has been proven to be a solution for web-based communication systems [17, 32, 33]. In order to evaluate an existing system for cloud migration suitability, the following must be taken into account [17, 34],

1. The existing environment that accepts communication via the internet.
2. Resource dependency not covered with system encapsulation
3. Data access limitations from a cloud-based platform.
4. System administrator lacking digital literacy related to digital privacy and security related to cloud platform.
5. Cloud platform latency negatively influencing the performance of the system.

If the above requirements are not met, it will require further development, which complicates the migration process. However, a system may be ready for migration if its life cycle is evaluated.

1.5 State of the art

A literature study was conducted to evaluate the status quo relating to the CSFs of digitisation as defined in the previous section, which involved critical evaluation of journals, articles and conference proceedings to formulate the need for the study.

Alahmari et al. [39] discuss a service identification framework that identifies systems with enough granularity to be considered for migration to Service-Oriented Architecture (SOA). System migration and the benefits of conversion are the most important topics in this literature where conversion in modern systems refers to to SOA. However, consideration of information availability or system scalability is not discussed.

Ali and Abdelhak-Djamel [40] evaluated various industry approaches to evolve legacy systems. These authors paid particular attention to the classification and identification of legacy systems. Although the analysis came up with criteria to compare different approaches, it was neglected to set criteria for the evaluation of delivered systems. All delivered systems have been modernised to improve expansion ease and adaptability. Furthermore, it has been shown in this literature that any of the approaches results in a more manageable system. It also indicates that, although different techniques may differ, they can be classified into migration and integration categories. However, consideration of information availability and the nature of web-based modern designs are not discussed.

Lewis et al. [41] discuss the reuse potential of migrating legacy systems by implementing SOA. According to the authors there are criteria to be taken into consideration when digitising legacy systems with excellent knowledge of modernisation. The criteria emphasise the importance of information availability to satisfy potential service users. However, no clear maintenance plan is set out for systems that have been converted using SOA, although it will run as an encapsulated service to ensure that the system can adapt to almost any environment with web access.

An investigation was conducted by Khanye et al. [42] regarding the issues with migration of legacy systems to cloud platforms. The article contains valuable information on the impact that legacy systems have on the economic competitiveness of businesses. Reasons why legacy systems are modernisation or migration resistant are further elaborated on. Although the focus is on examining the socio impact of system adoption, system-specific requirements are not discussed.

The research of Fayçal et al. [43] gives rise to a new agent-based method of integrating legacy systems into SOA. Further mention is made of the conversion of legacy systems to SOA after which the structure of such systems for encapsulation with valuable information for successful endeavors is identified. However, no mention is made of information availability or its maintenance.

Alexandrova [44] investigates legacy system migration using an agent-based approach in the form of a game. According to this literature, stakeholder cooperation is the biggest challenge for modernisation. The game seeks to attract stakeholders to ensure better participation in system migration, CSF identification and prioritisation. No details are provided regarding system requirements and the design followed.

Clarke et al. [45] investigated the relation between software process adaptive capability and organisational performance. Agile development has been found to be promising in terms of delivering time-tested software. The impact of information availability, web-connected systems or system migration is not discussed in the article.

Design features of identified software systems over the long term are discussed by Kelly [46]. The focus is on practices that ensure software scalability, maintenance and migration through encapsulation. Agile development that results in software that will remain flexible after installation is discussed in this literature. Availability of information is referred to but not discussed further.

Yu et al. [47] studied the criteria for predicting software defects. The article provides insight into the importance of information availability to prevent software defects after which scalability and ease of maintenance are considered as a result of proper software implementation. However, the importance of web-connected systems in a modern interconnected world did not appear in the article.

Taibi et al. [48] did an empirical study on the migration of monolithic systems to micro services. Interviews were conducted with professionals who have at least five years of experience in their respective fields after which three main methods with regard to modernisation implemented by professionals were considered. According to the interviews, maintainability and scalability are the most important factors when considering SOA. No attention was paid to the need for information availability during migration to SOA.

Assunção et al. [49] performed a systematic mapping of processes and studies that re-engineer legacy systems to Software Production Lines (SPL). Due to the definition of SPL being similar to that of SOA, the two terms are interpreted as comparatively similar. Although the capacity for expansion and system adaptability does appear in this literature, the consideration of information availability or maintenance of systems is not found anywhere.

Pahl and Jamshidi [50] describe a systematic mapping of micro-services. The article clearly defines micro-services, architecture and the need it addresses. It has also been shown that a legacy system adapts more easily to new systems through micro-services. However, there is no focus on details of delivered systems.

M'Baya et al. [51] present a conceptual assessment framework for the modernisation of legacy systems. The authors pay particular attention to needs for system maintenance. They also pay attention to the identification of legacy systems and the appropriate modernisation technique to implement a system with. However, it was neglected to discuss the environment of operation for said systems.

The work of Ortiz-Ochoa et al. [52] consists of a particle approach that identifies and prioritises the modernisation of legacy systems. Classification of legacy systems has been addressed in this literature in which the need for system and information availability in modern systems emerges. Although system maintenance is the focal point, the progress made in ensuring that modernised systems are more suitable for future migration efforts has been disregarded.

Table 1.1 summarises the literature review. The tick is an indication that a topic has been fully discussed.

Table 1.1: CSFs of digitalisation state of the art summarisation

Source	Ease of information availability	Capability for expansion	Ease of system maintenance	System adaptability	Function as a web-based system	Ease of system migration
[39]			✓	✓	✓	✓
[40]		✓	✓	✓		✓
[41]	✓			✓	✓	✓
[42]	✓	✓	✓	✓		✓
[43]		✓		✓	✓	✓
[44]					✓	✓
[45]		✓	✓	✓		
[46]		✓	✓	✓		✓
[47]	✓	✓	✓	✓		
[48]		✓	✓		✓	✓
[49]		✓		✓		✓
[50]				✓	✓	✓
[51]	✓	✓	✓			✓
[52]	✓		✓	✓		

It is evident from Table 1.1, there is no literature addressing all the identified CSFs required to successfully digitise legacy systems. CSFs that are most focused on, are Ease of System Maintenance, System Adaptability and Ease of System Migration. These focal points can be used in preparation to properly address needs in digitisation projects.

The least focused CSF is Ease of Information Availability, despite its importance emphasised in Section 1.4. The chasm between the focus in the literature being reviewed and its importance in Section 1.4, may lead to conflict with stakeholder expectations about ease of information availability.

1.6 Problem statement & objectives

Although paper-based systems are widely used in companies, they reduce efficiency. There is, therefore, a need to modernise paper-based systems by implementing digitisation to improve the efficiency within companies. However, the industry standard phases lack validation using the CSFs of digitisation.

To satisfy the need for the study, the following objectives should be met:

1. Collaborative evaluation of the CSFs of digitisation with stakeholders within the implementation phase.
2. Formalise method to digitise identified paper-based system effectively.
3. Investigate the impact of digitisation and the efficiency benefits obtained.

1.7 Dissertation layout

Chapter 1: Introduction

The research focus of this dissertation is set out in this chapter. It has become clear from background information (Section 1.1) that the ever-growing interconnected world is forcing companies to improve efficiency to remain competitive. One of the important aspects in this section is digital transformation related to paper-based systems. The efficiency disadvantage of paper-based businesses is also emphasised. The CSFs of digitisation and its ongoing evaluation can be seen as the focal point of the dissertation in Section 1.6. Chapter 1 concludes with an outline of the layout in Section 1.7.

Chapter 2: Methodology

Chapter 2 contains the methodology and design steps used to create a possible solution to the stated problem (Section 1.6). Such methodology is created by:

1. The Agile Framework (Section 2.3.2).
2. The decision matrix, D (Section 2.3.3).
3. The CSFs (Section 1.4).

Chapter 3: Results

Results of the implementation by following the methodology are given in Chapter 3. The implementation and results are case study oriented. The first case study involves digitisation of a paper-based reimbursement system. Digitisation of a paper-based diesel rebate system occurs in the second case study. Each of these case studies is critically analysed to be interpreted before being discussed. The result interpretation is used to confirm that the solution addressed the problem by considering the increase in efficiency and other additional benefits. The chapter concludes with a summary of the results.

Chapter 4: Conclusion

Chapter 4 contains a discussion of planned projects for the future after which the applied methodology is finally evaluated so that it can be determined whether the objectives, as set out in Chapter 1, have been achieved.

Chapter 2

Methodology

2.1 Preamble

The background, literature and shortcomings give rise to the need and understanding for digitisation of paper-based systems as well as the way in which they should be implemented by means of specifications, as set out in Section 2.2 and 1.5.

Modernisation and digitisation frameworks are discussed in Section 2.3. The background elaborates on the various frameworks that could be used. According to a study of benefits and setbacks, it seems that Agile is the best candidate framework for generic implementations

A methodology is developed to digitise paper-based systems for improvement of system efficiency (Section 2.4). Such methodology, formulated according to information from the literature review, uses the Agile Framework to deliver phased implementations. Each phase is subjected to stakeholder approval and CSF validation. The creation of systems takes place in 4 phases.

2.2 Requirements

Requirements for a suitable methodology stem from the problem statement and objectives in Section 1.6 as well as the shortcomings, as set out in Section 1.5. Such requirements include all CSFs of digitisation through which system implementation is validated.

In order to address this issue, a methodology is developed consisting of a framework with collaborative stakeholders, implementation delivery and validation of digitisation CSFs. According to the literature study and Table 1.1 there are certain requirements that this particular method must meet. It should:

- be applied to a paper-based system
- modernise the system through digitisation
- be implemented through a digitisation framework
- be validated by digitisation CSFs
- improve a company's efficiency

If the methodology is followed, implementation should yield the result of the original system. Although the delivered product meets the requirements of the original system, it is evaluated according to CSFs.

Delivered document

The format of a delivered document that has been ditigitised must be approved by stakeholders. A document may take one of the following forms, although it is not limited thereto [53]

- email
- text
- PDF
- web-based integrated

If a document is required to be delivered in a format other than the above, this must be done in consultation with stakeholders.

Efficiency improvement

A company's efficiency improvement must be measured by the futile time avoided, the monetary impact and benefits after implementation.

- Futile time avoided: Avoid losing time due to reduction of required work that falls outside the job description.
- Monetary impact: Revenue impact since system inception and use.
- Benefits after implementation: Capabilities of a system that is being expanded or introduced due to implementation.

2.3 Modernisation and digitisation frameworks

2.3.1 Background

Obsolete paper-based systems are being modified by modernisation to meet digital requirements [54]. Digitisation, an aspect of modernisation, refers to the transition of a paper-based system to the digital domain [55].

There are several frameworks, such as the following, that can modernise legacy systems [24],

- Adaptive software development
- Cleanroom software development
- Spiral model
- Agile development

As indicated in Section 1.3 (Phase 4) only one framework is used for a particular project. In order to choose a suitable framework for a certain project, it is of the utmost importance to have a thorough knowledge of each framework.

Adaptive software development consists of a repeating series of speculation, collaboration and learning cycles [56]. The framework is stakeholder-centered, feature-focused, repeated, timeboxed[1], open to change and has a risk-driven design. This framework is ideal for stakeholders who are willing to participate in continuous development and if the project requires rapid software delivery.

Cleanroom software development is a framework designed to deliver software with a certified level of reliability [57]. The framework is rather focused on defect prevention than defect removal. Formal methods are proposed to deliver software in incremental implementation under sound testing. This framework is ideal when a project does not require rapid software delivery and when the project scope is clearly defined and set.

The spiral model is a risk-driven software development framework and guides a given project to adopt one or more process models based on the unique risk pattern [58]. The framework focuses on six properties, namely [58],

1. Concurrent definition of artifacts.
2. Performance of four basic activities in every cycle.
3. Risk assessment of the effort level.
4. Risk assessment of the degree of details.
5. Use of anchor milestones.
6. Focus on a system and its life cycle.

The framework is ideal for project leaders with a good understanding of the working system because the framework becomes complicated if the system being implemented is not understood.

Agile development is a framework in which requirements and development solutions are delivered by the joint efforts of development teams and stakeholders [24]. The Agile Framework is ideal where the project scope and requirements have not yet been fully discussed or stated. It provides guidance to stakeholders and participants to discuss requirements as a project develops. This evolving nature of Agile development can generally be applied to a wide variety of projects. Furthermore, this framework is ideal if a rapid delivery of illustrative working demonstrations is required.

[1] Allocating a fixed maximum unit of time for an activity.

Table 2.1 arises from data from the above frameworks.

Table 2.1: Digitisation framework evaluation

Framework	Pro's	Con's	Complexity
Adaptive software development	• Repeating cycles • Collaboration • Feature-focused • Rapid delivery	• Requires participating stakeholders • Timeboxed	Medium complexity
Cleanroom software development	• Certified reliability level • Defect prevention • Formal methods	• Time consuming • Set scope • Formal methods	High complexity
Spiral model	• Clear steps and requirements • Optional multi model approach • Formal method	• Complex risk pattern analysis • In-depth understanding required	High complexity
Agile development	• Open to change and adapting • Evolving • Handles uncertainty • Generic	• Vulnerable to project scope creep	Low complexity

Due to the complexity of Cleanroom software development and Spiral model frameworks, neither can be generically applied to projects within the scope of this study [57, 58]. The requirement to assign a generic framework thus eliminates these frameworks for this discussion. However, these frameworks can be followed given a project with a set scope and project member expertise.

Adaptive software development meets the requirement to be applied generically in a particular project. However, the framework implements timeboxed steps that are not always easy to define any project. The medium complexity of the framework does make it a suitable candidate for implementation on various projects.

Agile development can, as needed, be applied generically to various projects and encourages project evolution. The evolution within the project is vulnerable to scope creep if stakeholders want to abuse the recurring discussion. However, the rapid delivery of job demonstrations is aimed at identifying shortcomings and requirements early in the project life cycle.

The Agile framework and its implementation is discussed here as it includes aspects of the Adaptive software development and due to the fact that it is preferred when the definition of the project scope is missing or when it can usually be applied to any project [24, 56]. However, due to the changing nature of a project, a different framework may be required (as stated in Section 1.3 Phase 4).

Evaluation of the nature of a project (Phase 3) will indicate whether the Agile development meets the requirements or not. An analysis of the frameworks and their respective attributes will indicate which appropriate framework to use according to the project requirements.

2.3.2 Agile development

Agile development is a framework that consists of many years of research and development [24]. The framework consists of many other frameworks despite shortcomings. By combining the properties and practices of other frameworks, Agile eliminates most shortcomings [24].

The Agile framework is described in a document known as the Agile Manifesto and consists of four principles and eight supporting principles (Table 2.2)[22]. Entries 1-4 are the main principles, and 5-12 are the supporting principles, which indicates that the principle number does not presuppose prioritisation.

Table 2.2: Principles of the Agile Manifesto

		Description
Main	1	Prioritise the needs of the team over processes and tools
	2	Develop working software before focusing on documentation
	3	Involve stakeholders in planning and development
	4	Remain flexible to change in project plans
Supporting	5	Prioritise the needs of stakeholders
	6	Allow stakeholders to adjust requirements
	7	Frequently demonstrate or deliver working software
	8	Frequently collaborate on progress with stakeholders
	9	Encourage team members to get them enthusiastic about projects
	10	Support face-to-face communication between team members
	11	Measure progress against working software delivered
	12	Maintain sustainable development

According to the Agile Manifesto, development and planning are successfully undertaken [22, 24],

- in phases
- with feedback from stakeholders who interrupt the progression stage
- to validate progress by demonstration

Each stage is aimed at producing minimal work demonstration software that illustrates the purpose or functionality of the final product.

The approach to break down software development reduces the risks associated with software development requested by customers. These risks include spending too much time, money and resources on development that is not in line with the clients' expectations due to unclear requirements or scope. Initial releases of the software will enable stakeholders to guide the development process to deliver the requested product as they propose.

The Agile framework requires that the developers and stakeholders define high-level criteria for success [22]. Various methods of ascertaining these criteria exist, but it is critical to the project's success that they need to be specified.

2.3.3 Project decision making

Project decision-making is the handling of various objectives or criteria for optimal promotion [59]. The relevant objectives or criteria of projects often have contradicting requirements that lead to shortcomings. Typical criteria are to reduce cost as far as possible, to deliver the project as soon as possible and to obtain an excellent quality from the project being delivered.

A project decision-making framework reduces the risk of contradicting objectives or criteria [59]. However, there are different project decision-making frameworks with distinct characteristics. Understanding a project and its environment will ensure that the best framework for the application is selected. Some project decision-making frameworks includes:

1. Consensus decision making [60].
2. Majority-, Plurality-, Score- or Quadratic voting-based decision making [61].
3. Analytic hierarchy process group decision making (AHP-GDM) [62].
4. Decision engineering process [63].

A consensus decision-making process promotes the cooperation between all parties involved to formulate a process and to make decisions about it [60]. Although the majority vote is decisive, the minority must still agree with a decision, otherwise a decision will be reconsidered and reformulated to accommodate each party. Consensus decision-making can be helpful if a problem is clearly defined and understood by all stakeholders. One of the biggest challenges, however, is to convince the minority to accept and support the decision.

Voting decision-making is the process by which the position of each stakeholder during a project is evaluated [61]. Majority voting implies 50% of stakeholder support determines the action. Plurality voting assumes that the largest faction of stakeholders determines action. Score voting classifies diverse actions based on stakeholder scores and the implementation of the highest assigned action. Quadratic voting is similar to score voting, although it is measured against preference and intensity of preference.

Voting-based decision-making is most effective when stakeholders clearly understand the impact of actions related to project requirements. However, voting-based decision-making can lead to division between stakeholders if members do not agree on the course of action.

AHP-GDM determines the weight of decision criteria [62]. Stakeholder team up to estimate the relative extent through pairwise comparisons. It is a numerical system that allows comparable criteria, where the criteria are often diverse. The advantage of the AHP-GDM framework is that stakeholders can understand a problem by evaluating the criteria or sub-issues, and consequent actions can be numerically justified. However, the AHP-GDM has an initial higher learning curve compared to similar processes.

The Decision Engineering process is a complex method [63]. Expertise required to accurately calculate the impact of a solution involves consultation with experts in a specific field. The Decision Engineering process is usually further evaluated by using advanced computer software to ensure accurate assumptions and conclusions, and can be implemented if the scope and requirements of the project are clearly defined. This process should rather be avoided if there is uncertainty about the project or if stakeholders do not have access to the required expertise.

It appears from information in Section 1.1 that enterprises specific to this study are not able to apply the Decision Engineering method. The individual bias involved in terms of Consensus and Voting frameworks can be detrimental to successful projects where stakeholders consist of different individuals. The benefit of the Agile framework, which encourages collaborative work, motivates the choice of AHP-GDM.

The Agile framework can best be implemented if a collaborative decision matrix is constructed to guide project decision-making [64]. The AHP-GDM framework is ideal for collaborative projects [62].

The decision criteria required for the AHP-GDM framework should be specified. According to Section 2.3.1 digitisation is used for the modernisation of systems. The factors that successfully digitise a system can be used as criteria for implementation within the AHP-GDM framework.

2.4 Paper-based system digitisation methodology

The diagram below (Figure 2.1) is a representation of the digitisation methodology that will be used in this dissertation to meet the objectives in Section 1.6. The methodology consists of an Agile framework with four repeating cycles, namely stakeholder collaboration, implementation, demonstration, and verification. This is Phase 4 Digitisation Activities, as set out in Section 1.3.

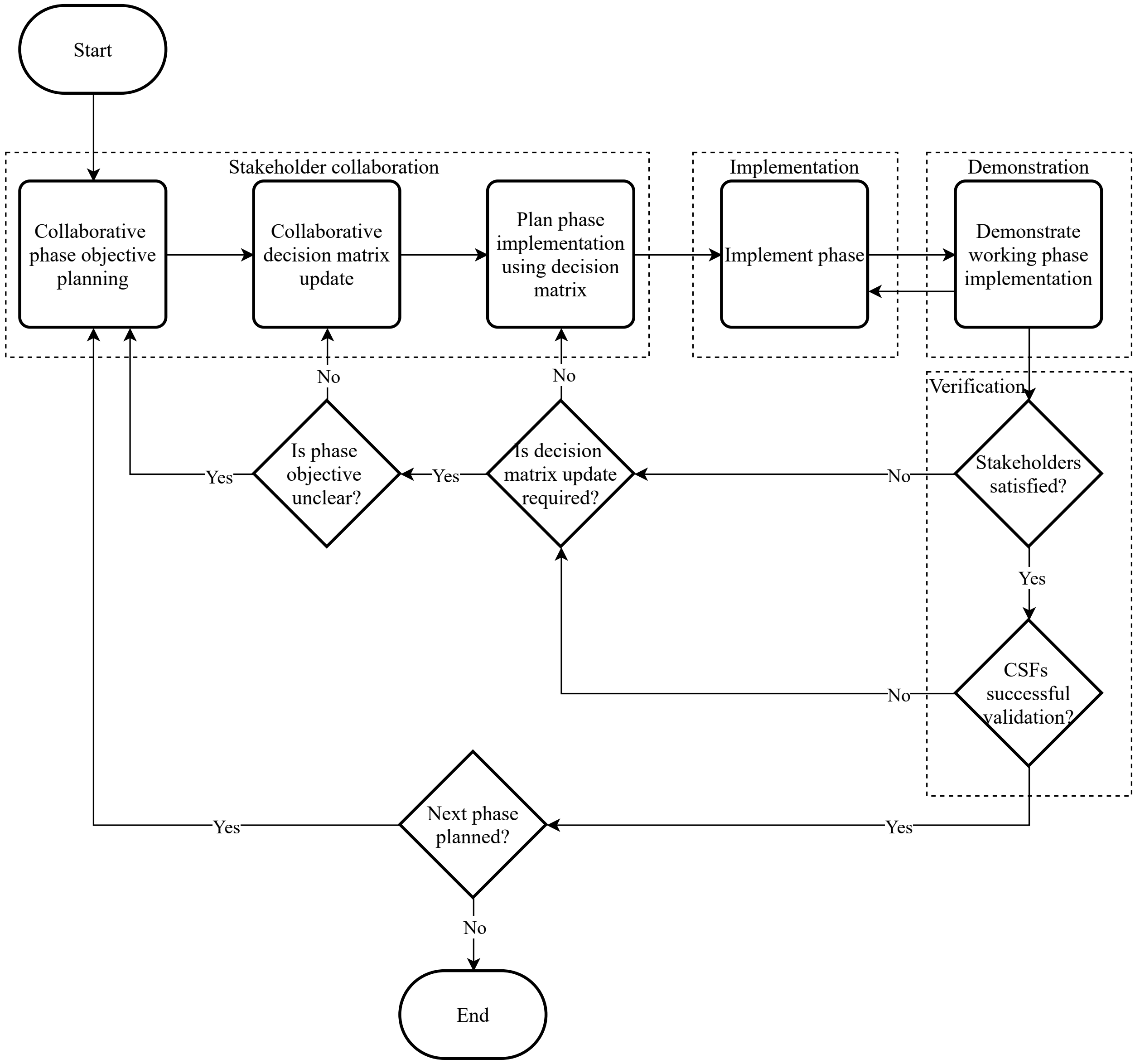


Figure 2.1: Methodology used in diagram format

Candidate systems and stakeholders can be identified by examining companies' paper-based systems according to the Operating Methodology in Section 1.3. Once the candidate paper-based system has been identified, the company's stakeholders can be approached with a digitisation proposal.

Stakeholder collaboration

The successful implementation of the Agile framework is based on the division of a project into phases. These phases contain specific objectives, as set by stakeholders. Complete objectives of the project phase are not yet set at the beginning of the project life cycle but are rather seen as developing guidelines. The phase objectives are set at the beginning of a phase cycle and are updated as required.

Decision-making forms part of an ongoing collaboration during the project. The criteria for a project decision consist of the CSFs of digitization, as set out in Section 1.4.

AHP-GDM (Section 2.3.3) is used as a project decision-making framework. Saaty's 9 system is commonly used to implement AHP-GDM framework to indicate the relative importance between factors influencing a decision [65]. Table 2.3 outlines the evaluation of the impact of factors.

Table 2.3: Saaty's 9 system

Degree of relative importance	**Description**
1	Equally preferred
3	Moderately preferred
5	Essentially preferred
7	Very strongly preferred
9	Extremely preferred
2, 4, 6, 8	Intermediate importance between two adjacent judgements

The problem decision matrix (Equation 2.1)was compiled using the identified factors and Saaty's 9 system [17]. Each factor within the decision matrix is estimated according to the outline in Table 2.3. The estimation is done by stakeholders and a development team, although much value is attached to the opinions of experts. The problem-solving matrix is defined as:

$$D = \begin{bmatrix} d_{11} & d_{12} & ... & d_{1n} \\ d_{21} & d_{22} & ... & d_{2n} \\ . & . & . & . \\ . & . & . & . \\ . & . & . & . \\ d_{m1} & d_{m2} & ... & d_{mn} \end{bmatrix} \tag{2.1}$$

where D is the decision matrix and the factor, d_{mn}, is described as the relative level of importance when comparing the m^{th} to the n^{th} factor.

The factors can be arranged in order of importance using the calculated weights for each factor to indicate decision-making and focus areas. The complete derivation of the decision matrix is indicated in Appendix A.1.

Implementation

The implementation of the phases uses phase objectives with a decision matrix that provides guidance during the project. The digitisation of paper-based systems can be divided into four phases [66]. An overview of the project phase is given in Figure 2.2. The phases are derived from the basic handling of administrative paper-based systems in enterprises, as discussed in Section 1.2.

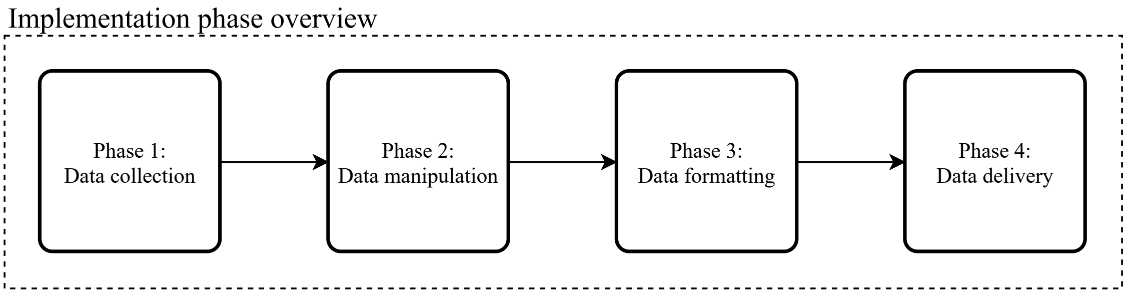


Figure 2.2: Methodology implementation phases in diagram format

The four phases of system creation are illustrated in Figure 2.2. These four phases can be described as [66],

- **Phase 1**: Required functionality to collect data.
- **Phase 2**: Required functionality required to manipulate the collected data.
- **Phase 3**: Required functionality to apply formatting to collected data.
- **Phase 4**: Functionality to deliver the data in the formatted form as required.

The phases are performed sequentially and implemented through the Agile framework (Section 2.3.2).

Phase 1

Data collection is an essential component of the system. The only requirement is the means by which data is collected, namely information forms that must be compiled and submitted to a database management system. A Database Management System (DBMS) is software designed to store, retrieve, define, and manage data in a database. Figure 2.3 illustrates the essential operation of this data collection platform.

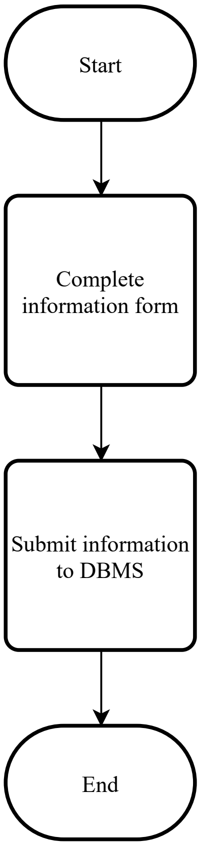


Figure 2.3: Overview of the data collection module

Phase 2

Data recovery from data management systems serve as a platform for users to interact with stored data. The most uncomplicated retrieval uses user data to retrieve information. Information that is detected can then be manipulated by other parts of the system. By using the user information, access control to data can be enforced. Figure 2.4 gives an overview of data recovery. The focal point of this design is to keep all elements – small and single-purpose – to reduce complications.

In Figure 2.4, the "Request data" module uses a user's details with the request details to retrieve the relevant data from a database management system. The "Request data" module would use the user information to enforce strict data access regulations. Once the data has been retrieved, the data is sorted by type. The different types of data are determined by the data structure stored within the database management system. The data is then sent back to the requesting module. Data retrieval must meet the requirement of a single purpose design, which means that only recorded data can be handled.

Since data recovery provides users with access to data, an information display platform is required. The information display platform is a user interface that visualises the structured data. This platform is a web-based application that enables the user to direct different requests. Figure 2.5 gives an overview of the display platform.

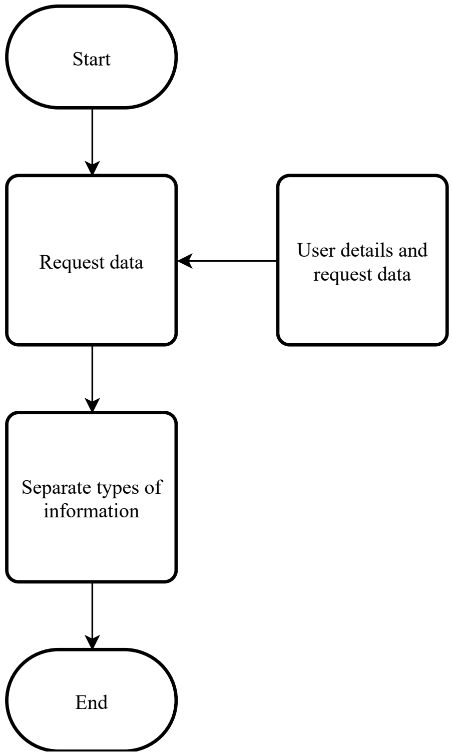


Figure 2.4: Retrieve raw information overview

In Figure 2.5, the request for data is sent to the request data module. The request must contain the user information as well as the type of request. The version depends on the type of request the user made to the data. The render view module controls the user input to lead to the appropriate action. The actions include being able to modify data, the ability to enable document generation and the ability to create document structures. The output action module enables the user to continuously activate more events on the system. These events include changing data, creating relationships and generating documents.

Phase 3

Creating relational connections is the process of enabling a user to combine recorded information to compile a document. The document is the product of the digitised system. Figure 2.6 illustrates an overview of the process of creating relational connections.

In Figure 2.6, the construction of the relational model requires the user's details as well as the data used. Once the model has been compiled, the model can be stored within the database. The saved model can be used to generate delivered documents through the system. Archived data ensures the prevention of data loss.

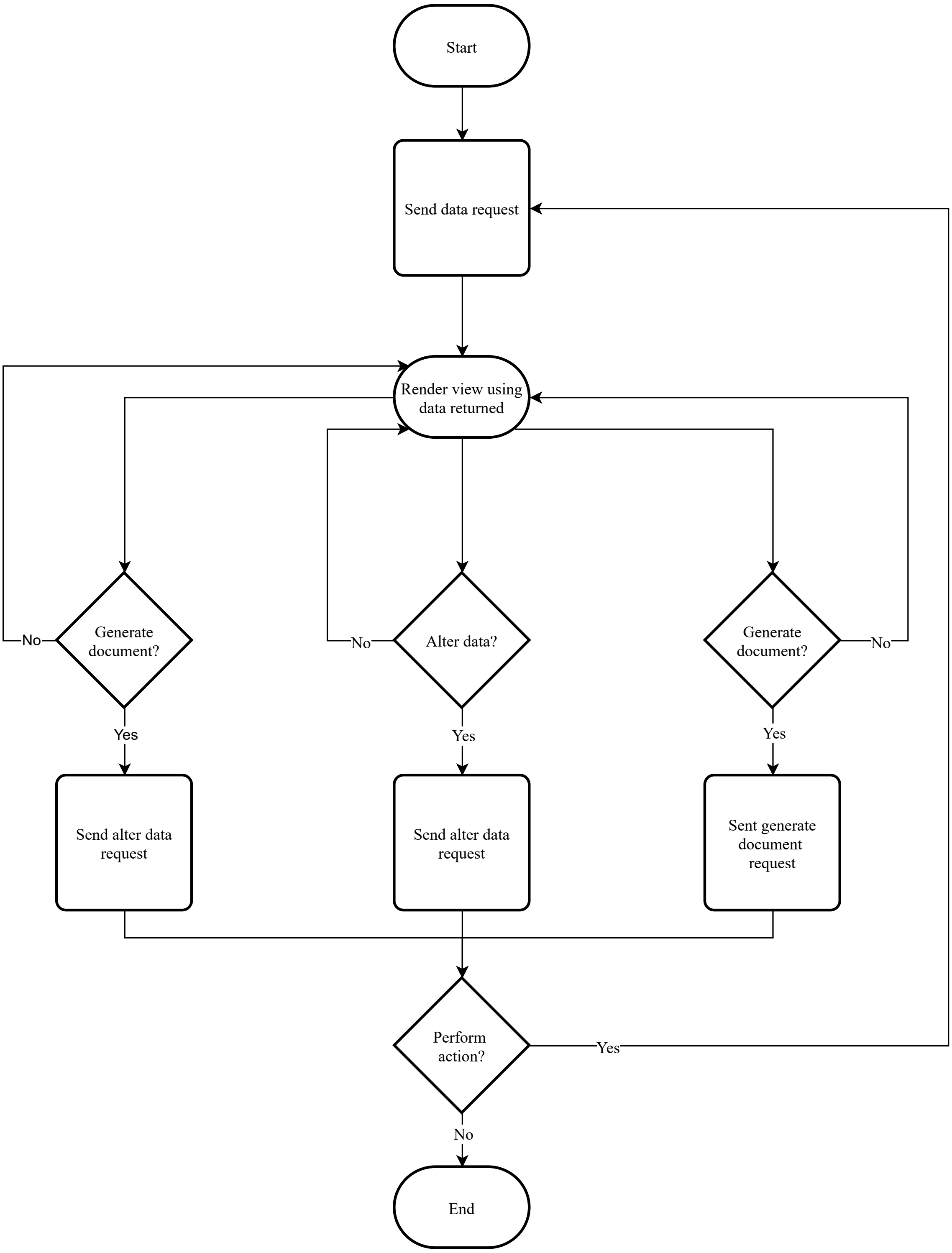


Figure 2.5: Information display platform overview

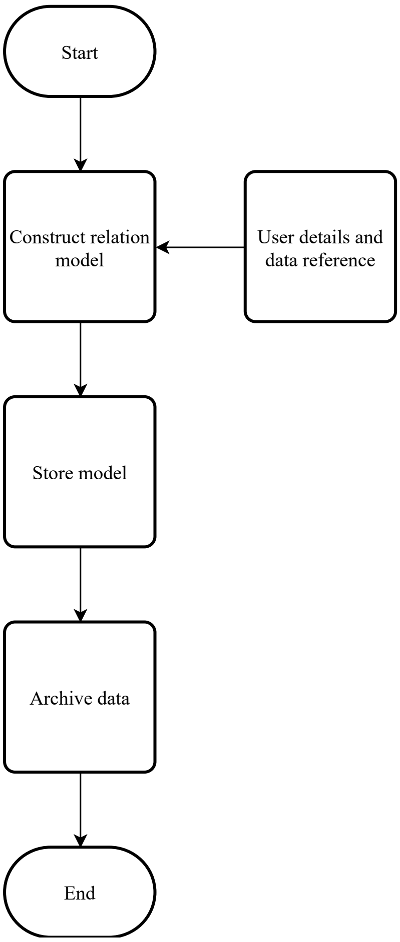


Figure 2.6: Creation of relational structure overview

Phase 4

The generated document is a product of the digitised system. A document is compiled by combining the relational connections made with a document layout. Figure 2.7 gives an overview of the creation of a document.

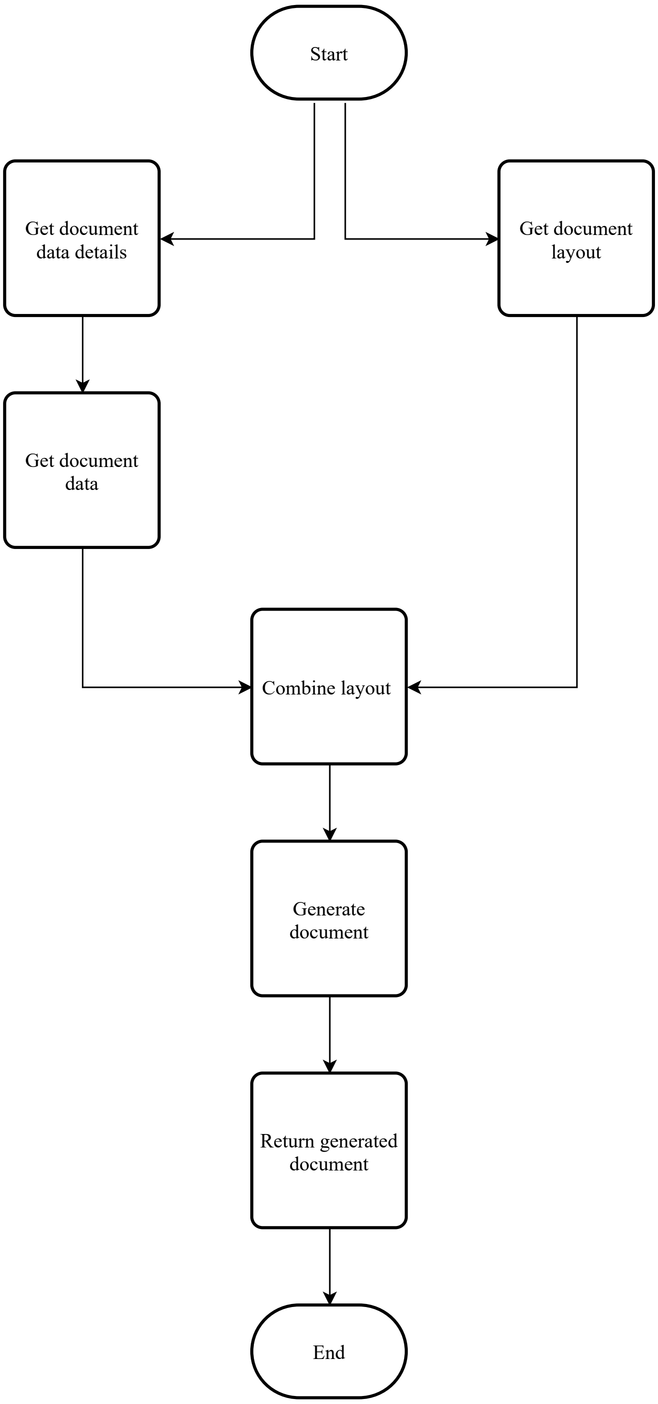


Figure 2.7: Document creation overview

According to Figure 2.7, generating a document is the combination of data and a document layout. The process of retrieving document data and locating the document layout is executed in parallel. The data used is determined by the request parameters. The layout is a fixed framework drawn up by stakeholders. The generated document return type and format is determined by the requirements of stakeholders, as set in Section 2.2.

Demonstration

The demonstration of the work phase implementation enables stakeholders to provide feedback through the implementation cycles, as set out in Figure 2.1. The demonstration shows the phase objectives achieved. In the case of stakeholders who declare that objectives have not been achieved, added or removed, the implementation is re-evaluated and implemented. The demonstration of a phase is completed when stakeholders are satisfied that the objectives have been achieved, and confirmation of CSFs has proved satisfactory.

Implementation verification

Phase implementation is verified through the CSFs of digitisation (Section 1.4). A summary of criteria that CSFs must meet appears in Table 2.4. Requirements related to each CSF criterion, is determined by industry standards obtained from literature regarding the criteria or quantifications of CSFs, which is proof of stakeholder satisfaction. CSFs listed in Table 2.4 are:

1. Ease of information availability.
2. Capability for expansion.
3. Ease of system maintenance.
4. System adaptability.
5. Capability to function as a web-based system.
6. Ease of system migration.

Table 2.4: CSF criteria summary

CSF	Criteria	Requirement
1	Backup policy specified	Specified and approved by stakeholders
	System data availability satisfactory	Above 95 % [67]
	User-perceived data availability satisfactory	Above 95 % [67]
	Storage system availability satisfactory	Above 95 % [67]
	Data loss rate satisfactory	Below 0.3 [67]
	Data loss ratio satisfactory	Below 8% [67]
2	Quantify system capability for expansion with load test	Shown to be stable on stakeholder accepted level
	Proof structural scalability is satisfactory	Stakeholder approved delivery cycle
3	Calculate the Halstead's volume	Preferably below 8000 [68]
	Calculate the McCabe's Cyclomatic Complexity	Preferably below 20 [68]
	Calculate the source lines of code with a revised version including a code/comment ratio	Preferably 33 % ratio [68]
	Proof the Maintainability index is satisfactory	Mandatory value above 20 [68]
4	Describe the system as elements involved	Fully defined system
	Derive the element adaptability index	Fully defined system
	Proof the Architecture adaptability index is satisfactory	Preferably above 70 % [19]
5	Proof that the system is using a standard communication channel	Communication of standard channel
6	Evaluate system communication	Stakeholder approved
	Evaluate system resource dependency	Stakeholder approved
	Evaluate system data access limitations	Data access limitations addressed
	Evaluate system administrator related knowledge	Stakeholder approved
	Evaluate system latency tolerance	No timed system dependency failure

2.5 Summary

The system specifications regarding the digitisation of paper-based systems were discussed in Section 2.2. The specifications are deduced from the literature review and the shortcomings in Table 1.1.

In Section 2.3 an analysis of frameworks delivered that Agile development is a possible candidate for implementation. This implementation further resulted in the selection of AHP-GDM as a project guiding framework. The AHP-GDM framework makes use of factors as criteria for implementation evaluation.

The methodology used to digitise paper-based systems was discussed in Section 2.4. The methodology uses the Agile framework to work iteratively with stakeholders to deliver system implementations that are validated according to CSFs of digitisation. The implementations are divided into four phases, each focusing on one aspect of a paper-based system.

Chapter 3

Results

3.1 Preamble

The methodology presented in Section 2.4 was applied to two case studies to determine whether the proposed solution meets the needs.

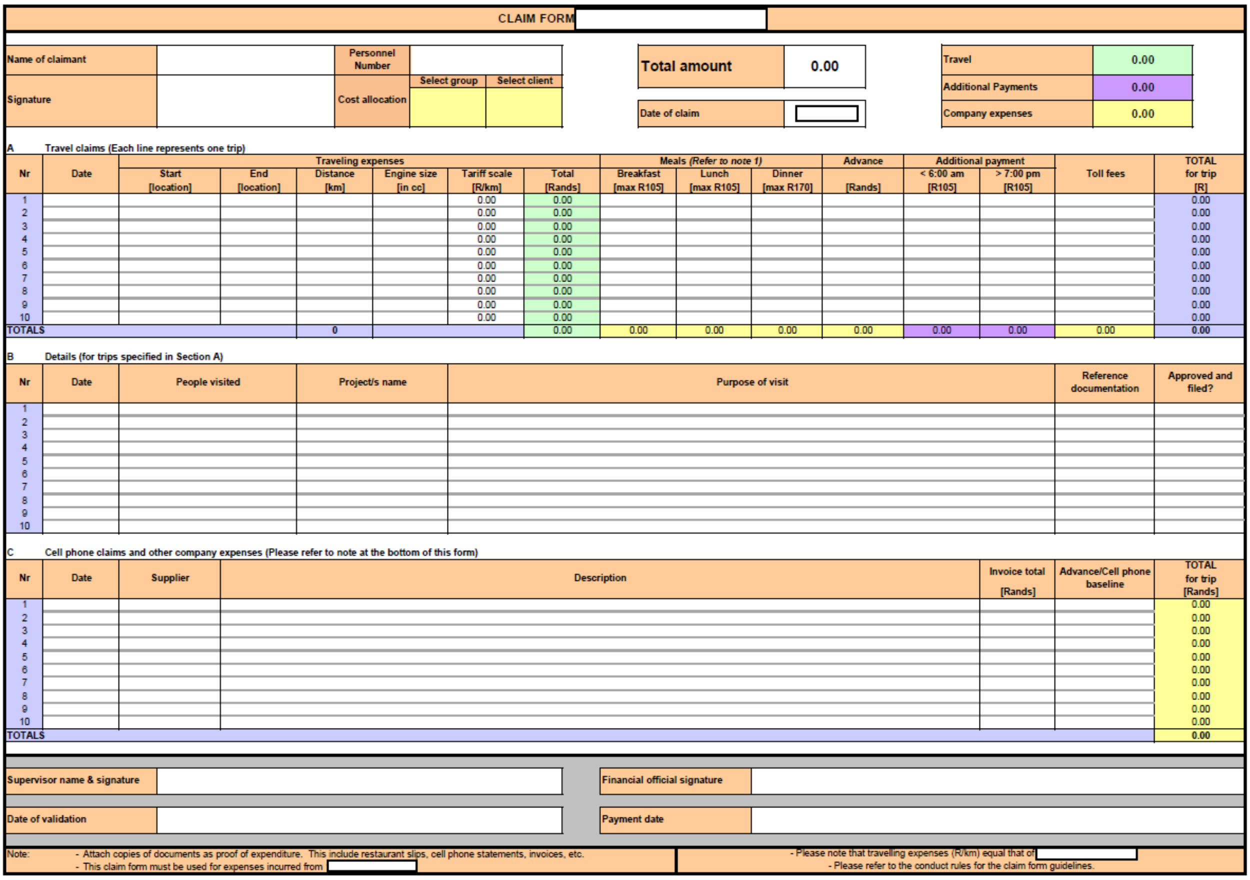
Case study 1 relates to the digitisation of a paper-based reimbursement system of Company A. Company A is a South African industrial company. The company mainly provides services to mines located in South Africa. The employees of company A rely on reimbursement forms submitted to receive reimbursement for costs due to operating activity. Due to the number of employees using the reimbursement system and the loss of time caused by the system, Company A's system was important. The company's existing system has been adapted to a digitised compensation system.

Case study 2 involved the digitisation of a paper-based diesel rebate log system within Company B. Company B is a consulting company located in South Africa. The company provides consultation predominately to mines located in South Africa. As a service, the company wants to digitise the existing paper-based diesel rebate log system of their clients. As Company B wants to deliver a service to a client, they want to ensure that the product they are delivering is reliable and modern to maintain business relation. Company B was identified as having a need to digitise the paper-based diesel rebate log system.

3.2 Case study 1: Compensation system

3.2.1 Background

Figure 3.1 is an example of the compensation form used by Company A. To complete the form, employees must write down their activities per day. These activities include their travel, dining and tolls. Each activity is accompanied by a purpose that explains the need for said activity. Costs that are not part of the mentioned criteria are included in the other expenses.



CLAIM FORM

Name of claimant		Personnel Number			Total amount	0.00
Signature		Cost allocation	Select group	Select client	Date of claim	

Travel	0.00
Additional Payments	0.00
Company expenses	0.00

A Travel claims (Each line represents one trip)

Nr	Date	Traveling expenses						Meals (*Refer to note 1*)			Advance	Additional payment		Toll fees	TOTAL for trip [R]
		Start [location]	End [location]	Distance [km]	Engine size [in cc]	Tariff scale [R/km]	Total [Rands]	Breakfast [max R105]	Lunch [max R105]	Dinner [max R170]	[Rands]	< 6:00 am [R105]	> 7:00 pm [R105]		
1						0.00	0.00								0.00
2						0.00	0.00								0.00
3						0.00	0.00								0.00
4						0.00	0.00								0.00
5						0.00	0.00								0.00
6						0.00	0.00								0.00
7						0.00	0.00								0.00
8						0.00	0.00								0.00
9						0.00	0.00								0.00
10						0.00	0.00								0.00
TOTALS				0			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

B Details (for trips specified in Section A)

Nr	Date	People visited	Project/s name	Purpose of visit	Reference documentation	Approved and filed?
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

C Cell phone claims and other company expenses (Please refer to note at the bottom of this form)

Nr	Date	Supplier	Description	Invoice total [Rands]	Advance/Cell phone baseline	TOTAL for trip [Rands]
1						0.00
2						0.00
3						0.00
4						0.00
5						0.00
6						0.00
7						0.00
8						0.00
9						0.00
10						0.00
TOTALS						0.00

Supervisor name & signature		Financial official signature	
Date of validation		Payment date	

Note: - Attach copies of documents as proof of expenditure. This include restaurant slips, cell phone statements, invoices, etc.
- This claim form must be used for expenses incurred from
- Please note that travelling expenses (R/km) equal that of
- Please refer to the conduct rules for the claim form guidelines.

Figure 3.1: Company A existing compensation form

Employees enter information during a week on a spreadsheet, as illustrated in Figure 3.1. The sheet is usually only available via an employee's company computer or similar electronic device that has access to Microsoft Excel or similar software. Any additional documents or proof of payments must be scanned and attached or the original copy must be attached. A lack of proof of payment documents will result in a refund being refused. The omission of any required information, for any reason, results in refusal of refunds.

Often due to working activity, access to the spread sheet is only available after a few days resulting in forgotten or lost information. After the sheet has been completed, it is printed out and submitted to supervisors. The supervisor reviews the sheet and either approves it, and sends it to the financial department, or returns the document for corrections. The financial department reviews the reimbursement request again and either denies the request, or complete the reimbursement payment.

The following problems are encountered with the current implementation of the compensation system:

1. The form must be continuously updated over time otherwise information may be forgotten.
2. The form can only be updated with Microsoft Excel or similar software on a computer

or similar device.

3. All proof of payment must be kept over time to attach to the final printed document.
4. Making photocopies of each proof of payment in the archive is tedious and time consuming.
5. Proof of payment's paper wears out over time, causing information to be lost.
6. Access to information on the compensation form is performed manually. It takes time, is inefficient and tedious.
7. The submitted and processed compensation form requires storage facilities to file the documents for the legally required five years.
8. Access to the archive for compensation forms is time-consuming and it can take days with older papers stored in storage facilities.
9. Modifications to the template means that users have to make sure that they are using the correct version of the template.

3.2.2 System implementation

The system implementation followed the methodology, as set out in Section 2.4. The implementation of the project began with a consultation with stakeholders according to the methodology. The stakeholders consist of seven parties, which include the Head of the Development Department, two team leaders, two senior developers and the Head of the Finance Department.

Consultation results from a decision matrix, as contained in Table 3.1. The particular Table is the final product of an iterative process.

Table 3.1: Compensation system digitisation decision matrix

	Availability	Expansion	Maintenance	Adaptability	Web-connected	Migration
Availability	1	8	6	8	0.143	4
Expansion	0.125	1	0.2	8	2	8
Maintenance	0.167	9	1	7	6	5
Adaptability	0.125	0.125	0.143	1	0.125	8
Web-connected	7	0.5	0.167	8	1	2
Migration	0.25	0.125	0.125	0.125	0.5	1

According to Table 3.1 the consistency index, C_I, and consistency ratio, C_R can be calculated (Appendix B.1) with a calculation

$$\lambda_{max} = 11.599$$
$$C_I = 1.119$$
$$C_R = 0.903 = 90.3\%$$

leading to the order of importance, namely:

1. Maintenance,
2. Availability,
3. Web-connected,
4. Expansion,
5. Adaptability,
6. Migration.

The resulting sequence results in a broad system implementation according to the phases set out in the methodology. This system implementation is presented to stakeholders and is continuously updated as the project develops. This evolution forms part of the Agile framework.

Following the methodology, the system can now be designed using the ordered CSFs as guideline. The highly valued CSFs – Maintenance and Availability – are the focal point of all design decisions. The first iterations of design and implementation are driven to complete Phase 1, according to the methodology. Phase 1 and each phase that follows provide a list of the design decisions taken to ensure that the CSFs are the focal point of the project and that the order of importance, as seen by stakeholders, is met.

The details of every iteration within this digitisation project will not be presented but a summary of some problems encountered is set in Table 3.2. The summary shows the most important decisions made through the phases and how the CSF order played an important role.

Table 3.2: Summary of issues resolved through the use of ordered CSFs

Issue	Resolution
Data collected format	Due to valued maintenance, it was determined that storing the data in JSON[1] format within a non-relational database would be the best solution. For more information on non-relational database, see Jatana et al. [69].
Document delivery format	The document delivery format – PDF – was requested by the Finance Department to ensure consistency between systems as consistency improves the availability of the delivered document to existing systems.
Access control	Access to data was verified through the system user credentials. This decision was motivated by the need for availability of information so that future systems could possibly make use of collected data.
Stakeholder collaboration meetings	Meetings with stakeholders had issues with arranging time and locations that suited everyone. To resolve this, we arranged online video meetings to accommodate for everyone's schedule and had a monthly get together for in person discussions.
Initial decision matrix complexity	The stakeholders initially misunderstood elements of the decision matrix. This initial confusion was resolved by continuous iterations where the outcome was explained using the resulting decision matrix.
Demonstration	Demonstration of the system was most effective when stakeholders had the time to work with the system on their own. To utilise this, stakeholders were encouraged to interact with the system outside of demonstration meetings. Any feedback given was then communicated with all stakeholders and if necessary, a meeting was scheduled.

[1]JSON (JavaScript Object Notation) is a lightweight data-interchange format. It is easy for humans to read and write. It is easy for machines to parse and generate.

Verification	The verification of satisfaction led to prompts of feature requests outside the stakeholder collaboration phase that would spiral if left unchecked. To address these feature requests stakeholders were encouraged to formalise requests in the collaboration phase so that everyone involved would be aware of discussions.

Phase 1: Data collection

Data collection implementation of a system involves the creation of a mobile application. A mobile application is selected as the best candidate because:

1. The application can be designed to be small and light weight with the sole purpose of being a collection method. This lightweight implementation is more maintainable. As system maintainability has been identified as the most important CSF, a mobile application seems to be the most suited application. However, the cross mobile platform implementation that ensures availability leads to longer implementation cycles due to bigger difficulties.

2. Information access on mobile applications is more available as the popularity of smartphones has increased. Installation through applications stores provides wider application access. Stakeholders accepted the limitation of mobile data being required on mobile devices or alternatively through Wi-Fi access.

3. The collection of data through a mobile application uses cellular or other internet access connections that are typical of smartphones. This internet connection ensures that the devices can perform as a web-connected system. The stakeholders assumed that this would have consequences for data users.

4. A mobile application that serves only one user results in a system that can easily expand to the demand of the single user. The application communicates with the server that handles the recording of the information in a database.

5. The mobile application and server are the only systems involved with data collection, which improve system compatibility. Less involved systems lead to higher system adaptability.

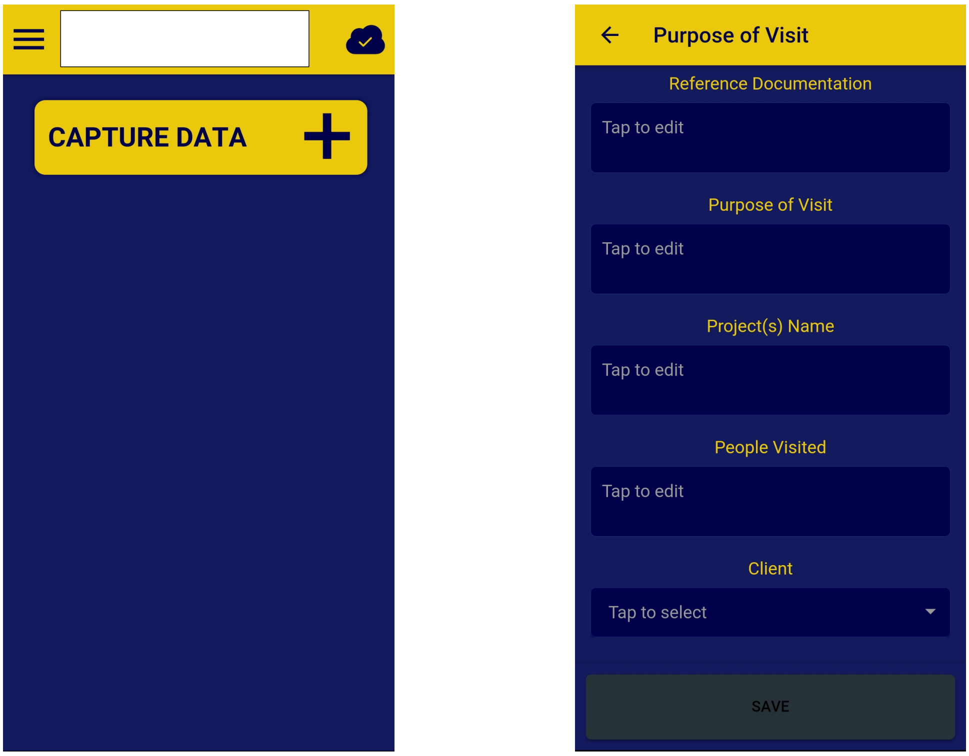
6. The mobile application which is cross platform enhances the readiness for application migration. However, the lightweight design makes it easier to re-implement such a system if necessary.

Other system implementation options that were considered are integrating a data collection method into the company's existing system and improving the existing Excel data collection method. Collaboration with stakeholders led to the choice of the mobile application.

The mobile application responsible for data collection is implemented, as shown in Figure 3.2 and Appendix B.2. The different forms that can be filled out are purpose of visit, travel expenses, meals, inconvenience, tolls, other expenses and advances. These forms relate to the fields in the compensation document.

Figure 3.2(a) represents the main landing page for the application. From this page navigation is possible to capture data and to synchronise it with the database.

Figure 3.2(b) is a form that enables users to capture the purpose of visit data. Fields derived from the original paper-based system (Figure 3.1) are displayed as *Date*, *People Visited*, *Project Name*, *Purpose of Visit*, *Reference Documents*, *Image of Documents*, *Approved and Filed*, *Client* and *Group*.



(a) Mobile application landing page (b) Mobile application purpose of visit form

Figure 3.2: Mobile application: Compensation form

Phase 2: Data manipulation

The data manipulation implementation of the system involves the creation of a web-platform that is integrated into the system of the company. Such a platform is considered the best candidate for the following reasons:

1. The existing system of Company A is a web-platform system. The integration of the interactive platform leads to fewer complications between systems and consequently less maintenance. The maintainability of the system is improved by the reduction of inter system complications. Digitisation of a system increases the system load on an existing system to which stakeholders have agreed.
2. The ease of information availability is the biggest driver for choosing integrated system implementation. By storing and reading data in an existing environment, stakeholders are assured of system reliability. The maintenance policy of an existing system applies to the data collected. The collected data stored within the DBMS gives rise to more storage requirements that were not originally provided for in the system. Stakeholders agreed to evaluate the new requirements and adjust the DBMS specifications as necessary.
3. The existing system is implemented as a web-platform resulting in the implementation inheriting the ability to function as a web-connected system.
4. Implementation in an existing system leads to potential expansion. The scalability will depend on an existing environment in which the system is introduced.
5. By implementing a system in an existing environment, adaptability can be maintained. There is also no additional dependence on other systems.
6. Implementing a method extension in an existing environment ensures migration readiness. By isolating this system, it can be easily removed/moved from the existing system to a new system.

Another system implementation option is the creation of a new web-based platform exclusively for manipulating recorded data. Stakeholders did not choose this option as they felt that available information, when needed, would not be sufficient for their exiting environment.

Figure 3.3 depicts the integrated platform with which users manipulate recorded data. The platform was introduced into the existing system of Company A. A specific section for manipulating visitor entries appears in it. Appendix B contains other sections with a similar design. To integrate with an existing system, SQL data interactions are required. This requirement is case study specific.

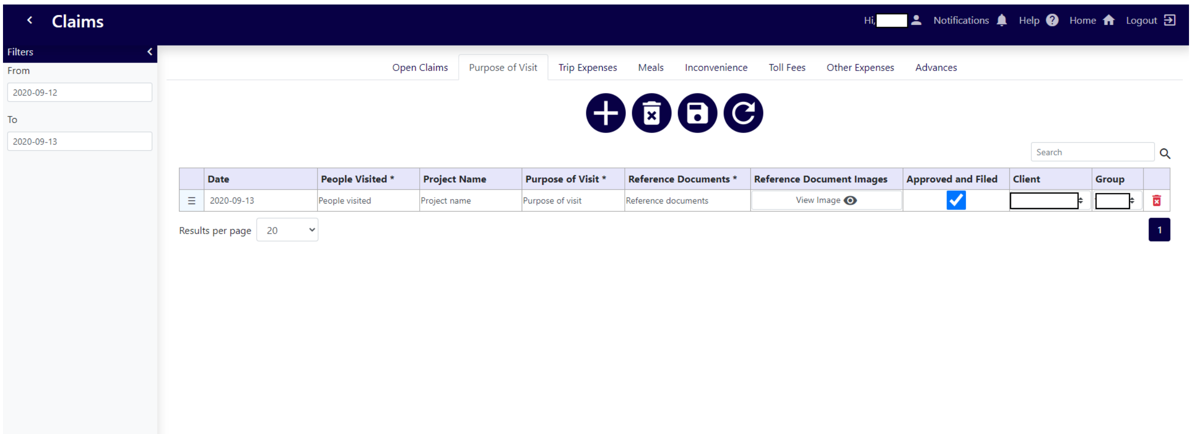


Figure 3.3: Data manipulation platform

Phase 3: Data format

The Phase 2 system implementation has led stakeholders to unanimously agree that the data formatting should be extended on the web-platform. The evaluation of CSFs remained unchanged. The ease of availability of information was again the driving force behind the chosen implementation. However, an extensive system still stores previous information in a localised area.

Figures 3.4 - 3.6 contain the platforms on which users can enter their compensation request. Stakeholders requested that "claim" rather than "compensation" be made by the implementation. The illustration below indicates the amendment field in which the term "compensation" appears. The title enables users to better label their request. In the "Supervisors" field users have an option of pre-filled details of their respective supervisors regarding remuneration.

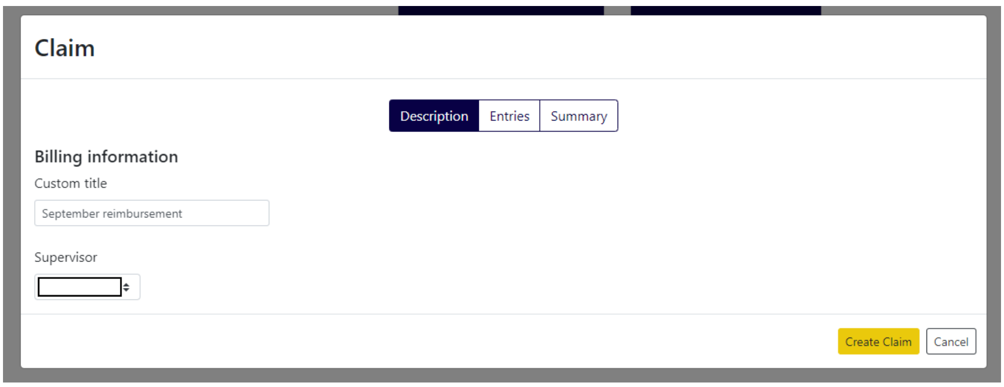


Figure 3.4: Data formatting platform: Description

Figure 3.5 illustrates the entries used to set up a relational model. The entries are grouped according to date. Stakeholders asked for an option to automatically balance meals during the development phase.

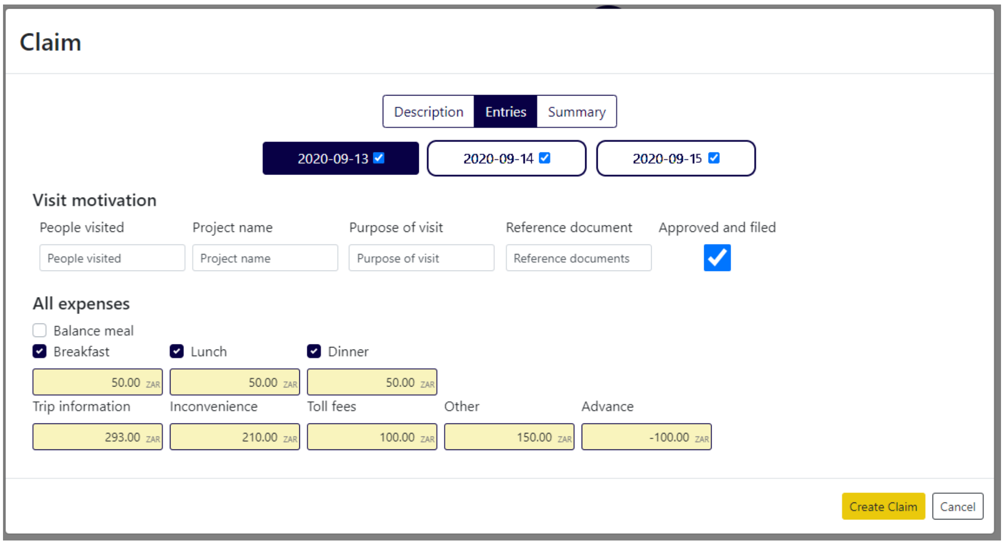


Figure 3.5: Data formatting platform: Data entries

Figure 3.6 contains a summary of the refund form with the total compensation at the end.

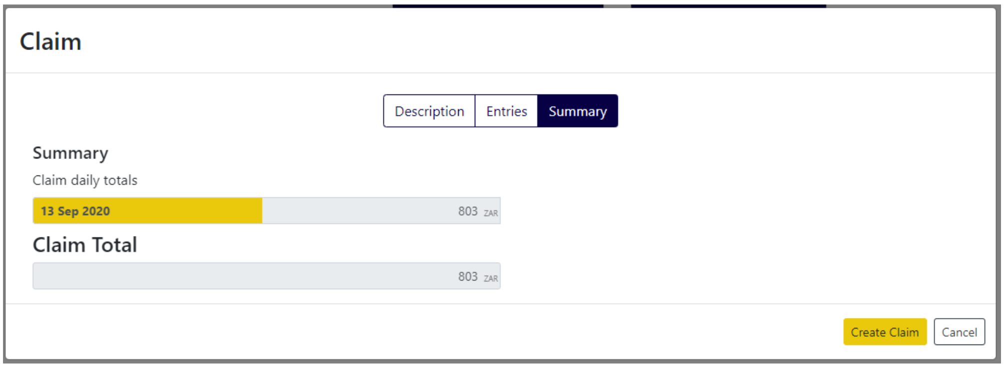


Figure 3.6: Data formatting platform: Summary

Phase 4: Data delivery

Stakeholders requested that the system implementation for document delivery should be an extension on the system in Phase 2. The driving force behind this decision is the ease of system maintenance and availability of information. Stakeholders agreed that the expansion of the system would result in a more sustainable system as opposed to creating a new subsystem to handle document delivery.

The delivered document is depicted in Figure 3.7. Stakeholders requested that the structure be the same as the original. After the document is generated, the document is downloaded in the user's browser. Fields with images associated have a number linked to images attached to the document, which serves as proof of payment.

Name of claimant	
Personnel number	

Signature	

Total amount	803.00
Date of claim	2020-09-13

Travel	293.00
Additional payments	210.00
Company expense	300.00

Travel claims

	Traveling expenses						Meals			Additional payment			
Date	Start [location]	End [location]	Distance [km]	Engine size [in cc]	Tariff scale [R/km]	Total [Rands]	Breakfast [max R105]	Lunch [max R105]	Dinner [max R170]	<6:00 am [R105]	>7:00 pm [R105]	Toll fees	Total for trip [R]
2020-09-13	Start location	End location	100.00	0-1400	2.93	293.00	50.00[2]	50.00[3]	50.00[4]	105.00	105.00	100.00[6]	753.00
TOTALS			100.00			293.00	50.00	50.00	50.00	105.00	105.00	100.00	**753.00**

Trip details

Date	People visited	Project/s name	Purpose of visit	Reference documentation	Approved and filed?
2020-09-13	People visited	Project name	Purpose of visit	Reference documents[1]	Yes

Cell phone claims and other expenses

Date	Supplier	Description	Invoice total [Rands]	Advance/Cell phone baseline	TOTAL for trip [Rands]
2020-09-13	Supplier	Description	150.00[5]	100.00[7]	50.00
TOTALS					**50.00**

Supervisor : ____________

Date of validation : ____________

Financial official : ____________

Payment date : ____________

Image references indicated above entry

Figure 3.7: Data delivery document: Reimbursement form

3.2.3 Implementation verification

The system implementation verification is done as set out in the method followed. The implementation is continuously evaluated on the CSFs. Failure to meet the required levels of satisfaction will result in redesign and implementation.

To quantify the ease of available information, the system and recorded data were analysed. Consequently, the data was extracted and evaluated from the system for a period of 11 days to be evaluated. Due to the sensitive nature of the information, only the date of recording and the type of document were evaluated. Findings (Table 3.3) include system performance and data recording statistics, which derived from the existing system and the performance of the system implementation. The existing system performance information is provided by the system administrator.

Table 3.3: System availability parameters

Parameter	**Symbol**	**Value**	**Description**
Hours in a month	H_m	720 h	The number of hours in a 30-day month
Work hours in a month	H_w	160 h	The number of working hours per month (8 hours per working day, 5 days a week)
Start date	-	2020-08-31	Observation starting date
End date	-	2020-09-11	Observation final date
Number of hours analysed	-	264 h	Number of hours between starting and ending observation
Number of entries	-	788 *Entries*	Number of information transactions while observing
Transaction arrival rate	λ_a	2.98 $Entries/h$	The information transactions per hour
Storage failure rate	λ_f	2 $Failure/year$	Number of storage failures per year. This is an overview of the performance of the existing system
Coverage of storage failure	C	98 %	The percentage of information that is ensured to be secure when storage failure occurs
Time between full backups	T	168 h	The number of hours between full backup of data
Full backup time	-	20 min	The estimated time that a database is occupied due to backups
Hours down due to backup	P_d	1.33 h	Number of hours the database is occupied due to backups over a four-week period
System down time over month	S_d	2 h	Estimated time the system is unavailable over a four-week period

According to the backup policy (Table 3.3) a complete backup of data must be done weekly – a feature of the existing system. The transaction arrival rate is determined by the number of entries per number of hours analysed. The coverage of storage failure, full back up time, hours off due to backup and system time during the month are features of the existing system. Table 3.4 shows the resulting availability.

Table 3.4: System data availability evaluation

Metric	Result	Meets requirement
System data availability	99.8 %	✓
User-perceived data availability	97.9 %	✓
Storage system availability	99.7 %	✓
Data loss rate	0.0274	✓
Data loss ratio	0.921 %	✓

The values in Table 3.4 (Appendix B.4) were derived using values provided in Table 3.3 and the verification set out in the methodology. The availability of data met the needs of stakeholders. The data loss ratio is low enough so that the specified backup policy is sufficient to prevent data loss.

The digitised system capability for expansion quantifications is set out in Figures 3.8 & 3.9. The load scalability is determined by varying the load on the system and measuring the performance of the system on requests.

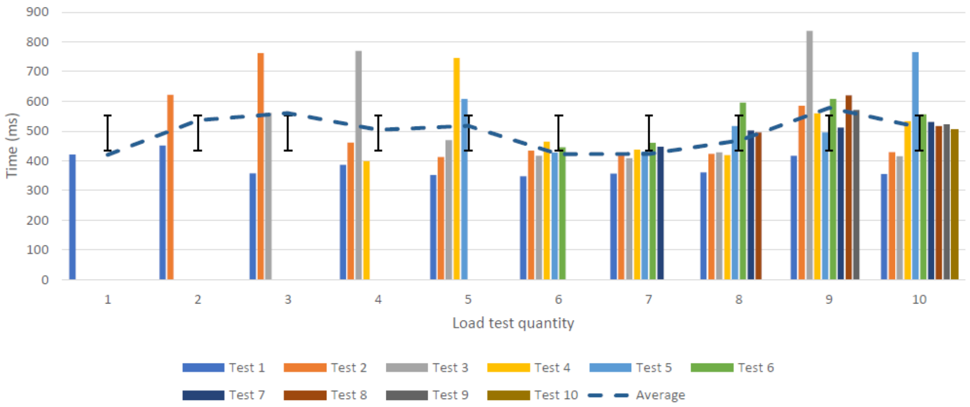


Figure 3.8: Compensation load scalability

The following properties can be deduced from a calculation of the average processing time (Figure 3.8):

1. Average of 494 ms.
2. Standard deviation of 58.25 ms.

3. Maximum of 432 ms, 615 ms, 758 ms, 761 ms, 746 ms, 455 ms, 449 ms, 597 ms, 821 ms and 776 ms for Test 1 through 10 respectively.
4. Minimum of 432 ms, 451 ms, 362 ms, 395 ms, 356 ms, 357 ms, 356 ms, 357 ms, 411 ms and 358 ms for Test 1 through 10 respectively.

According to the above, the average execution period remains low despite the divergent load. The scalability evidence of the system load is satisfactory according to the stakeholder needs.

Structural scalability of the system implementation is shown in Figure 3.9. The Figure illustrates a timeline and does not indicate any information on the y-axis. The short iterative delivering of implementations indicates structural scalability. The Agile methodology is clearly visible through the rapid sequence of phase requirements set by stakeholders. The successive delivery indicates a satisfactory structural scalability.

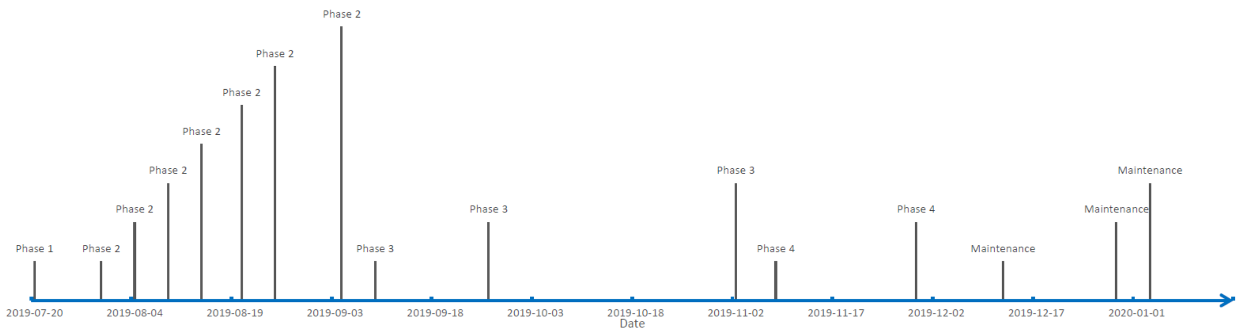


Figure 3.9: Compensation software delivery timeline

Quantification of the ease of system maintenance is shown in Table 3.5. Calculation of the values of the maintainability index is calculated using Visual Studio's built-in analysis tool. The labelled areas Controllers, View model grids, View model image handling and View model pages are only a convention to refer to the functional areas of the implementation. Each area is evaluated separately, as well as the overall performance. The ease of system maintenance is evaluated according to the overall maintenance index obtained.

Table 3.5: Reimbursement system maintainability

Area	**Maintainability index**	**Cyclomatic complexity**	**Depth inheritance**	**Class coupling**	**Lines of source code**	**Lines of excecutable code**
Overall	88	3	2	4	26	3
Controllers	80	619	3	146	5 559	1 694
View models overall	91	17	1	12	59	9
View model grids	87	559	2	43	1 534	544
View model image handling	92	8	1	3	19	1
View model pages	92	86	1	24	244	36

The overall maintenance index of the system is 88. Therefore the requirement of stakeholders is met.

The quantification of system adaptability requires that the system be described according to relevant elements (Figure 3.10). Only the implemented system is evaluated and not the overall system environment. According to the illustration the system has 5 customisable elements, namely C#, SQL and Mongo. There are a total number of 7 elements in the system, namely C#, SQL, Mongo, Html, LaTeX where C# is present on three components (Generate document consists of C# and LaTex, Modify/Structure data consists of C#, SQL and Mongo and lastly Save data consists of C# and Html).

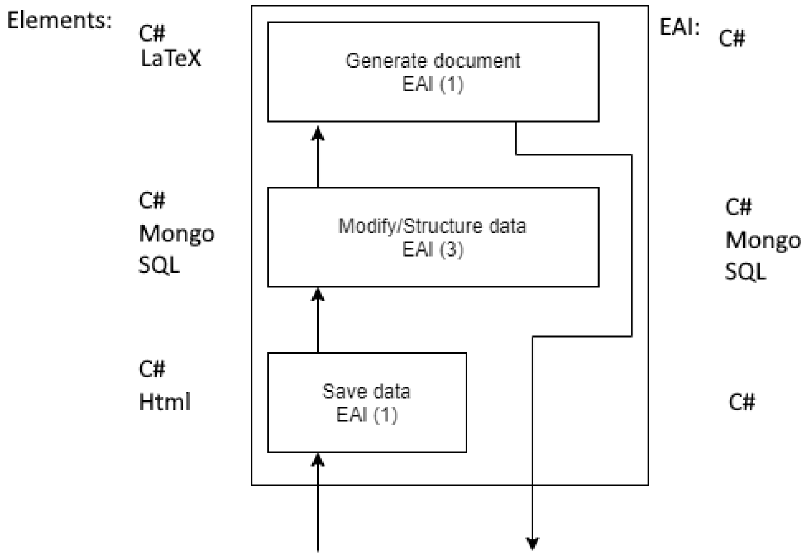


Figure 3.10: Reimbursement system Adaptability

According to Figure 3.10 the AAI can be calculated as:

$$\begin{aligned} AAI &= \frac{EAI}{T} \\ &= \frac{5}{7} \\ &= 0.714 \\ &= 71.4\% \end{aligned}$$

where EAI is the element adaptability index, T is the total number of elements and AAI is the architecture adaptability index. Although the architecture adaptability index is not as high as possible, it nevertheless satisfies the needs of stakeholders as they have rated this CSF lower.

The system migration analysis involves the evaluation of all dependencies. The system is dependent on the SQL- and Mongo-database as well as the LaTeX structural file. The system is migration ready because:

1. The databases are presented on a web platform, which regulate access restriction.
2. The LaTeX structural file is stored in a cloud storage system presented on Google Cloud Platform (GCP), which ensures reliable access to authorised connections.
3. The system administrator appointed has years of experience maintaining database, server and file system operations for product systems. The stakeholders are satisfied with the cloud system being entrusted to their expertise.
4. The reimbursement system has no time dependency that would prevent it from operating within a cloud environment.

Due to this dependency, restrictions on migration are removed, leading to the satisfaction of stakeholder needs.

3.2.4 Results

System implementation resulted in futile time avoidance per week (Table 3.6). The values were obtained by observing employees before the digitisation of the paper-based system and after implementation of the system. Selected employees were requested to record the time spent on the Compensation Form using the legacy system and thereafter the digitised system. The difference between these values gives an estimate of the futile time avoided.

Table 3.6: Reimbursement futile time avoided

System aspect	**Time avoided**
Data recording	21.93 *min*
Document construction	6.78 *min*
Processing document	4.45 *min*

According to Table 3.6 the compensation system of Company A improved by reducing the overall futile time spent per week. The monetary impact of the system implementation can be calculated according to the values in Table 3.6. Table 3.7 records the futile time avoided results in cost-savings.

In Table 3.7 the annual savings is calculated at approximately R620 000 where 100 employees, consisting of mechanical and professional mechanical engineers make use of the compensation system. The average hourly rate is not a fixed salary for Company A, but rather represents a conservative average hourly salary in South Africa. The mechanical engineering group consists of engineers with experience between one and four years. The full calculation appears in Appendix B.5.

[2]URL: `https://www.payscale.com/research/ZA/Job=Mechanical_Engineer/Salary`
[3]URL: `https://www.payscale.com/research/ZA/Job=Professional_Engineer/Salary`

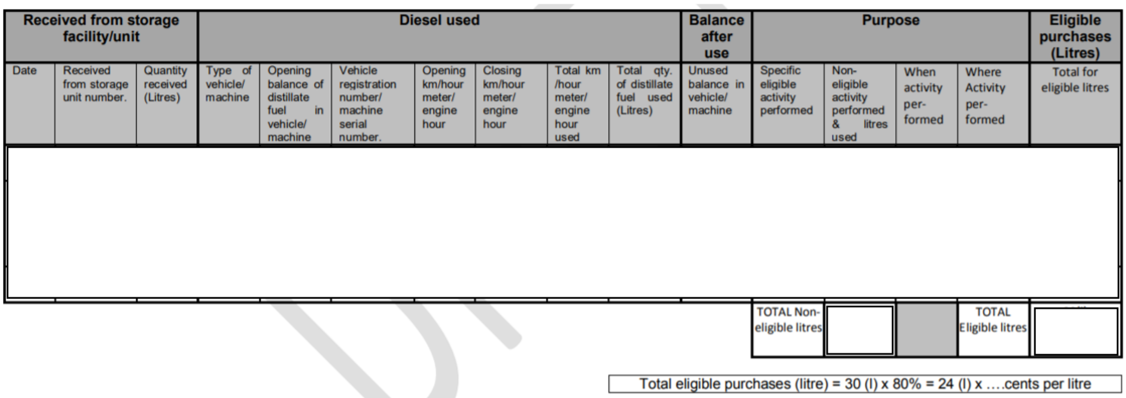
Table 3.7: Implementation cost avoidance

Employee description	**Average hourly rate**	**Percentage of group**	**Annual saving**
Mechanical engineer	R120.00[2]	80 %	R254 719.70
Professional mechanical engineer	R700.00[3]	20 %	R371 466.30
Total			R626 186.00

3.3 Case study 2: Diesel rebate system

3.3.1 Background

Figures 3.11 & 3.12 show the diesel rebate system. Employees must provide information of each diesel interaction. The information is recorded on sheets of paper that employees must keep with them. Figure 3.11 shows the entries that need to be provided after diesel has been supplied to a machine. Figure 3.12 shows the entries that need to be provided after diesel has been stored. Both forms are in line with the requirements set by SARS[4] to submit for diesel tax rebate. The forms are completed underground. The information required includes the reference number on the machine, the amount received, the odo-meter on the machine and the location where diesel is received.



Received from storage facility/unit			Diesel used							Balance after use	Purpose				Eligible purchases (Litres)
Date	Received from storage unit number.	Quantity received (Litres)	Type of vehicle/ machine	Opening balance of distillate fuel in vehicle/ machine	Vehicle registration number/ machine serial number.	Opening km/hour meter/ engine hour	Closing km/hour meter/ engine hour	Total km /hour meter/ engine hour used	Total qty. of distillate fuel used (Litres)	Unused balance in vehicle/ machine	Specific eligible activity performed	Non-eligible activity performed & litres used	When activity per-formed	Where Activity per-formed	Total for eligible litres
											TOTAL Non-eligible litres			TOTAL Eligible litres	

Total eligible purchases (litre) = 30 (l) x 80% = 24 (l) x ….cents per litre

Figure 3.11: Company B existing diesel usage form

[4]South African Revenue Service

Opening metre reading		Purchase receipts			Metre reading before disposal	Disposal				Metre reading after disposal
Date	Opening balance reading (litres)	Invoice number	Date	Litres received	Opening balance plus receipts	Date	Litres disposed (if losses occurred, also note here)	Disposed to each vehicle/unit to be indicated separately	Purpose of Disposal (State whether or eligible or non-eligible use)	Opening balance plus receipts minus disposals
Opening balance		**Plus**	**Total Received**		**Minus**	**Total Disposed**		**equals**	**Closing Balance**	

Figure 3.12: Company B existing diesel storage form

The problems with the current implementation of the diesel rebate system are:

1. Before any diesel exchange can take place there must be an appropriate form present.
2. Omission of entries results in unbalanced diesel rebate forms, which may lead to fewer diesel rebate opportunities.
3. An underground work environment is not suitable for handling paper or storage purposes.
4. The manual extraction of information is extremely tedious and requires meticulous work to ensure that all the information is correctly interpreted and stored.
5. Errors on data recording or extraction on the form results in wasted diesel rebate opportunities.

3.3.2 System implementation

The system implementation followed the phases described in the methodology (Section 2.4). The implementation of the project started with a stakeholder consultation consisting of six parties, which included 1 development team leader, 1 senior developer, 2 project leadership engineers and 2 project engineers.

The consultation gave rise to the compilation of a decision matrix (Table 3.8).

Table 3.8: Diesel rebate system digitisation decision matrix

	Availability	Expansion	Maintenance	Adaptability	Web-connected	Migration
Availability	1	7	9	8	0.143	8
Expansion	0.143	1	0.125	5	0.143	6
Maintenance	0.111	8	1	8	8	8
Adaptability	0.125	0.2	0.125	1	0.125	6
Web-connected	7	7	0.125	8	1	6
Migration	0.125	0.167	0.125	0.167	0.167	1

Table 3.8 is the final product of an iterative process. Figures in Table 3.8 result in the following calculation (Appendix C.1)

$$\lambda_{max} = 11.813$$
$$C_I = 1.163$$
$$C_R = 0.937 = 93.7\%$$

resulting in the order of importance:

1. Availability,
2. Maintenance,
3. Web-connected,
4. Expansion,
5. Adaptability,
6. Migration.

The resulting order leads to the compilation of a broad system implementation according to the phases set out in the methodology. This system implementation is presented to stakeholders and is constantly updated as the project evolves. This evolution forms part of the Agile framework.

Following the methodology, the system can now be designed using ordered CSFs as a guideline. The higher-rated CSFs, Availability and Maintenance, are the focus of all design decisions. According to the methodology, the first iterations of design and implementation are driven to complete Phase 1. Phase 1 and each thereafter has a list of design decisions taken to ensure that the CSFs are the focal point of the project and that the order of importance, as seen by stakeholders, is met.

Although the details of each iteration of this digitisation project are not discussed, a summary of some of the problems encountered is set out in Table 3.9. The summary shows the most important decisions made through the phases and the important role that CSF order played.

Table 3.9: Summary of issues resolved through the use of ordered CSFs

Issue	**Resolution**
Data collected format	As maintenance is considered very valuable, stakeholders considered storing the data in JSON format in a non-relational database as the best solution. For more information on non-relational databases, see Jatana et al. [69].
Document delivery format	The format for delivering documents was specified by collaboration, which required a PDF. The decision stems from the need to submit the document to SARS in a generally accepted format.
Client system adoption	The mobile application implemented to collect the data has been kept in a simplified form for easier use of the system. The simplicity and availability of the system was necessitated by collaborative work. Continuous iterations on simplification of the application were followed after opportunities to reduce unnecessary complications were identified by stakeholders.

Phase 1: Data collection

The data collection implementation of the system involves the creation of a mobile application. A mobile application is selected as the best candidate because:

1. The ease of information availability was considered as the most important factor, therefore the application is built to easily record the information and store data securely. The application, available for installation through Google Play Store and Apple Store offers wide access.

2. The application is small and light weight and is implemented only as a data collection method. Maintaining such a smaller system is much easier.

3. Stakeholders have compromised on choosing a mobile application knowing that it is a good candidate option, but they will have to provide a more robust mobile device given the conditions of a mining environment. The mobile device provided by their service, will result in higher mobile deployment costs.

4. The underground environment of the data collection is a problem for internet connection. Implementing the application to store the information until an internet connection is established, removes the restriction.

5. The mobile application that can store the recorded information until an internet connection is established results in a greater system extensibility. Stakeholders accept the compromise made not to design the application to work under the pretense of constant network access, but rather to design the application to only try data synchronisation when internet network is available and give mine personnel instruction to synchronise after each working shift.

6. The mobile application and server are the only systems involved in data collection and improve the system's adaptability. The fewer systems involved lead to a higher system adaptability.

7. The mobile application being cross platform improves the migration readiness. The lightweight design of an application makes it easier to re-implement such a system if needed.

Stakeholders who have to remove the limitations set by the existing paper system and who lack an existing digital system made collaboration on other system implementation options difficult. No other option was considered in the data collection implementation.

The mobile application responsible for data collection is implemented as shown in Appendix C.2. The two forms that must be filled in are diesel usage logbook and diesel storage balance, which relate to documents used.

Phase 2: Data manipulation

Stakeholders specifically asked for a platform to keep detailed records of changes made to recorded data. The platform therefore requires a detailed description of the reason for change due to any manipulation. Data integrity is improved by keeping track of any changes.

The data manipulation platform involves the creation of a web-platform that is integrated into a service. Company B provides such a service to their customers. A web-platform is chosen as the best candidate because:

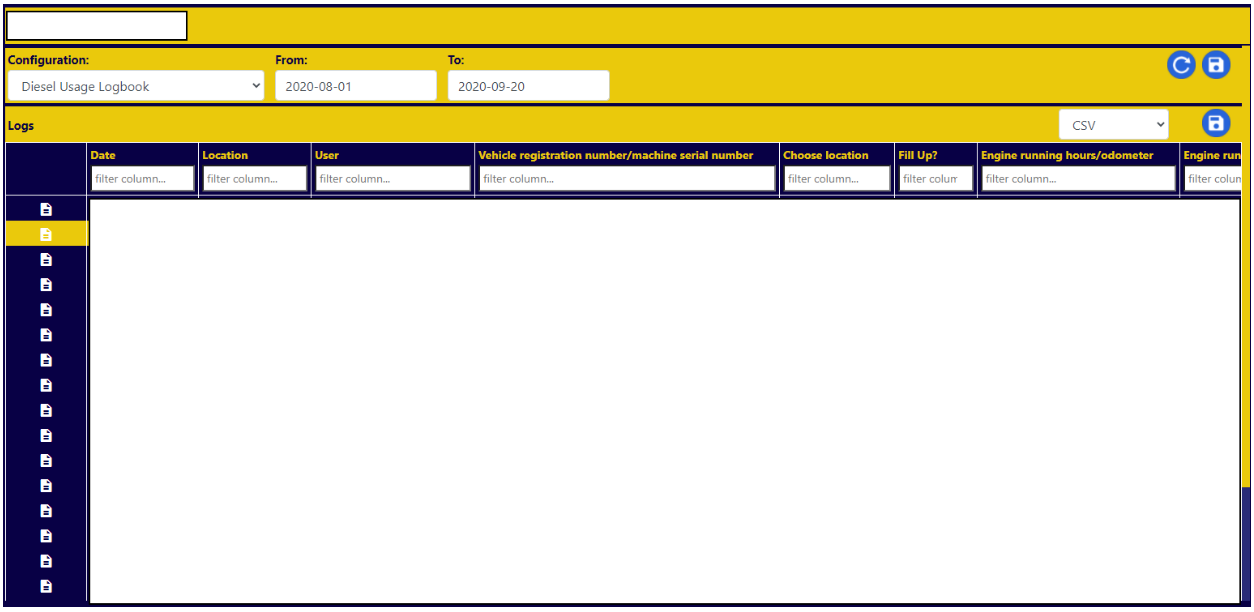
1. The ease of information availability is improved by providing the recorded data on the web-platform, which Company B provides as a service to their customers.
2. Integration of the implemented system into an existing system reduces inter -system complications, improving system maintainability.
3. The existing system is implemented as a web-platform resulting in implementation inheriting the ability to function as a web-connected system. This inheritance ensures that only specific parties have access to information.
4. System implementation into an existing system results in capability for expansion. Capability to expand depends on the specific existing environment.
5. System adaptability is maintained by implementing the system in an existing environment. There are no new system dependencies due to application of this system.
6. Migration readiness is assured by implementing the system as a method extension in an existing environment. Isolation of this system has the advantage that it can be easily moved from an existing system into a new system, or even removed.

Another system implementation option considered was the creation of a new web-based platform to manipulate recorded information. Stakeholders removed this option as it would remove the possibility to show other services provided by the existing system.

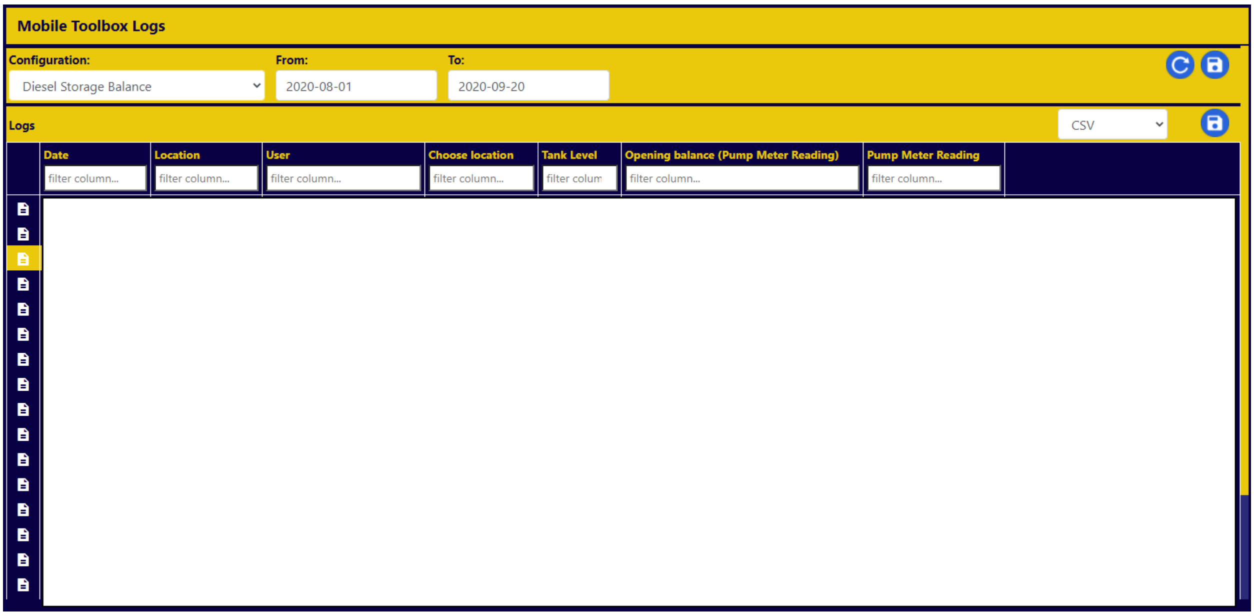
The created platform is illustrated by Figures 3.13. The platform was integrated into the Company B's existing system – a service provided to their customers. Figure 3.13(a) contains an illustration of the diesel usage data. Figure 3.13(b) contains an illustration of the diesel storage data. All sensitive information has been edited.

Phase 3: Data format

The system implementation in Phase 2, and the agreement with stakeholders that functions should be kept within the existing system, led to the formatting implementation being extended on Phase 2 implementation. The availability of information was the driving force behind the decision.



(a) Data visualisation platform: Diesel usage



(b) Data visualisation platform: Diesel storage

Figure 3.13: Data visualisation platform: Diesel rebate

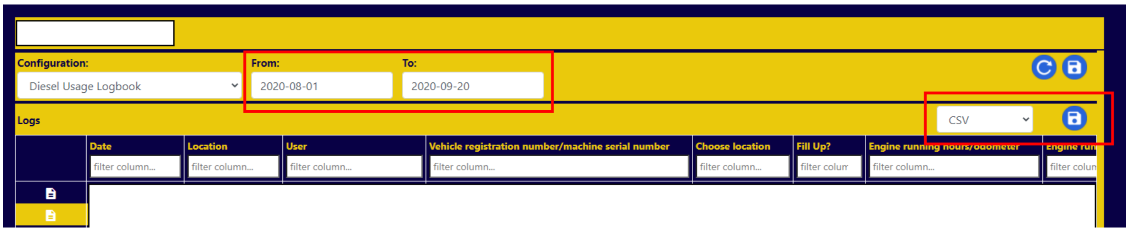
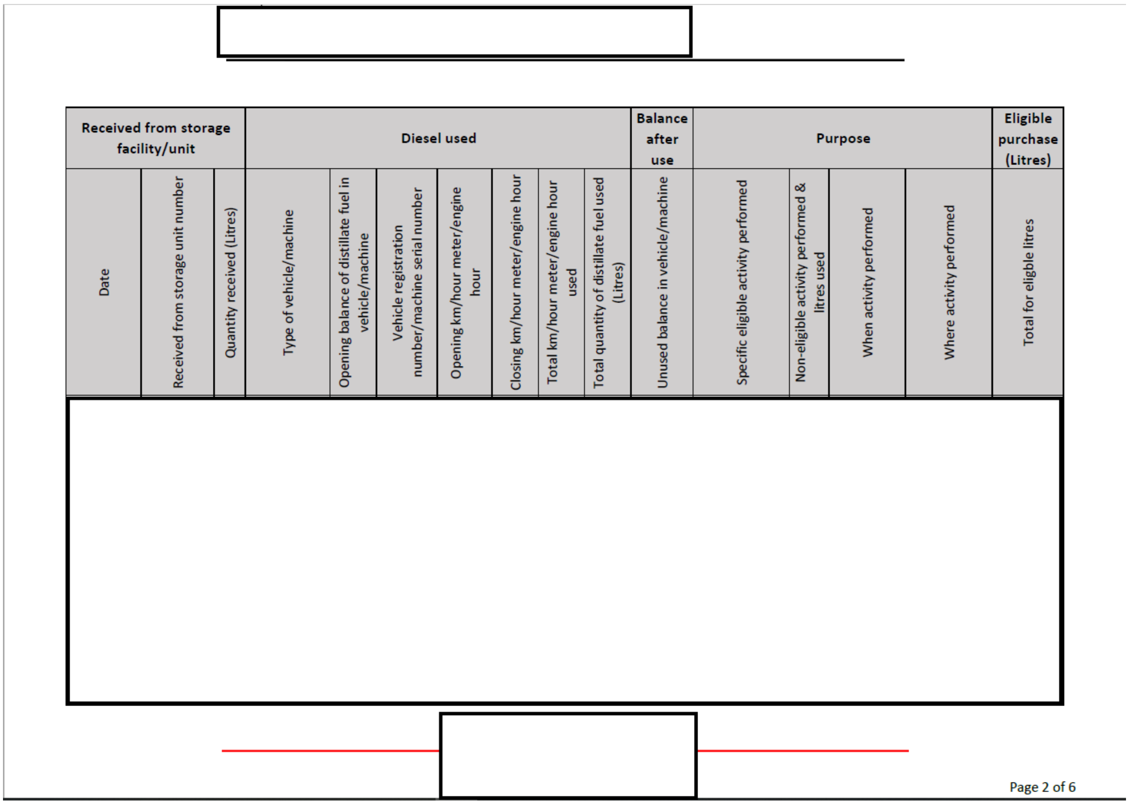


Figure 3.14: Data formatting platform

The layout, a request from stakeholders on the platform, is shown in Figure 3.14. The platform allows custom date range filtering of recorded data, as well as manipulating the format in which the data is displayed.

Phase 4: Data delivery

Figure 3.15 shows the delivery document for diesel use. The document must have the same structure as that issued by SARS. Similarly, Figure 3.16 shows the remote diesel storage document. All sensitive information has been removed from the documents.



Received from storage facility/unit			Diesel used							Balance after use	Purpose				Eligible purchase (Litres)
Date	Received from storage unit number	Quantity received (Litres)	Type of vehicle/machine	Opening balance of distillate fuel in vehicle/machine	Vehicle registration number/machine serial number	Opening km/hour meter/engine hour	Closing km/hour meter/engine hour	Total km/hour meter/engine hour used	Total quantity of distillate fuel used (Litres)		Unused balance in vehicle/machine	Specific eligible activity performed	Non-eligible activity performed & litres used	When activity performed	Where activity performed	Total for eligible litres

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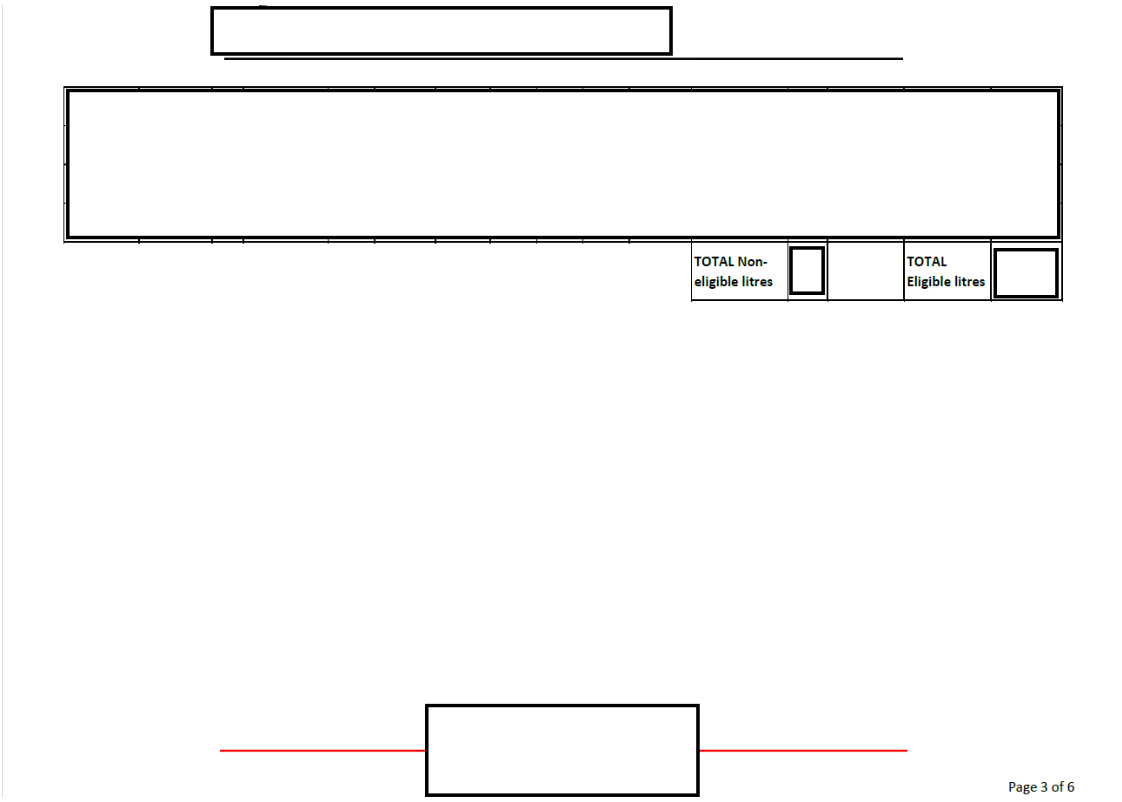
(a) page 1



TOTAL Non-eligible litres		TOTAL Eligible litres	

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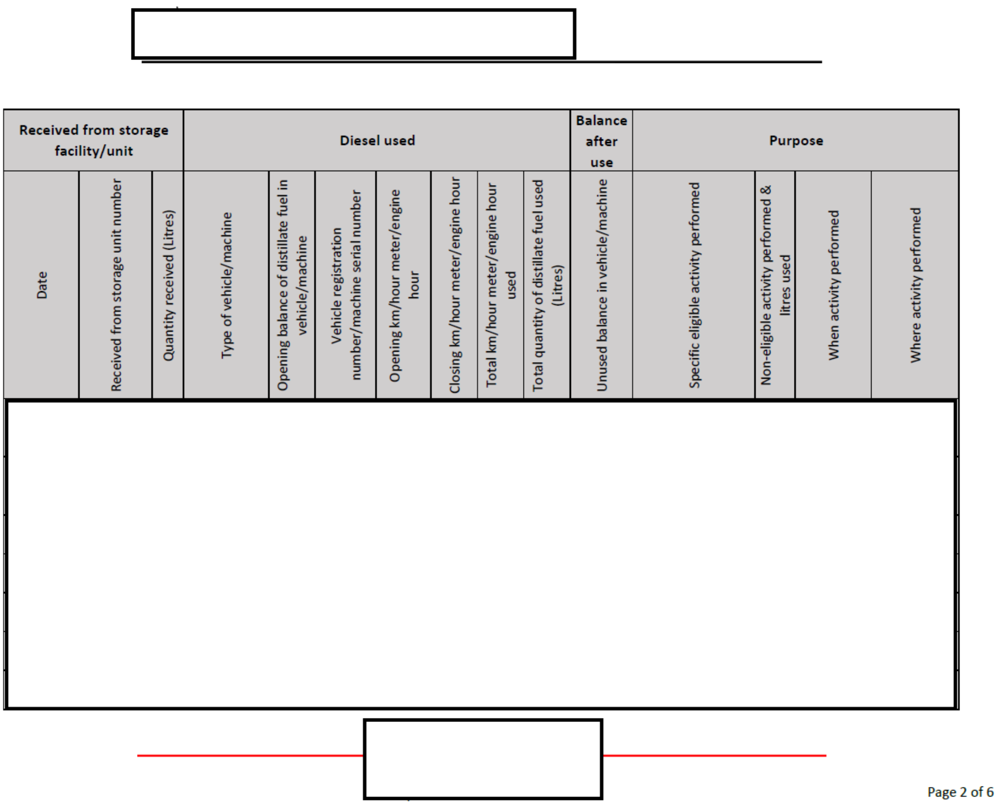
(b) page 2

Figure 3.15: Data delivery document: Diesel usage form



Received from storage facility/unit			Diesel used							Balance after use	Purpose			
Date	Received from storage unit number	Quantity received (Litres)	Type of vehicle/machine	Opening balance of distillate fuel in vehicle/machine	Vehicle registration number/machine serial number	Opening km/hour meter/engine hour	Closing km/hour meter/engine hour	Total km/hour meter/engine hour used	Total quantity of distillate fuel used (Litres)	Unused balance in vehicle/machine	Specific eligible activity performed	Non-eligible activity performed & litres used	When activity performed	Where activity performed

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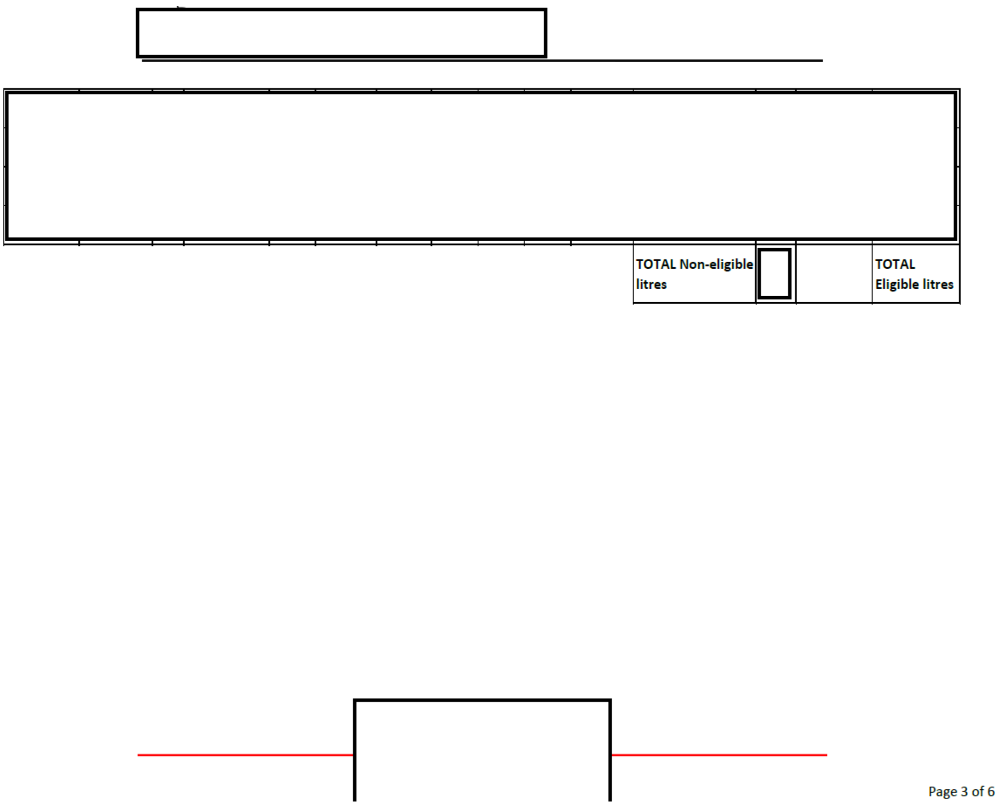
(a) page 1



(b) page 2

Figure 3.16: Data delivery document: Diesel storage form

3.3.3 Implementation verification

The system implementation verification is done as set out in the method followed. The implementation is continuously evaluated against the CSFs. Failure to meet the required levels of satisfaction will result in redesign and implementation.

To quantify the ease of available information, the system and recorded data were analysed. Consequently, the data was extracted and evaluated over 1-month period. Due to the sensitive nature of the information, only the date of recording and the type of document were evaluated. Findings (Table 3.10) include system performance and data recording statistics, which derived from the existing system and the performance of the system implementation. The existing system performance information is provided by the system administrator.

Table 3.10: System availability parameters

Parameter	**Symbol**	**Value**	**Description**
Hours in a month	H_m	720 h	The number of hours in a 30-day month
Work hours in a month	H_w	160 h	The number of working hours per month (8 hours per working day, 5 days per week)
Start date	-	2020-08-01	Observation starting date
End date	-	2020-09-01	Observation final date
Number of hours analysed	-	744 h	Number of hours between starting and ending observation
Number of entries	-	1324 $Entries$	Number of information transactions while observing
Transaction arrival rate	λ_a	1.779 $Entries/h$	The information transactions per hour
Storage failure rate	λ_f	2 $Failure/year$	Number of storage failures per year
Coverage of storage failure	C	85 %	The percentage of information that is ensured to be secure when storage failure occurs
Time between full backups	T	168 h	The number of hours between full backup of data
Full backup time	-	20 min	The estimated time that a database is occupied due to backups
Hours down due to backup	P_d	1.33 h	Number of hours the database is occupied due to backups over a four-week period
System down time over month	S_d	15 h	Estimated time the system is unavailable over a four-week period

According to the backup policy (Table 3.10) a complete backup of data must be done weekly. The transaction arrival rate is determined by the number of entries per number of hours analysed. The coverage of storage failure, full back up time, hours off due to backup and system time during the month are features of the existing system. Table 3.11 is a summary after the ease of information availability analysis.

Table 3.11: System data availability evaluation

Metric	**Result**	**Meets requirement**
System data availability	99.1 %	✓
User-perceived data availability	95.4 %	✓
Storage system availability	99.8 %	✓
Data loss rate	0.121	✓
Data loss ratio	6.9 %	✓

The values in Table 3.11 (Appendix C.3) were derived using the values in Table 3.10 and the verification set in the methodology. The availability of data met the needs of stakeholders. The data loss ratio is low enough so that the specified backup policy is sufficient to prevent data loss.

The digitised system capability for expansion quantifications is set out in Figures 3.17 & 3.18. The load scalability is determined by varying the load on the system and measuring the performance of the system on requests.

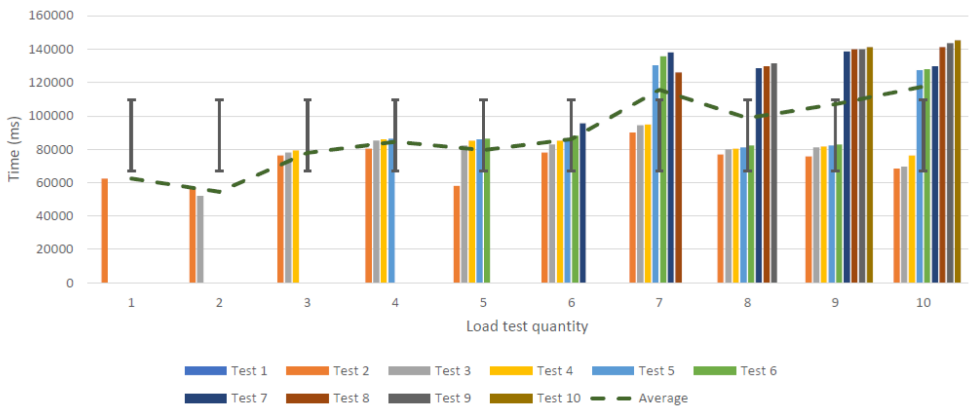


Figure 3.17: Diesel rebate load scalability

The following properties can be deduced from a calculation of the average processing time (Figure 3.17):

1. Average of 1.47 min.
2. Standard deviation of 0.355 min.
3. Maximum of 1.01 min, 0.99 min, 1.33 min, 1.42 min, 1.43 min, 1.59 min, 2.28 min, 2.18 min, 2.35 min and 2.43 min for Test 1 through 10 respectively.
4. Minimum of 1.01 min, 0.87min, 1.3 min, 1.34 min, 0.88 min, 1.32 min, 1.52 min, 1.31 min, 1.29 min and 1.16 min for Test 1 through 10 respectively.

It is important to note that the reports are generated in thread pools that handle a maximum of 5 requests at a time. This becomes clear from load tests that involve more requests. The average time of execution satisfactory met the needs of stakeholders whilst requests remained below 10 simultaneous requests.

The delay seen with the times averaging at 1.47 min is caused by the sheer amount of information being used. Though the information is readily available, the processing time of constructing an information report causes delay. The stakeholders make use of the report generation on a monthly basis and have stated that the delay is acceptable.

Figure 3.18 shows the structural scalability of the system implementation. The short iterative delivering of implementations indicates structural scalability. The Agile methodology is clearly visible through the rapid successive delivery of phase requirements. The successive delivery indicates a satisfactory structural scalability.

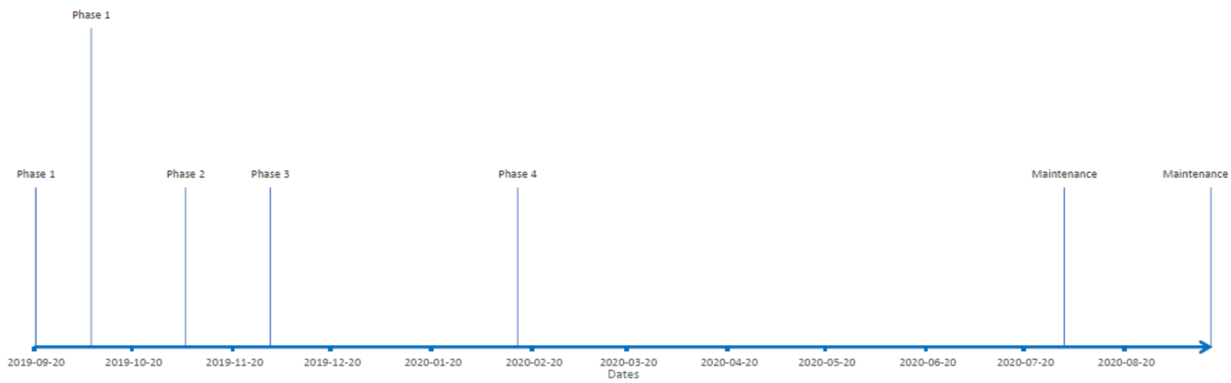


Figure 3.18: Diesel rebate software delivery timeline

Quantification of the ease of system maintenance is shown in Table 3.12. Calculation of values of the maintainability index is calculated using Visual Studio's built-in analysis tool. The labelled areas Controllers, Models and View models are only a convention to refer to the functional areas. Each area is evaluated separately because of the system environment that implementation is introduced to. The ease of system maintenance is evaluated according to each area individually.

Table 3.12: Diesel rebate system maintainability

Area	Maintainability index	Cyclomatic complexity	Depth inheritance	Class coupling	Lines of source code	Lines of excecutable code
Controllers	56	99	3	92	824	212
Models	97	341	1	6	977	82
View models	90	9	1	4	33	2

Table 3.12 shows each individual maintainability index of the various areas. The maintainability calculated for each area satisfactory met stakeholder requirements, although controllers could be improved .

The quantification of system adaptability requires that the implemented system be described as involved elements, as indicated in Figure 3.19. Only the implementation is evaluated and not the overall system environment. According to the illustration the system has 5 customizable elements, namely C#, SQL and Mongo. There are a total number of 8 elements in the system , namely PHP, C#, SQL, Mongo, Html, LaTeX where C# is present on three components (Generate document consists of C# and Latex, Modify/Structure data consists of C#, SQL and Mongo and lastly Save data consists of C#, PHP and Html).

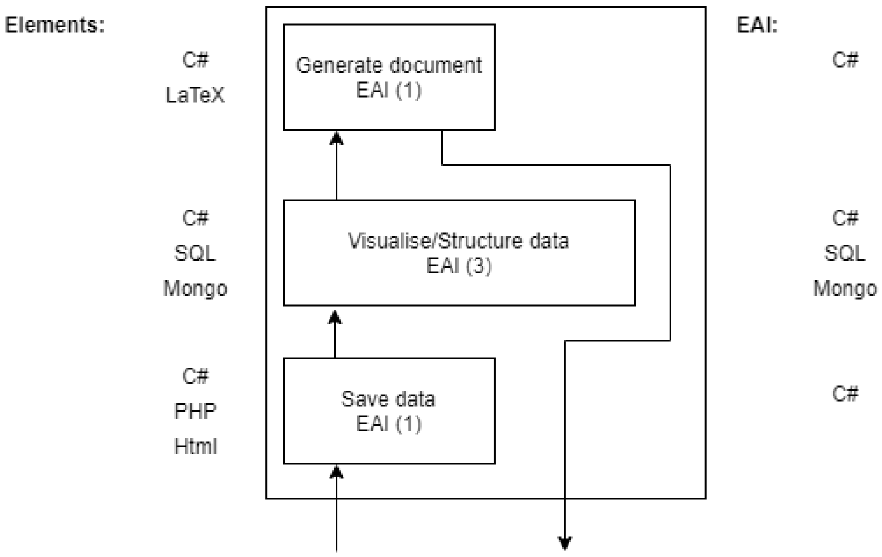


Figure 3.19: Diesel rebate system Adaptability

According to Figure 3.19 the AAI can be calculated as:

$$
\begin{aligned}
AAI &= \frac{EAI}{T} \\
&= \frac{5}{8} \\
&= 0.625 \\
&= 62.5\%
\end{aligned}
$$

where EAI is the element adaptability index, T is the total number of elements and AAI is the architecture adaptability index. Although the architecture adaptability index is not as high as possible, it nevertheless satisfactory satisfies the needs of stakeholders as they have rated this CSF lower.

The system migration analysis involves the evaluation of all dependencies. The system is dependent on the SQL- and Mongo-database as well as the LaTeX structural file. The system is migration ready because:

1. The databases are presented on a web-platform, which regulate access restriction.
2. The LaTeX structural file is stored within a cloud storage system presented on Google-Cloud Platform (GCP), which ensures reliable access to authorised connections.
3. The appointed system administrator has had hands on experience with hosting cloud environment system and is very confident in their ability. The stakeholders are confident in the system administrator's ability and are satisfied.
4. The reimbursement system has no time dependency that would prevent it from operating within a cloud environment.

Due to this dependency, restrictions on migration are removed, leading to the satisfaction of stakeholder needs.

3.3.4 Results

According to Company B, availability of information and data security rather than completion had monetary value. Using this system, Company B estimated that they submit a diesel rebate request of R5 000 000 per annum on the instructions of one of their clients.

Data security and availability also improved the management capability of the company. The company can make accurate estimates based on patterns in the legacy data through future data analysis. These predictions on legacy data can be applied to various other systems such as the company's budgeting and diesel order to avoid low storage levels.

The data analysis also contains information on areas of higher diesel consumption. The company can improve management over these areas to ensure that right diesel distribution practices are applied by employees. By ensuring the best practices of employees, the company reduces the waste of diesel in the mining industry.

3.4 Discussion

The decision matrix of both Companies A and B has an acceptable consistency ratio, which is achieved through ongoing discussions and evaluations with stakeholders. Company A had less incidence where the stability ratio fell below the requirement of being above 90%. This may be due to different stakeholders backgrounds at each company. Company A has a larger number of stakeholders with technical background in system implementation and design than Company B.

Enterprises A and B's decision matrices are in contrast to the main focus in the literature review (Chapter 1). It was reported that journals focused strongly on the ease of system maintenance, system adaptability and ease of system migration. However, only the ease of system maintenance gives the decision matrix more priority. System adaptability and ease of system migration were rated as the lowest priority of the CSFs.

The ease of information availability quantified for Company A and B appears to be satisfactory as both scored above 90% in all fields. Company B had an incident with mobile devices responsible for data collection. This incident negatively affected the usage feelings of the availability of data and the loss of data ratio. The data was not lost indefinitely as it was retrieved after maintenance intervention.

The systemic capability for expansion within Company A was satisfactory in evaluating load and structural scalability. The scalability of the system load showed that the average processing time remained stable. The structural scalability is evident in the rapid software delivery presented over the project timeline. Company B's system capability for expansion is satisfactory when evaluating the load and structural scalability. The load scalability showed that the average processing time remained stable with requests in groups of five. Company B plans to make use of the system functionality to construct and deliver a document in monthly intervals. The scalability of the system load is sufficient to meet the requirement to generate one document per month. The structural scalability is evident in the rapid delivery of software as shown on the project timeline.

The maintenance index calculated for Company A and B was satisfactory. Overall Company A's system total score is 88 which is above the proposed 20. Company B's system was also above, with the lowest 56. Company B's system maintenance index can be improved by introducing better structured coding standards in the existing system.

The system adaptability for both Company A and B's systems is acceptable but lower than ideal. The system adaptability is acceptable because both parties have through the decision matrices indicated that it is of lower priority.

The readiness for system migration of both Company A and B's systems was satisfactory. This was achieved for both systems using the information provided from the literature. Both systems are designed taking into account container and cloud platforms, as suggested by literature.

Section 2.2 sets out the specifications for the digitisation of a paper-based legacy system.

Table 3.13 shows the list of specifications. All the design specifications have been implemented in the digitised system.

Table 3.13: Specification check-list of digitised system

Specification	**Accomplished**	
	Reimbursement system	**Diesel rebate system**
Applied to a paper-based system	Yes	Yes
Modernised system through digitisation	Yes	Yes
System implemented through the Agile framework	Yes	Yes
System implementation verified using the CSFs of digitisation	Yes	Yes
Company efficiency increase due to system inception	Yes	Yes

3.5 Summary

Company A and B are used as case studies to implement the paper-based digitisation methodology set out in Chapter 2.

Company A is an industrial enterprise in South Africa. The company is a candidate to digitise a paper-based legacy system as their compensation system is paper-based. The implemented digitised system resulted in an effective 33.16 *min* futile time avoidance per week per person. This futile time avoidance results in an estimated monetary cost-savings of R620 000 per annum.

Company B is a consulting company in South Africa. The company wants to deliver diesel rebate assistance as a service to their clients. The existing method is a paper-based system that identified Company B as a candidate. Company B stated that the time reduction had no monetary value but that the information availability and security resulted in an estimated R5 million per annum diesel rebate on the behest of one of their clients. The data security and availability allow the company to further analyse various other systems affected by the diesel usage.

Company A and B's system implementations have met the requirements of the system specifications as set out in Section 2.2.

Chapter 4

Conclusion

4.1 Overview of study

The objective of this study is to develop a method to modernise paper-based systems by implementing the Critical Success Factors (CSF) of digitisation to improve the efficiency in companies.

The need for such a method arose because of,

- the ever-growing interconnected world,
- companies are forced to improve efficiency to be competitive,
- businesses aim to improve their legacy systems as they make major contributions to inefficiency,
- paper-based legacy systems are one of the oldest of these legacy systems.

Literature revealed that legacy systems can be modernised through digitisation. The digitisation of a system is evaluated according to CSFs of digitisation. These factors are the ease of information availability, the ability to expand the ease of system maintenance, system adaptability, the capability to function as a web-based system and the ease of system migration. Each factor can be quantified as a measure of the system.

A methodology has been developed that focuses on the Agile framework that provides step-by-step implementations validated using the CSF of digitisation. The methodology implements the system in phases that focus on satisfying the needs of stakeholders. The phases involve the,

1. Ongoing evaluation of a decision matrix,
2. The creation of a platform to record data,
3. The creation of a platform to visualise, modify and apply structure to recorded data,
4. And the delivery of a document that satisfies the requirements of the stakeholders.

The methodology was applied to two case studies. Case study A used a paper-based compensation system that had problems resulting in futile time wastage. Case study B wants to provide a diesel rebate assistance service to their clients, but the existing paper-based system has created problems that have led to wasted discount opportunities.

Both case studies are viable candidates for implementing the methodology as they have paper-based legacy systems that reduce the company's efficiency.

Case study A's digitised compensation system resulted in a 33.16 *min* futile time avoidance per week per person with an estimated monetary value of R620 000 per annum. The CSF evaluation of the digitised system has shown that the system meets all the requirements set by stakeholders.

Case study B's digitised diesel rebate system resulted in the company being able to deliver a diesel rebate request of R5 million per annum on the behest of one of their customers. The company stated that the availability of information and data security has proven valuable. By having the security and availability of data, the company can analyse the data to provide predictions and recommendations for operation within the company.

By considering the above results and case studies, it is clear that the methodology has effectively increased the efficiency of enterprises by digitising legacy paper-based systems.

4.2 Need for the study objectives

Based on the results obtained in Chapter 3, the objectives of the study set in Chapter 1 can be evaluated. The evaluation leads to proof whether the methodology addressed the problem statement. Table 4.1 contains the evaluation results.

Table 4.1: Methodology evaluation against the study objectives

Description	**Accomplished**	**Section**
Collaborated evaluation of CSFs with stakeholders?	Yes	3.2.2 & 3.3.2
Formalised a method to digitise paper-based system?	Yes	3.2.3 & 3.3.3
Investigated the impact of digitisation and the efficiency benefits obtained?	Yes	3.2.4 & 3.3.4

According to the above table each of the objectives is met satisfactorily.

4.3 Study limitations and recommendation for further work

Case study A and B had identical placement for CSFs ranked three and lower. This could be caused by the specific implementation environments or influenced by the participation of the researcher on both projects. Further studies could determine if this pattern continues on other projects or if specific stakeholder preference could influence project implementation despite decision matrix evaluation.

The methodology in Chapter 2 aims to deliver digitised systems according to the requirements of stakeholders. However, the Agile framework cannot provide the assurance that stakeholders have the knowledge to set requirements that will meet their needs. This lack of knowledge can produce unnecessary iterations within the methodological structure. It therefore creates an opportunity to focus in the future on the formulation of system requirements from a stakeholder perspective.

Decision matrices of stakeholders in Company A and B indicate a contrast between the focus industrial needs and literature focus in Chapter 1 & 3. More research needs to be done on industrial needs in relation to CSF prioritisation. The focus of such research should be on high-level perceptions about the importance of CSFs in different project groups.

Companies differ in their operations and system needs. A study focusing on the differences between CSF evaluations of different companies can provide insight into the construction of more robust decision matrices at shorter intervals.

The methodology developed in this study evaluated the CSFs manually. An automated, continuous system evaluation contains valuable information for system administrators and stakeholders. This information can be used to guide system planning, expanding and the eventual classification of a legacy system.

The Agile development framework, which was used to implement digitisation, often resulted in long loop periods. This becomes particularly clear from the project timeline of Company A where several iterations occurred during Phase 2, as seen in Section 3.2.3. Further research on determining the phase needs of stakeholders will significantly reduce the number of iterations. The research can determine what methodology experienced project managers use and the possibility of establishing a combined methodology.

The adoption rate of the new digitised system was not evaluated within this study. Important information can be derived from the user adoption with regards to the CSFs as viewed by stakeholders. The proposed study can evaluate the correlation between adoption rate and the CSF evaluations on the project. Using this correlation, the methodology set within this study can be adapted to accommodate larger stakeholder groups.

This study focused on paper-based legacy systems, although there are many other legacy systems that can reduce the efficiency of companies. It is therefore proposed that digitisation with regard to other legacy systems will also be studied in future in accordance with CSF principles.

The modernisation of paper-based legacy systems by means of digitisation was investigated in this study. As technology evolves, so does the standard for modernity. Another study evaluating the frequency at which systems need to be investigated is proposed. This frequency may in turn be related back to the evaluations of CSFs to determine whether there is a link between poorer performance factors and rapid aging of systems.

Finally, the digitised system provides a document that meets the needs of stakeholders, as set out in the system required in Section 2.2. The system that produces a document means that the company does not have to adapt to other systems to comply with change. This document can be replaced with a web-based platform that handles all exchanges with this particular document, enhancing multiple systems by removing other legacy systems.

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Appendix A

Problem decision matrix

A.1 Derivation

The geometric means are obtained by completing the matrices pairwise decisions [17]. Thus the decision matrix can be completed by following the rule of

$$d_{km} = \frac{1}{d_{mk}} \tag{A.1}$$

where k is the column index and m is the row index.

The priority vector value is the normalisation of each of the geometric mean values [17]. To calculate the summation of the decision matrix, λ_{max}, the following equation is used,

$$\lambda_{max} = \sum_{i,j=1}^{k} C_j PV_i \tag{A.2}$$

where C_j is the column vector sum and PV_i is the priority vector value.

The consistency index, C_I, is calculated as follows [17],

$$C_I = \frac{\lambda_{max} - n}{n - 1} \tag{A.3}$$

where n is the number of criteria within the decision matrix.

The consistency ratio, C_R, is a measure that indicates the consistency within the matrix and can be calculated using [17],

$$C_R = \frac{C_I}{R_I} \tag{A.4}$$

where R_I is the random index that can be determined from a lookup table based on the number of criteria in the matrix. If C_R is smaller than 90%, revision on the decision matrix is required.

Appendix B

Case study 1

B.1 Calculations

The decision matrix for Case study 1 can be seen in Figure B.1.

Table B.1: Reimbursement system digitisation decision matrix Case study 1

	Availability	Expansion	Maintenance	Adaptability	Web-connected	Migration
Availability	1	8	6	8	0.143	4
Expansion	0.125	1	0.2	8	2	8
Maintenance	0.167	9	1	7	6	5
Adaptability	0.125	0.125	0.143	1	0.125	8
Web-connected	7	0.5	0.167	8	1	2
Migration	0.25	0.125	0.125	0.125	0.5	1

The calculations begin by determining the column vector sums (C_j). This is done by summing each column.

Table B.2: Column vector sums

	Availability	Expansion	Maintenance	Adaptability	Web-connected	Migration
C_j	8.667	18.75	7.635	32.125	9.768	28

Next, the root of the products is calculated. The calculation multiplies each category's values and applies the 6th root. The calculation applies the 6th root because there are six categories.

$$\begin{aligned}
\text{Availability} &= (1 \times 8 \times 6 \times 8 \times 0.143 \times 4)^{\frac{1}{6}} && = 2.456 \text{ rank } 2 \\
\text{Expansion} &= (0.125 \times 1 \times 0.2 \times 8 \times 2 \times 8)^{\frac{1}{6}} && = 1.214 \text{ rank } 4 \\
\text{Maintenance} &= (0.167 \times 9 \times 1 \times 7 \times 6 \times 5)^{\frac{1}{6}} && = 2.608 \text{ rank } 1 \\
\text{Adaptability} &= (0.125 \times 0.125 \times 0.143 \times 1 \times 0.125 \times 8)^{\frac{1}{6}} && = 0.364 \text{ rank } 5 \\
\text{Web-connected} &= (7 \times 0.5 \times 0.167 \times 8 \times 1 \times 2)^{\frac{1}{6}} && = 1.451 \text{ rank } 3 \\
\text{Migration} &= (0.25 \times 0.125 \times 0.125 \times 0.125 \times 0.5 \times 1)^{\frac{1}{6}} && = 0.25 \text{ rank } 6
\end{aligned}$$

By summing each root of products, a total of 8.341 is calculated. This total will be used to calculate the priority vector.

$$\begin{aligned}
\text{Availability} &= \frac{2.456}{8.341} && = 0.294 \\
\text{Expansion} &= \frac{1.214}{8.341} && = 0.146 \\
\text{Maintenance} &= \frac{2.608}{8.341} && = 0.313 \\
\text{Adaptability} &= \frac{0.362}{8.341} && = 0.043 \\
\text{Web-connected} &= \frac{1.451}{8.341} && = 0.174 \\
\text{Migration} &= \frac{0.25}{8.341} && = 0.0299
\end{aligned}$$

Using the priority vector and the column vector sums we can calculate λ_i.

$$\begin{aligned}
\text{Availability} &= 8.667 \times 0.294 && = 2.552 \\
\text{Expansion} &= 18.75 \times 0.146 && = 2.729 \\
\text{Maintenance} &= 7.635 \times 0.313 && = 2.388 \\
\text{Adaptability} &= 32.125 \times 0.0433 && = 1.392 \\
\text{Web-connected} &= 9.768 \times 0.174 && = 1.699 \\
\text{Migration} &= 28 \times 0.299 && = 0.839
\end{aligned}$$

Now λ_{max} can be calculated as the sum of λ_i.

$$\lambda_{max} = 11.599$$

Finally with the calculated λ_{max}, the consistency-index and -ratio can be calculated.

$$
\begin{aligned}
C_I &= \frac{\lambda_{max} - n}{n - 1} && \text{where n} = 6 \\
&= \frac{11.599 - 6}{6 - 1} \\
&= 1.119 \\
C_R &= \frac{C_I}{R_I} && \text{where } R_I = 1.24 \\
&= \frac{1.119}{1.24} \\
&= 0.903
\end{aligned}
$$

B.2 Mobile application forms

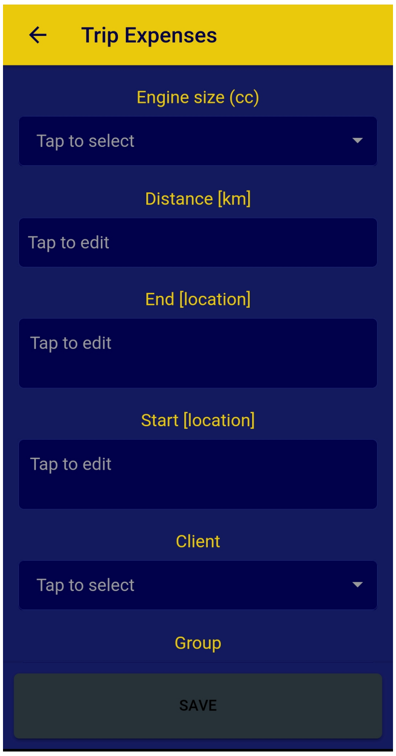

Figure B.1: Mobile application trip expense form

Figure B.1 shows the form that allows users to capture the trip expense data. From Figure 3.1 the fields are derived to be *Date*, *Start Location*, *End Location*, *Distance*, *Engine Size*, *Total*, *Client* and *Group*.

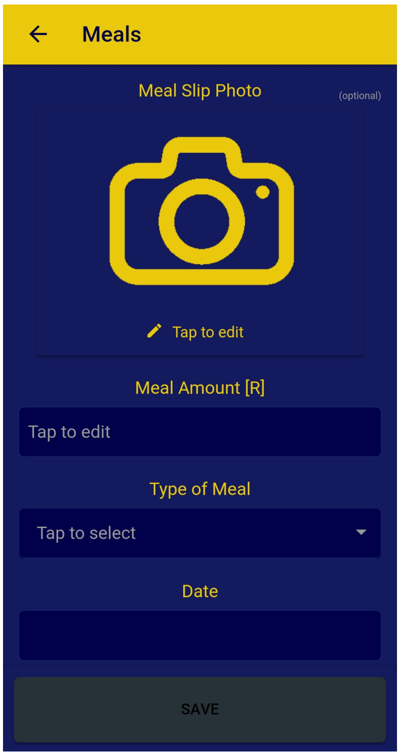

Figure B.2: Mobile application meal expense form

Figure B.2 shows the form that allows users to capture the meal expense data. From Figure 3.1 the fields are derived to be *Date*, *Type of Meal*, *Meal Amount*, *Proof of Payment*, *Client* and *Group*.

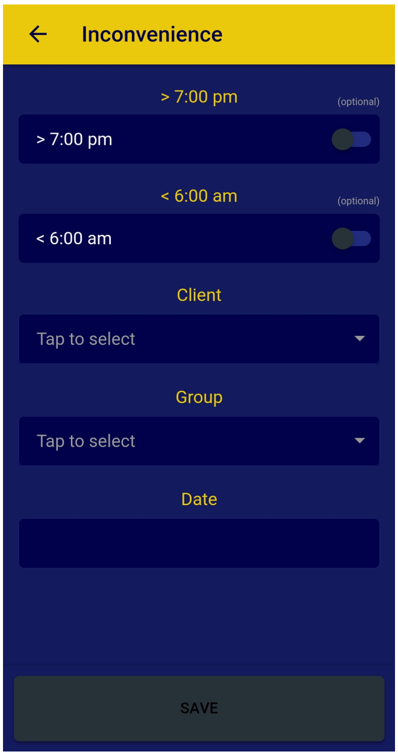

Figure B.3: Mobile application inconvenience form

Figure B.3 shows the form that allows users to capture the Inconvenience data. From Figure 3.1 the fields are derived to be *Date*, *Morning Inconvenience*, *Evening Inconvenience*, *Client* and *Group*.

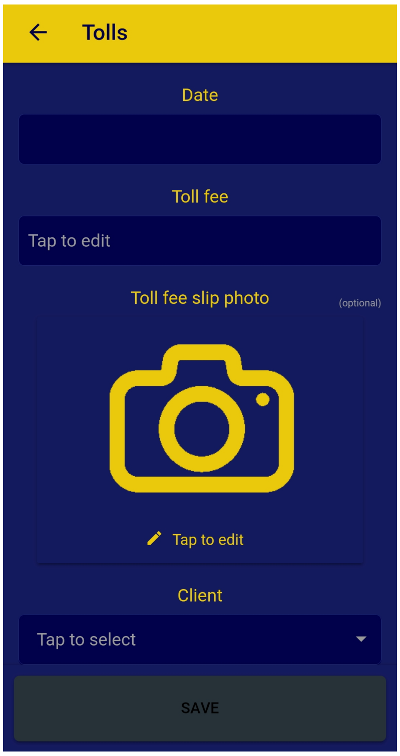

Figure B.4: Mobile application toll expense form

Figure B.4 shows the form that allows users to capture the toll data. From Figure 3.1 the fields are derived to be *Date*, *Toll Fee*, *Toll Slip Photo*, *Client* and *Group*.

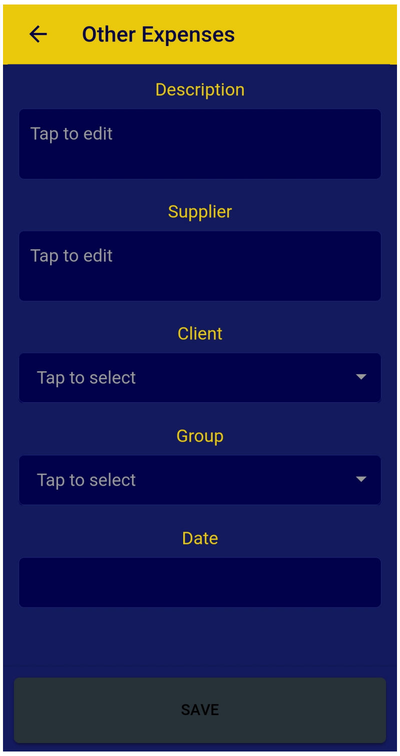

Figure B.5: Mobile application other expense form

Figure B.5 shows the form that allows users to capture the other expense data. From Figure 3.1 the fields are derived to be *Date*, *Supplier*, *Description*, *Invoice Total*, Invoice Photo, *Client* and *Group*.

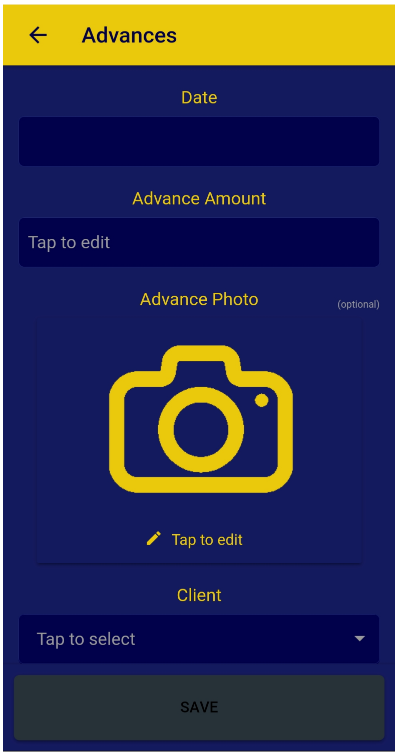

Figure B.6: Mobile application advance form

Figure B.6 shows the form that allows users to capture the advance payment data. From Figure 3.1 the fields are derived to be *Date*, *Advance Amount*, *Proof of Advance*, *Client* and *Group*.

B.3 Data manipulation platform

Figures B.7 - B.12 shows the platform created to manipulate the recorded data. The sub sections allow the modification of trip expense, meals, Inconvenience, toll fees, other expenses and advances respectively.

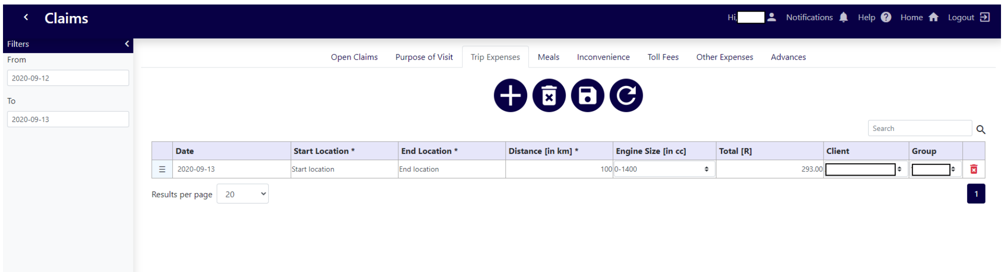

Figure B.7: Data manipulation platform: Trip expense

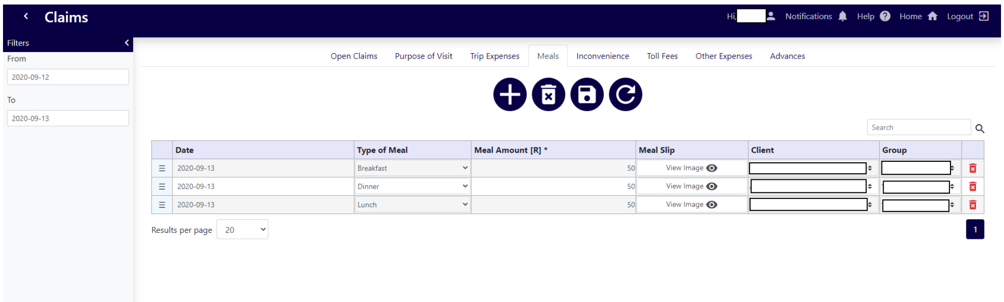

Figure B.8: Data manipulation platform: Meals

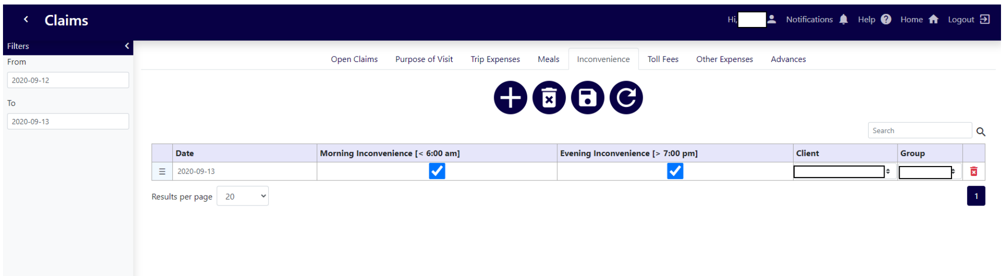

Figure B.9: Data manipulation platform: Inconvenience

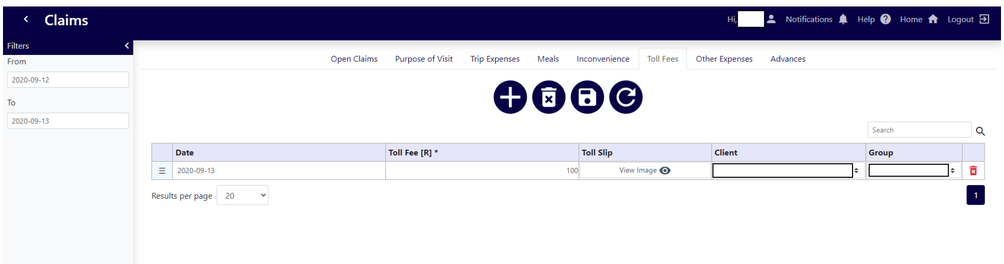

Figure B.10: Data manipulation platform: Toll fees

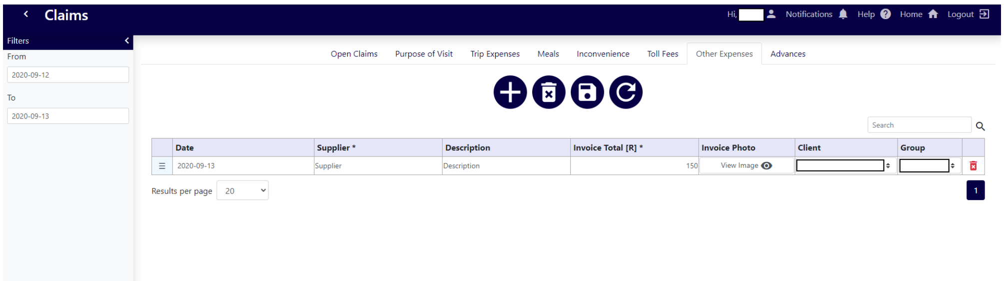

Figure B.11: Data manipulation platform: Other expense

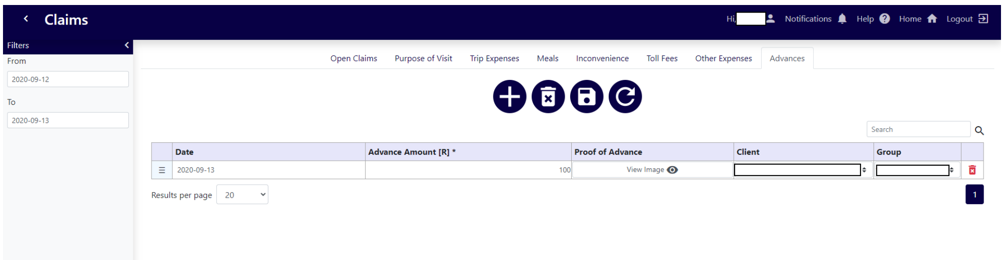

Figure B.12: Data manipulation platform: Advance

B.4 Implementation analysis calculations

The storage system availability, A_s, can be calculated as,

$$\begin{aligned} A_s &= 1 - \frac{P_d}{H_m} \\ &= 1 - \frac{1.33}{720} \\ &= 0.998 \\ &= 99.8\% \end{aligned}$$

where P_d is the hours the storage system is unavailable and H_m is the amount of hours in a month.

The system data availability, A_d, can be calculated as,

$$\begin{aligned} A_d &= 1 - \frac{S_d}{H_m} \\ &= 1 - \frac{2}{720} \\ &= 0.997 \\ &= 99.7\% \end{aligned}$$

where S_d is the hours the system is unavailable.

The user-perceived data availability, A_u, can be calculated as,

$$\begin{aligned} A_u &= 1 - \frac{P_d + S_d}{H_w} \\ &= 1 - \frac{1.33 + 2}{160} \\ &= 0.979 \\ &= 97.9\% \end{aligned}$$

where H_w is the number of working hours in a month.

Data-loss rate, γ, can be calculated as,

$$\begin{aligned}\gamma &= A_d \times \lambda_f \times (1 - C) \times \lambda_a \times \frac{T}{2} \\ &= 0.997 \times 0.00547 \times (1 - 0.98) \times \frac{168}{2} \\ &= 0.0274\end{aligned}$$

where λ_f is the storage failure rate. C is the coverage of storage failure and T is the time between backups.

Data loss ratio, θ, can be calculated as,

$$\begin{aligned}\theta &= \frac{\gamma}{A_d \times \lambda_a} \\ &= \frac{0.0274}{0.997 \times 2.98} \\ &= 0.0092\end{aligned}$$

B.5 Validation calculations

Table B.3 the parameters of the futile time avoided can be seen.

Table B.3: Reimbursement futile time avoided parameters

Parameter	**Symbol**	**Value**
Futile time avoided per week	t_W	33.16 min
Futile time avoided per month	t_M	132.67 min
Number of employees	E_n	100
Working hours per month	t_H	160 h
Percentage time waste avoided	p_{ft}	1.382 %

Using Table B.3 the monthly cost avoided per mechanical engineer can be calculated as,

$$\begin{aligned} C_{me} &= R19\,200 \times p_{ft} \\ &= R19\,200 \times 0.01382 \\ &= R265.33 \end{aligned}$$

resulting in a annual cost saving of R3 183.99 per year per mechanical engineer. Applying this annual savings to the group of 80 engineers results in a annual savings of,

$$\begin{aligned} C_A &= 80 \times R3\,183.99 \\ &= R254\,719.70 \end{aligned}$$

where C_A is the annual savings.

Similarly the group of professional engineers can have their annual savings calculated as,

$$\begin{aligned} C_A &= 20 \times R18\,573.31 \\ &= R371\,466.30 \end{aligned}$$

Appendix C

Case study 2

C.1 Calculations

The decision matrix for Case study 2 can be seen in Figure C.1.

Table C.1: Diesel rebate system digitisation decision matrix Case study 2

	Availability	Expansion	Maintenance	Adaptability	Web-connected	Migration
Availability	1	7	9	8	0.143	8
Expansion	0.143	1	0.125	5	0.143	6
Maintenance	0.111	8	1	8	8	8
Adaptability	0.125	0.2	0.125	1	0.125	6
Web-connected	7	7	0.125	8	1	6
Migration	0.125	0.167	0.125	0.167	0.167	1

The calculations begin by determining the column vector sums (C_j). This is done by summing each column.

Table C.2: Column vector sums

	Availability	Expansion	Maintenance	Adaptability	Web-connected	Migration
C_j	8.5	23.367	10.5	30.167	9.578	35

Next, the root of the products is calculated. The calculation multiplies each category's values and applies the 6th root. The calculation applies the 6th root because there are 6 categories.

$$
\begin{aligned}
\text{Availability} &= (1 \times 7 \times 9 \times 8 \times 0.143 \times 8)^{\frac{1}{6}} && = 2.884 \text{ rank } 1 \\
\text{Expansion} &= (0.143 \times 1 \times 0.125 \times 5 \times 0.143 \times 6)^{\frac{1}{6}} && = 0.652 \text{ rank } 4 \\
\text{Maintenance} &= (0.111 \times 8 \times 1 \times 8 \times 8 \times 6)^{\frac{1}{6}} && = 2.773 \text{ rank } 2 \\
\text{Adaptability} &= (0.125 \times 0.2 \times 0.125 \times 1 \times 0.125 \times 6)^{\frac{1}{6}} && = 0.364 \text{ rank } 5 \\
\text{Web-connected} &= (7 \times 7 \times 0.125 \times 8 \times 1 \times 6)^{\frac{1}{6}} && = 2.579 \text{ rank } 3 \\
\text{Migration} &= (0.125 \times 0.167 \times 0.125 \times 0.167 \times 0.167 \times 1)^{\frac{1}{6}} && = 0.204 \text{ rank } 6
\end{aligned}
$$

By summing each root of products, a total of 9.457 is calculated. This total will be used to calculate the priority vector.

$$
\begin{aligned}
\text{Availability} &= \frac{2.884}{9.457} && = 0.305 \\
\text{Expansion} &= \frac{0.652}{9.457} && = 0.0689 \\
\text{Maintenance} &= \frac{2.773}{9.457} && = 0.293 \\
\text{Adaptability} &= \frac{0.364}{9.457} && = 0.0385 \\
\text{Web-connected} &= \frac{2.579}{9.457} && = 0.273 \\
\text{Migration} &= \frac{0.204}{9.457} && = 0.0216
\end{aligned}
$$

Using the priority vector and the column vector sums we can calculate λ_i.

$$
\begin{aligned}
\text{Availability} &= 8.504 \times 0.305 && = 2.594 \\
\text{Expansion} &= 23.367 \times 0.0689 && = 1.61 \\
\text{Maintenance} &= 10.5 \times 0.293 && = 3.0794 \\
\text{Adaptability} &= 30.167 \times 0.0385 && = 1.163 \\
\text{Web-connected} &= 9.578 \times 0.273 && = 2.612 \\
\text{Migration} &= 35 \times 0.0216 && = 0.755
\end{aligned}
$$

Now λ_{max} can be calculated as the sum of λ_i.

$$\lambda_{max} = 11.813$$

Finally with the calculated λ_{max}, the consistency-index and -ratio can be calculated.

$$\begin{aligned}
C_I &= \frac{\lambda_{max} - n}{n - 1} && \text{where n} = 6 \\
&= \frac{11.813 - 6}{6 - 1} \\
&= 1.163 \\
C_R &= \frac{C_I}{R_I} && \text{where } R_I = 1.24 \\
&= \frac{1.163}{1.24} \\
&= 0.938
\end{aligned}$$

C.2 Mobile application forms

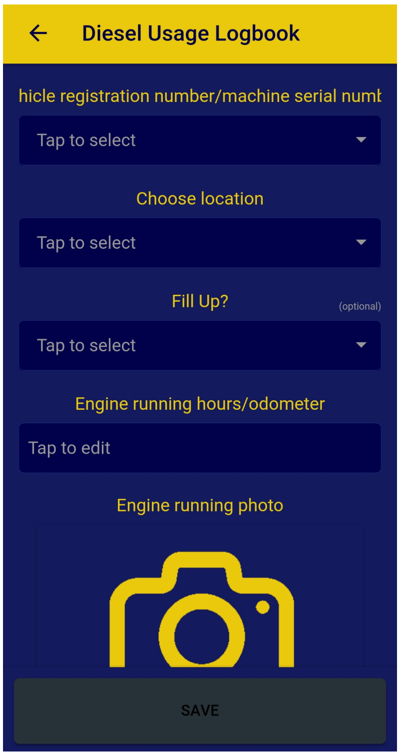

Figure C.1: Mobile application diesel usage form

Figure C.1 shows the form that allows users to capture the diesel usage data. From Figure 3.11 the fields are derived to be *Vehicle registration number/machine serial number*, *Choose location*, *Fill up?*, *Engine running hours/odometer*, *Engine running photo*, *Quantity received (Litres)* and *Quantity received photo*.

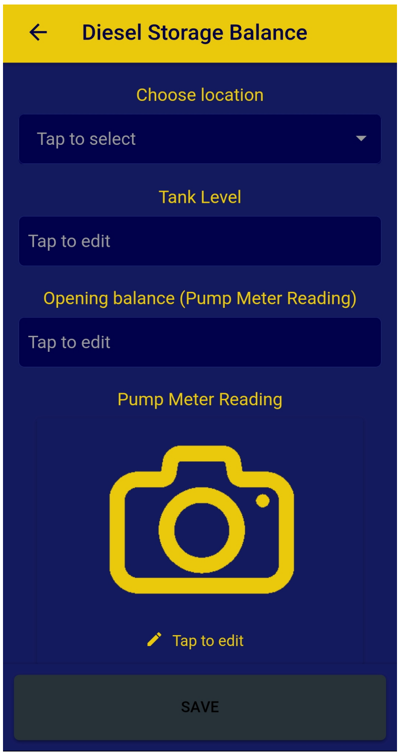

Figure C.2: Mobile application diesel storage form

Figure C.2 shows the form that allows users to capture the diesel storage data. From Figure 3.12 the fields are derived to be *Choose location*, *Tank level*, *Opening balance (Pump Meter Reading)* and *Pump Meter Reading*.

C.3 Implementation analysis calculations

The storage system availability, A_s, can be calculated as,

$$\begin{aligned} A_s &= 1 - \frac{P_d}{H_m} \\ &= 1 - \frac{1.33}{720} \\ &= 0.998 \\ &= 99.8\% \end{aligned}$$

where P_d is the hours the storage system is unavailable and H_m is the amount of hours in a month.

The system data availability, A_d, can be calculated as,

$$\begin{aligned} A_d &= 1 - \frac{S_d}{H_m} \\ &= 1 - \frac{6}{720} \\ &= 0.991 \\ &= 98.1\% \end{aligned}$$

where S_d is the hours the system is unavailable.

The user-perceived data availability, A_u, can be calculated as,

$$\begin{aligned} A_u &= 1 - \frac{P_d + S_d}{H_w} \\ &= 1 - \frac{1.33 + 6}{160} \\ &= 0.954 \\ &= 95.4\% \end{aligned}$$

where H_w is the number of working hours in a month.

Data-loss rate, γ, can be calculated as,

$$\begin{aligned}\gamma &= A_d \times \lambda_f \times (1 - C) \times \lambda_a \times \frac{T}{2} \\ &= 0.991 \times 0.00547 \times (1 - 0.85) \times \frac{168}{2} \\ &= 0.122\end{aligned}$$

where λ_f is the storage failure rate. C is the coverage of storage failure and T is the time between backups.

Data loss ratio, θ, can be calculated as,

$$\begin{aligned}\theta &= \frac{\gamma}{A_d \times \lambda_a} \\ &= \frac{0.122}{0.991 \times 1.78} \\ &= 0.069\end{aligned}$$