A comprehensive mobile data collection and management system for industrial applications

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It all starts here ™

Abstract

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Industrial organisations rely on quality information to remain sustainable in competitive markets. To obtain high quality information, data must be collected and processed in an accurate and timely manner. Many automated systems have been developed to actively monitor industrial systems and record data. However, automated data acquisition systems are often costly to implement due to high infrastructure costs. Furthermore, typical systems are limited to a fixed range of measurements and do not support event-based data collection.

Due to the shortfalls associated with automated data acquisition systems, industrial organisations implement alternative methods to collect data. These alternative methods include manual handwritten notes, which involve significant amounts of human interaction with data. Consequently, the collected data is error prone and cannot be used as credible data sources. Data collected through manual human methods are therefore not suitable for audited applications.

Mobile data collection systems offer a possible solution, however no single system that offered a comprehensive solution that addresses all the identified industrial data collection needs was found. A novel mobile data collection and verification system was therefore developed to collect data related to industrial activities. The developed system provides users with a generic framework that can adapt to individual data collection needs. Furthermore, the developed system implements a unique combination of components that improve data accuracy, ensure full traceability and provides assistance to users on various levels.

The novel system was created by combining both new and existing components to form a single comprehensive data collection and management system. These components include data verification, version control, calculation and data validation, task management, system restriction and user support, as well as data processing and integration. These components interact with one another to form a integrated solution that addresses the industrial data collection needs.

The system was implemented at numerous industrial sites throughout South Africa, including a steel production facility, water utilities and mines. The range of data collection applications include plant maintenance on steam networks, compressed air networks and water networks, validated water meter readings, electricity meter readings and a range of specific audits. The system was integrated with client systems to enable automatic data handling according to client specifications.

Various users utilised the system to capture data at the aforementioned facilities. Efficiency improvements were observed during the data collection, consolidation and reporting, as well as the action phases. The system also improved the accuracy of collected data. This was achieved through real time data verification, user guidance and task management structures. Accurate data with advanced measurements was used to improve client processes and produce high quality data sets that can be used to base important decisions on.

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Nomenclature

Units of measure:

GJ	Gigajoule
GWh	Gigawatt-hour
kg	kilogram
kl	kilolitre
km	kilometre
kWh	kilowatt-hour
m^3/min	cubic metre per minute
m	metre
Ml	Megalitre
MW	Megawatt
t	tonne

Abbreviations and acronyms:

API	Application Programming Interface
CSV	Comma Separated Values
DSM	Demand Side Management
DVR	Data Verification and Reconciliation
ERP	Enterprise Resource Planning
$ESCO$	Energy Services Company
FCM	Firebase Cloud Messaging
GDP	Gross Domestic Product
GPS	Global Positioning System
GRI	Global Reporting Initiative

HRM	Human Resource Management
IDM	Integrated Demand Management
IP	Internet Protocol
JSE	Johannesburg Stock Exchange
JSON	JavaScript Object Notation
KPI	Key Performance Indicators
NO	Nitrogen Oxide
OLE	Object Linking and Embedding
OPC	OLE for Process Control
PCB	Polychlorinated biphenyl
PDA	Personal digital assistants
PLC	Programmable Logic Controller
QR	Quick Response
SCADA	Supervisory Control And Data Acquisition
SO	Sulfur Monoxide
SRG	Sustainability Reporting Guidelines
UI	User Interface

1

Data collection and the industrial sector

The present conditions surrounding the industrial sector in South Africa are considered in this chapter. Various industries within the industrial sector are considered to determine its specific data collection needs. This revealed the need for a structured, cross-industry data collection and task management system. A novel mobile system, that addresses data traceability, human resource utilisation, data quality, maintenance and awareness, as well as system integration requirements, is then proposed. Lastly, the novel contributions and the structure of the thesis are discussed.

1.1 Industry and economic circumstances

At the onset of the twenty-first century, a global economic crisis affected developing and established countries alike. The economic crisis had a lasting effect on many countries, including South Africa. Between 2004 and 2007 South Africa reported an average economic growth of 5%. However, this dropped to roughly 2% for the period ranging from 2008 to 2012 (Statistics South Afirca, 2014). This economic stress placed South African organisations under pressure to remain profitable.

Along with economic challenges, Deloitte (2012) indicated that production costs are escalated by energy cost increases. Inglesi-Lotz and Pouris (2012) and Kohler (2014) argue that low energy tariffs led to an energy-intensive economy based on international standards. Figure 1.1 was adapted from Donev et al. (2012) and provides a graphic representation of energy distribution among South Africa's economic sectors. South Africa's industrial sector consumes roughly 37% of the country's total produced energy.

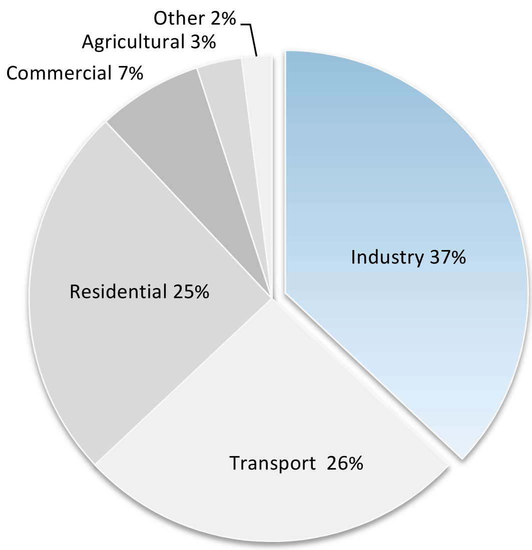


Figure 1.1: *Energy consumption per sector*

Many industrial organisations rely on electricity as their primary energy source. However, electricity tariffs have escalated dramatically in recent years. Maneschijn et al. (2016) documented that 2016 electricity tariffs have risen to 290% of equivalent rates in the year 2000. Figure 1.2 was adapted from Winkler (2006) and illustrates electricity distribution among South African industries. It can therefore be deducted that electricity tariff increases have a profound impact on the capital expenditure and profitability of these industries (Blignaut et al., 2015).

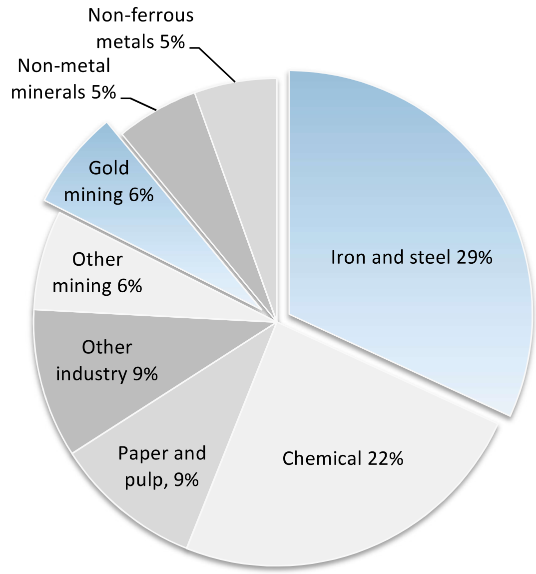


Figure 1.2: *Electricity distribution in South Africa's industrial sector*

The South African economy relies heavily on mineral extraction and processing (Chamber of Mines of South Africa, 2014). The Industrial Development Corporation (2013) states that South African organisations are struggling to remain competitive in global markets. Economic deceleration and increased operational expenses reduce the feasibility of industrial activities, because delivered products do not hold the revenue generation capacity that it previously held.

In 2013 the South African Department of Mineral Resources, in association with Deloitte South Africa, reported that South Africa's gold mining industry is experiencing challenges. These challenges include lower commodity value, declining ore grades, labour disruptions, reduced productivity and escalating operational expenses (Lane et al., 2015; Department of Communications, 2014; Groenewald, 2015). Mining companies must therefore balance expenses related to these challenges, while remaining competitive in global markets.

Analogous to the mining industry, Popescu et al. (2016) stated that the global steel industry is in a crisis state. Decreased economic growth in many countries has led to excess steel production capacity. A large number of new steel plants in China contribute to a significant portion of the oversupply (Australian National University Press, 2015). Two factors that contribute to China's oversupply are low labour costs (Stewart et al., 2014) and government funding (Haley and Haley, 2013).

Competing steel producers are therefore forced to decrease costs to remain competitive. Zeelie et al. (2015) noted that South Africa's steel industry is affected by low international prices brought forward by the international oversupply. In addition to oversupply concerns, slow economic development also contributes to the decreased steel demand (EYGM Limited, 2016).

In addition to escalating operational expenses, large industries are placed under pressure by resource constraints and environmental challenges. One limited resource is water. Water forms a crucial part of operations in many industries. South Africa is currently in the early stages of a water crisis (Daws, 2015). Some parts of the country are already burdened with an inadequate water supply.

Water suppliers rely on large pump sets and piped networks to transport the water. Khan (2015) stated that this presents many challenges, due to ageing pipeline assets which have limited life expectancies. Moreover, the physical condition of pipeline assets is unknown, because the majority of the network is buried. In addition to water loss concerns, the large pump sets used in the industry are high electricity consumers, which relate to high electricity expenses (Rand Water, 2013).

Improved maintenance structures will reduce the environmental impact of operations and preserve precious water resources. A reduction in system losses does not only preserve resources, but offers the utility provider many financial advantages including reductions of electricity bills and water treatment expenses. These advantages motivate the need for improved maintenance structures and accurate maintenance information.

1.2 Industrial data needs

Amid the reduced profitability, industrial organisations have growing data needs. The increase in data requirements are motivated by two factors. Firstly, stricter legislative requirements pressure these organisations to report on data that were previously neglected. Secondly, funding opportunities are made available, but require substantiating data. New data collection and management systems are therefore needed to address the increased data requirements.

Many industrial activities are not monitored by automatic systems. These systems require human interaction and rely on manual data recordings. Selected industrial activities that rely on manual data collection have been identified and were investigated in more detail. These activities include environmental data collection, various maintenance tasks and human resource management. Data needs for these activities are presented in this section.

1.2.1 Environmental data collection

While financial expenses related to industrial activities are well documented, associated environmental costs are often overlooked. However, in recent years environmental reporting is considered equally important when compared to production- and safety targets. The Global Reporting Initiative (GRI) provides guidelines for environmental reporting in the Sustainability Reporting Guidelines (SRG) document (Brand, 2014).

The SRG document sets reporting guidelines for water and air pollution. The key water reporting values are total water used, water quality combined and location of discharge. Core reporting values with regards to air pollution include direct and indirect greenhouse gas emissions by mass, emission of ozone depleting gasses and other hazardous gasses and particles.

Declining ore grades increase the gold mining industry's influence on the environment. Mudd (2007) studied the correlation between ore grades and pollution produced by mines. The results showed that, in order to produce 1 kg of gold, 691 kl of water, 143 GJ energy, 11.5 t carbon dioxide and between 100 kg and 1 t of cyanide are consumed. These figures indicate the scale of the environmental influence of industrial activities.

Van Berkel (2007), and Newbold (2006) both note that society has become reliant on the mining of precious metals. One of the largest polluters in South Africa is the gold mining industry. According to Cloete et al. (2013), mines produce only 10% of South Africa's effluent water. However, due to the quantities and type of pollutants present in this water, it poses great environmental risks.

Effluent water generated by deep-level mining operations is considered the industry's most dangerous pollutant (Kalin et al., 2006). The environmental impact of these mining activities must therefore be reduced to improve the industry's sustainability. Effective management of effluent water is therefore critical. Accurate environmental data and reports will inform stakeholders of the effects of operations and allow auditors to assess compliance with legal requirements.

Key Performance Indicator (KPIs) reported by South African mines and industries should therefore be studied to establish where improvements can be made. Additionally, this will reveal the company's level of compliance with the SRG. Brand (2014) investigated sustainability reports published by large South African mining groups. In this study, Brand (2014) considered KPIs reported on by these groups.

Table 1.1 shows a correlation of only 55% between published reports and the SRGs. In general, the considered mining groups reported on energy consumption and associated greenhouse gas emissions, as well as water consumption and environmental incidents. In addition to this, two companies published the water discharge amount and quality. This allows stakeholders to monitor the water pollution caused by mines.

Table 1.1: *KPI reporting on gold mines*

KPI Reporting	Mining companies			
	1	2	3	4
Total electricity consumption	●	●	●	●
Water recycled		●		●
Total direct greenhouse gas emissions				●
Ozone depleting gas emissions				●
Total indirect greenhouse gas emissions	●	●	●	●
Other dangerous gas emissions				
Total water usage	●	●	●	●
Total water discharge			●	●
Location of water discharge				
Water discharge quality monitoring			●	●
Amount of environmental incidents	●	●	●	●

1.2.2 Maintenance and system performance

In industrial activities such as mining, there are many variables that constantly change. Maintenance is required to sustain the performance of energy efficiency implementations and ensure alignment with adjusted circumstances. This is crucial in the South African industry where companies rely on Demand Side Management (DSM) projects for financial relief. Eskom's new DSM process is shown in Figure 1.3. This process stipulates that project performance should be sustained for a period of three years.

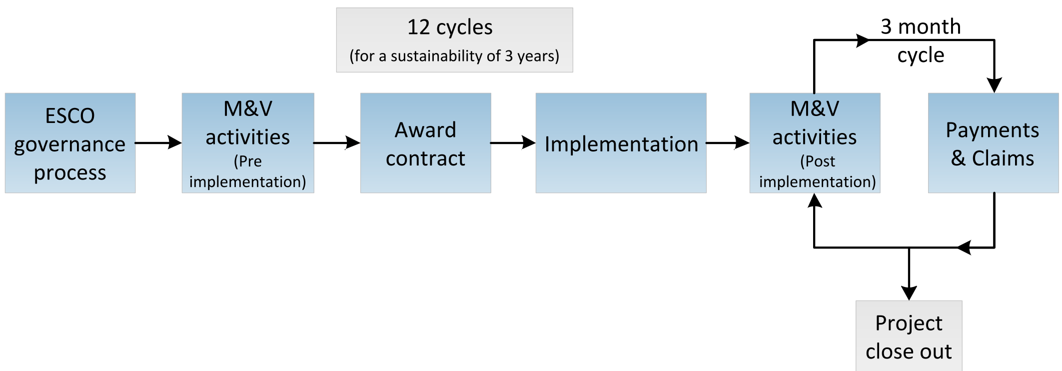


Figure 1.3: *High level stages in a new ESCO process project*

Moubray (1997) defined maintenance as: Ensuring that physical assets continue to do what their users want them to do. Without proper maintenance, the performance of industrial DSM projects are expected to decrease (Groenewald et al., 2015). Figure 1.4 illustrates the gradual performance decrease of a load-shifting project. Groenewald et al. (2015) continues that, in order to maintain DSM performance, the project should be correctly maintained.

Companies in the industrial sector are acknowledging the importance of maintenance (Baglee and Jantunen, 2014; Alsyouf, 2007). Alsyouf (2009) states that maintenance implications are recognised based on the effect it has on the organisation's competitiveness. Additionally, Alsyouf (2009) noted that maintenance departments spend 33% of their time attending to unplanned maintenance. Figure 1.5 shows how effective maintenance links to other business processes and ultimately influences the organisation's profitability.

Service networks such as compressed air networks, water reticulation systems and steam transportation systems are often used to support industrial activities. These systems are robust and capable of supporting a range of services. Harsh conditions and regular changes have significant effects on service networks. Maintenance and control optimisation can therefore improve system efficiency and reduce energy expenses.

Kotze and Visser (2012) investigated maintenance activities within the South African mining industry. Results indicated that South African mines perform maintenance tasks on a reactive basis, instead of following a more structured or proactive approach. Visagie (2005) identified the need to develop maintenance performance indicators and suggested that a responsible person must manage maintenance activities pro-actively.

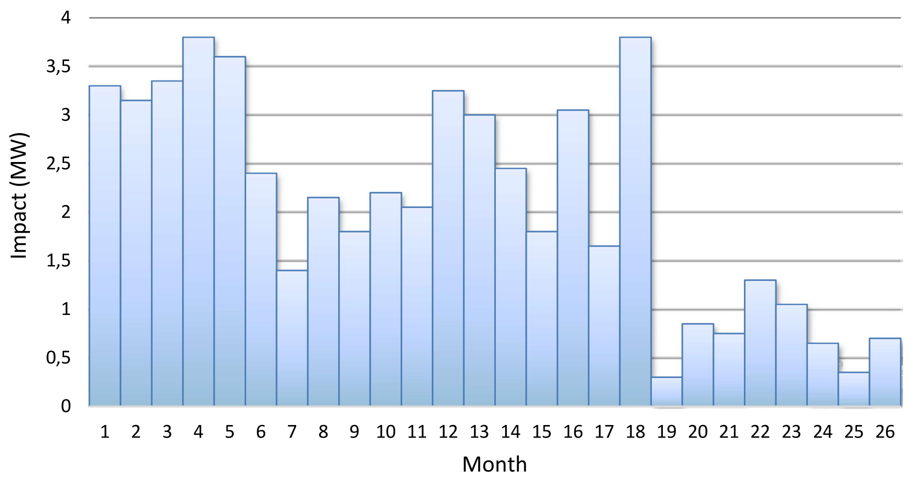


Figure 1.4: *Gradual performance decrease of a load shifting project*

Compressed air systems are widely used in South African mines. Large compressors are used to supply the compressed air. These compressors have individual capacities of up to 15 MW and can supply approximately 3500 m^3/min. Compressed air pipe networks on selected South African mines exceed 75 km. Leaks can therefore cause major energy losses and induce high energy costs.

Compressed air systems on mines consist of several components including compressor houses, surface pipe segments, valves, shaft pipe columns and level piping. These components are all susceptible to leaks. These leaks usually manifest at bends, couplers, end connections, flanges, valves and welded joints (Cengel and Boles, 1989). These components are typically linked using 9 m pipe sections, which are bolted together with flanges and sealed with gaskets.

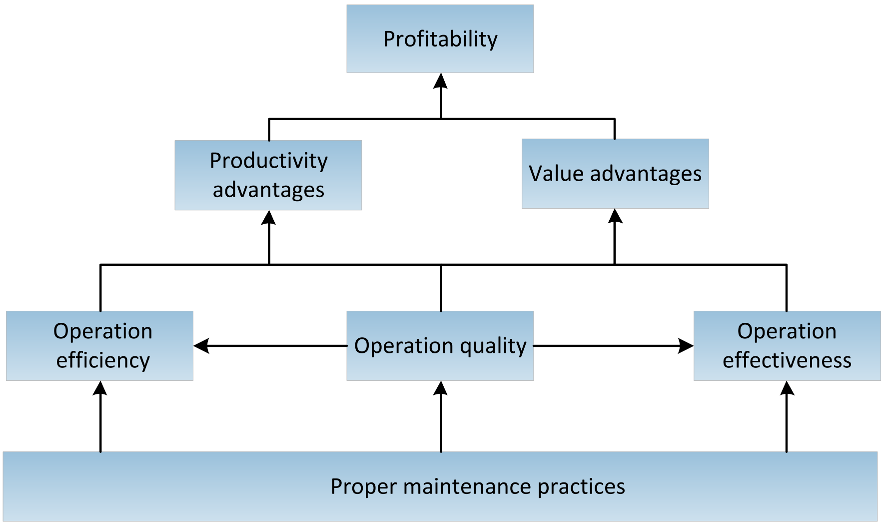


Figure 1.5: *Impact of proper maintenance practices on competitive advantages*

Unfortunately leaks and inefficiencies in compressed air systems are often overlooked or ignored. Tolko Industry Ltd's paper and saw mill saved 1.1 GWh per annum by optimising its compressed-air system. Leakages and open-ended pipes consumed 35% of the available compressed air (Hydro, 2000). Van Tonder (2011) highlighted that an independent study reported compressed air leakage rates in excess of 20%. The Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (2001) reported that 36% of compressed air was lost through air network leaks.

In another case, operational costs were halved by effectively monitoring the pipeline condition and optimising operational procedures by end users (Hydro, 2000). The compressor house in this study had an installed capacity of 17 MW that supplies compressed air to a 13 km piped network. Optimisations reduced the need to install additional compressors to meet higher compressed air demands.

Air-leak detection and reporting systems differ from mine to mine. Van Tonder (2011) found that mines did not have any dedicated leak detection systems in place. Additionally, Van Tonder (2011) identified the following shortfalls in leak detection systems:

- The effect of leakages are not quantified
- Follow-up inspections on repairs are not conducted
- Managing staff are not aware of actual system status
- Misuse of air systems are not documented
- Poor record keeping of previously detected leaks
- Unused levels are not monitored to avoid leaks

1.2.3 Human resource utilisation

Human resources contribute to a significant portion of operational expenses. The chart shown in Figure 1.6 illustrates the cost distribution on a South African gold mine. In the diagram, costs associated with wages and salaries attribute to 40% of business expenses. Human resources therefore have the ability to influence the profitability of an industry and must be managed properly.

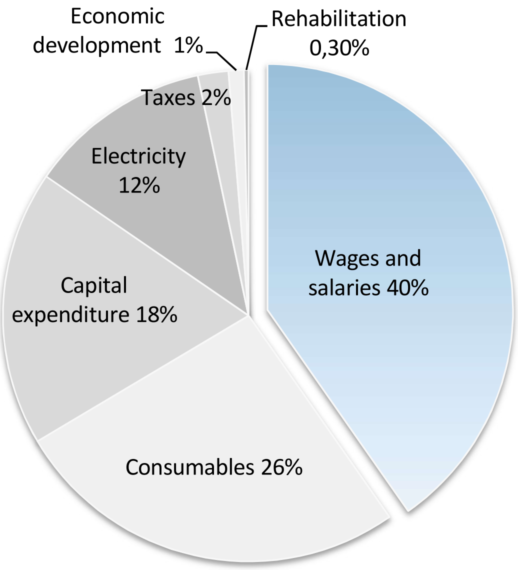


Figure 1.6: *Typical expenditure for a gold mining group*

Van der Walt et al. (2016) states that the two main concerns associated with human resources are skill shortages and dissatisfaction among workers. Musingwini et al. (2013) elaborated on the skill shortages associated with technical professionals in the mining industry. According to Rasool et al. (2011), the South African economy has been affected by severe skills shortages.

These skill shortages present South African industries with new challenges. Stanz (2009) noted that employee retention is becoming critical due to a combination of skill shortages, high vacancy rates, increased personnel hiring cost and employee attitudes. Terera and Ngirande (2014) found that, due to the competition for scarce skills, the greatest challenge in human resource management is employee attraction and retention.

The skill shortages caused by the outflow of knowledgeable workers place additional pressure on the remaining workers (Mabuza and Gerwel Proches, 2014). Additional pressure impacts the job satisfaction of the workers, and may cause skilled employees to leave the organisation. Organisations should therefore ensure that sufficient skilled and educated personnel are available to fill core occupational categories.

Promotional opportunities play an important part in the level of job satisfaction reported by employees (Man et al., 2011). Development opportunities, including training and educational courses, should also be made available to employees. This will improve the quality of work delivered by employees and provide promotion opportunities.

Unskilled workers can be utilised to assist with basic tasks that do not require the attention of skilled workers such as engineers. Proper management structures and guidance systems will enable unskilled workers to perform certain tasks. Skilled workers can provide guidance and verify that the job has been executed up to standard. This empowers skilled workers to a management position and promotes an unskilled worker to perform a special task.

1.2.4 Summary of industrial data needs

The preceding sections offer insight into current conditions surrounding the South African industrial sector. Current data collection and management needs were investigated. Needs associated with environmental reporting, maintenance management and human resource utilisation were considered. Five system needs were identified from these investigations. The following discussions elaborate on the identified needs, based on the literature in the preceding sections.

Data traceability

Traceable data sources and substantiating data are increasing in importance among a wide range of industries. Historically organisations have favoured production performance figures above the impact of operations. Contributing factors were poor reporting standards and weak legislation enforcement. In recent times, international pressure has promoted the importance of non-performance data such as environmental data. Furthermore, organisations are placed under pressure on a financial front, due to escalating energy costs and competitive market conditions.

Incentives were implemented to motivate adoption of new standards. The incentives offer organisations financial rewards in return for verifiable improvements on environmental- and energy systems. Accurate data is essential when compiling feedback reports to governing authorities or funding sources. Non-compliance with agreed upon targets have significant financial impacts on all stakeholders. Organisations are therefore subjected to data audits to confirm claimed performance figures. Source documentation should therefore be preserved for verification purposes.

Not all industrial organisations have systems in place to record all the required information, and in particular do not account for support data. A cost-effective resource management system with the capability to gather information and manage support data is therefore needed. Support data in the form of photographs, GPS coordinates, time stamps and user details can be used to provide audit evidence.

Human resource utilisation

Human resources contribute to a significant portion of operational expenses in industrial activities. Skilled workers are valuable resources in the industrial sector, but skill outflow and competitive offers by other organisations make retaining these individuals a difficult task. Although personnel can be trained, it is an expensive and time-consuming process.

Utilising unskilled personnel is therefore a cost-effective method to manage human resources. Unskilled personnel can be employed to perform basic tasks, such as remote data collection if sufficient guidance can be provided. This will reduce the workload of skilled employees and allow time to attend to advanced tasks. Utilisation of unskilled workers will also provide promotion opportunities and improve worker satisfaction rates.

Modern computerised systems have the ability to perform various actions based on predefined inputs. These systems can therefore perform actions such as item detection and verification to guide users and reduce the chance of human error. Users from varying backgrounds are accustomed to using computer based systems. Unskilled workers can therefore be utilised by providing guidance through mobile computer-based systems.

Data quality

Accurate data is essential when compiling reports, especially in cases where decisions based on the data have large financial implications. Often formal data management systems are limited only to production-based data sets. In these cases, personnel are tasked with manual data collection tasks. Manually-generated documents are used to maintain records of collected data. This approach involves human interaction with data, which reduces data integrity and increases faults.

A data management system is therefore required to collect and maintain data that is not currently managed by formal structures. A system with automated capabilities will reduce human interaction with data and support users to collect accurate samples. Data validation and verification tests will improve the accuracy of recorded data. Validation will be particularly useful if it is implemented during collection at the data source.

Mobile systems can be utilised to ensure accurate data collection. Data confidence can be improved by maintaining source documentation. This can be used to verify data and make corrections at later stages. Furthermore, mobile systems have the ability to perform statistical analysis on historic data, evaluate new readings and notify users of detected anomalies during the data collection process.

Maintenance and awareness

Certain industrial activities, such as mining rely on constantly changing environments. Maintenance activities are required to repair damaged infrastructure and ensure that control systems remain aligned with updated requirements. Sustained performance over extensive time periods are required by modern funding initiatives. It is therefore crucial to maintain affected systems to ensure adequate performance.

Collected data must be processed to extract meaningful information. Real-time calculations will help users to identify severe situations and serve as motivation to escalate the urgency of corrective action. Moreover, comprehensive maintenance structures will provide a platform to manage the tracking of maintenance task completion. To enable this, recorded data must be consolidated and managed by a central system.

A well-maintained data set will allow the generation of maintenance reports. These reports can be used for a range of management applications, including task scheduling and follow-up prompts. Problem patterns can be identified and high risk areas can be addressed with preventative maintenance activities. Lastly, automated systems can be utilised to generate work orders or similar internal documentation.

System integration

Organisations rely on a range of systems and applications to perform daily operations. Many of these systems perform specific tasks or handle restricted access to certain business elements. These systems often perform related tasks and must therefore be integrated to extract its full potential. This causes data duplication and work repetition. Integration is not always achievable, due to system restrictions and incompatibility issues among suppliers.

Operators require specialised training in order to utilise the advanced features offered by the various software systems. This places the organisation at risk due to its reliance on a specific person. This risk increases when the organisation relies on multiple specialists to manage its systems. If any of these users are unavailable, those systems cannot be utilised and may influence other dependent systems.

A unified system is therefore required to perform a range of tasks. This will allow many users to be trained to use a single platform. Users who are familiar with the platform will be able to utilise additional system features with minimal additional training requirements. Integration with support systems will eliminate work duplication and reduce human errors.

1.3 Problem statement

The preceding sections identified challenges and data needs within the industrial sector. Challenges that plague multiple industries include expanding data requirements, poor maintenance practices, and ineffective personnel management. Furthermore, financial constraints limit affected organisations' ability to manage the challenges effectively. The industrial sector therefore needs an affordable data collection and management system to address:

- Data traceability
- Human resource utilisation
- Maintenance and awareness
- Data quality concerns
- System integration

1.4 Objective of this study

Five data collection needs, within the industrial sector, were identified and presented in the problem statement. The aim of this study is to develop a single flexible data collection and management system, capable of addressing all of the identified needs. The required system must therefore present a single solution that satisfies the following items:

- Manage data and configurations in a fully traceable structure;
- Guide users with task management structures and provide automated assistance where possible;
- Perform data validation during data collection activities;
- Offer maintenance-related assistance and structure to users; and
- Provide a single platform with multiple functions and integration capabilities.

Advanced functionality and user acceptance make smart-phones the ideal data collection platform. Modern portable devices offer advanced technological advantages that can be harnessed to improve the quality of collected data. Mobile data collection therefore offers a solution to modern industrial data collection problems. A mobile data collection system was thus developed to address the system objectives.

1.5 Contributions of this study

Current economic strain places pressure on industrial organisations to improve efficiency in order to remain competitive. In addition to these stricter reporting requirements on various socio economic levels, a need exists to improve data collection and reporting standards. However, improved data collection and reporting requires improved infrastructure which is often too expensive to implement in difficult economic conditions.

This study investigates an alternative data collection and task management system to address the shortfalls with current industrial data collection systems. Traditional automated data collection systems such as Supervisory Control and Data Acquisition systems, are often too expensive to implement and have expansion restrictions. Manual data collection methods do not offer traceable data solutions and is inefficient. Mobile device based data collection was considered as an alternative. However, no single comprehensive system that offered a comprehensive solution capable of addressing all the identified industrial data collection needs was documented.

The primary novel contribution of this study is the conceptualisation and development of a comprehensive mobile data collection and management system for industrial applications. The developed system offers a single generic platform that consolidates data collection and task management needs for a wide range of industrial activities. The integrated system enables users to address multiple data gathering and reporting needs using a single comprehensive and cost effective system.

A novel system was obtained by combining a unique selection of software structures into a single comprehensive system. Software elements and structures that contribute to the unique system include data verification, version control, calculation and data validation, task management, system restriction and user support, as well as data processing and integration. The developed system offers unique capabilities which were made possible by seamlessly combining these structures into a single system.

1.5.1 Data verification and archiving structure

Verifiable documentation is required to substantiate information presented in many industrial reports. Various reports are used to publish inspection results, performance figures and environmental management claims. Support data is used to verify claimed results and data authenticity in cases where legal or financial implications are involved. Supporting documents and evidence must therefore be collected and safeguarded for auditing purposes.

Various automated and manual systems exist and offer possible methods to collect and manage supporting documentation. However, both these methods of data collection have shortfalls. Automated systems are often costly and have restrictive data collection and data access structures. Manual systems allow human interaction with collected data. This allows room for data corruption which lowers data confidence and places the authenticity of the support data in question.

Data verification entails more than collecting proof documents. A three-phase verification structure was subsequently developed as a part of this study. Firstly, data verification is performed on the mobile device during the data collection phase. Secondly, instantaneous data processing is performed and results are distributed to relevant personnel during the data consolidation phase. Lastly, the data is stored in a managed database and is used to extract data for auditing purposes. The database stores complete version history and records the system state for each data entry.

The system developed in this study offers facilities to collect the required proof, including time stamps, user authentication, photographs and GPS coordinates. The integrated solution offered by the developed system allows advanced data verification on the mobile device. This verification structure links with historic data stored on the mobile device and centralised server. Moreover, the verification structure links user guidance tools, mathematical models and external systems to provide a comprehensive data management solution.

1.5.2 Configuration and version control structure

Industrial data collection systems are subject to changing environments. Furthermore, changing data requirements and standards brought forward by group policies and legislation create the need to adapt data collection systems on a regular basis. However, without record of configuration changes, historic data may lose support values. In many cases the original structure is preferred above the update, and the system must be reverted to the prior state.

Existing systems offer limited access to adapt or update data structures. In many cases changes to data structures cause compatibility issues with previous data records. Other systems allow interfaces to manage data collection interfaces, but do not offer extensive options to maintain accurate references to changes. System state records are not typically stored along with data logs.

The developed system allows configuration and data management by means of an advanced version control structure. The configuration structure allows centralised access to manage configuration data such as users and linked devices. Moreover, the structure preserves a history of input sets, data fields within the input sets, list options and test configurations. Full version control access and revert functionality are provided by the system and can be used to trace historic system states.

Version control forms an integral part of the combined system and offers access to manage the entire system state. The version control structure is linked to the data verification structure and maintains record of historic data structures. These data structures are used to populate interfaces and guide users when using the applications. Similarly, parameters used in the calculation and validation modules are managed using this structure. Lastly, user accounts and links, as well as device licensing, are managed using this structure.

1.5.3 Calculation and data validation structure

Information can be extracted from collected data through processing. Collected data must therefore be consolidated and processed. However, corrupted data cannot be used to generate useful information. Collected data must thus be validated as soon as possible to promote the opportunity to take corrective action. With mobile data collection this can be achieved by performing real-time validation calculations on the collection device.

Existing systems offer calculation options during the reporting phase. These systems often have severe restrictions on calculation options, and often only perform tests based on historic data after data consolidation on a central database. This reduces the ability of the system to prompt action while the responsible user has access to the investigated item and the system state has not changed with time.

The developed system introduces a unique calculation and validation module, which allows users to apply a range of tests to collected data. Each test has unique sets of parameters and can be adapted to match the user needs. Tests can be applied to existing data fields to validate input data. Alternatively, multiple data fields can be used as parameters to calculate an output value. The system offers a unique approach to perform calculations based on historic values by accessing data stored in the database on the mobile device. Calculations consider time variation to select relevant values and normalise test input parameters.

Functionality provided by this component is not attainable without the support structures offered by the other components. The system relies on historic data stored in local and centralised databases. The system furthermore relies on the central system to synchronise collected data among linked devices. In addition to this, the version control structures are used to store test parameters and allow updates to tests. These tests form part of the data verification structures and provide a form of user guidance on the mobile device.

1.5.4 Task management structure

Task management structures are useful tools and can be used to guide users to perform routine tasks and once-off activities. Additional information related to small tasks and specific operations are often required to support users in remote locations. Data sharing in combination with task management enables collaboration between users and teams and allows staff to share workloads, while administrators can track task completion and assign specific tasks.

Data collection systems rarely include task management facilities. Systems that feature task reminders and follow-up tasks do exist, but intelligent task lists cannot be created on demand by other systems. This is partially the result of incomplete data sets on the device and the lack of support for routine checks.

The developed system offers three task types, namely recurring tasks, assigned tasks and follow-up tasks. The developed system offers a novel method to generate recurring tasks. These tasks are generated based on users, time changes, available data sets and recent data recordings. Assigned tasks are generated manually and can be directed at a particular user to perform specific tasks. Finally, follow-up tasks are linked to data recordings and will prompt users to perform follow-up inspections after a certain time period has passed.

The task management structure relies on the combined system in order to generate intelligent task lists. The data verification and archiving structure in association with the configuration and version control structure is used to determine whether follow-up tasks or routine tasks can be created. In the case of routine activities, the task management structure will utilise the data verification structure and stored historic data to determine a list of active elements and to gather support detail. Integrated access through the central control system allows data and task sharing between remote teams.

1.5.5 System restriction and user support structure

Data privacy is important in the industrial sector. Electronic equipment such as mobile phones and cameras are often prohibited on site. Smart-phone use therefore presents a threat to industrial entities and account-based management is required to ensure that only appointed users have access to these digital systems. In addition to access restrictions, user accounts can be used to provide users with relevant options to improve work accuracy and effectiveness.

Many other mobile applications provide powerful features to handle data. The investigated systems rely on user accounts to manage system access and offer user restrictions in certain cases. However, the investigated systems did not offer sufficient user support or system restrictions and did not address user-based support through specific interfaces or tasks.

The developed application utilises multiple levels of restriction to eliminate misuse of the system and mobile devices. The developed system allows management of assigned devices and licences and can revoke device access remotely. User access is controlled and restricted based on access levels. Users are assigned access to appropriate data sets. During automatic item detection, only options linked to the specific user are considered.

System restrictions and user control integrate with other components of the developed system to allow powerful capabilities. The configuration and version control structure maintains a full history of linked devices, licences, users and access levels. Access to application features such as management privileges and task allocation are restricted based on user control settings.

1.5.6 Data processing and integration structure

Gathered data must be processed in order to produce useful information. The information must be presented in a form that allows users to interpret the data. Alternatively, other systems can access the data in order to present the data to users in a suitable fashion.

Other existing data collection systems offer limited integration options with external systems. Commercial data collection systems offer communication with selected third-party systems. Other systems integrate with linked systems to generate reports. In the case studies, users requested specific outputs, but these specific outputs could however not be produced by other data collection systems.

The system developed as part of this study offers multiple communication options with external systems. Secure communication between mobile devices and the centralised system takes place using structured requests. The central system is used to send relevant data to linked devices and support systems. Among these support systems are a custom report generation program, a web-based energy management system and a commercial system used by an external party. Communication with these systems are managed using the centralised system and do not influence remote users.

In order to allow effective system integration options, the system relies on support systems to provide a complete solution. The configuration and version control structure allows administrators to assign export options and send relevant data to support systems. In addition to this, the data verification structure relies on the integration with the web-based energy management system and reporting system to produce reports for auditing purposes.

1.6 Thesis overview

Chapter 1: Introduction to energy data consolidation

The present conditions surrounding the industrial sector in South Africa are considered in this chapter. Various industries within the industrial sector are considered to determine its specific data collection needs. A need for a cross-industry, structured data collection system is established. A novel mobile data collection system is then proposed, based on identified requirements. Lastly, the novel contributions and the structure of the thesis are discussed.

Chapter 2: Evaluation of data collection systems

Six software structures that were identified namely verification, version control, calculation and data validation, task management, user restriction and assistance, as well as integration with support systems. In this chapter, existing data collection systems are considered. Literature findings related to the six identified software elements are discussed. Lastly, existing commercial systems, are evaluated.

Chapter 3: A new mobile data management system

In the preceding chapters a mobile data collection system was identified as the optimal solution. Existing mobile data collection systems were considered. The investigation revealed shortfalls associated with the existing applications. A novel data collection system was therefore designed with these shortfalls in mind. A new data collection system with unique components and capabilities is introduced in this chapter.

Chapter 4: Support system design

A data management system which consists of five distinct elements was presented in the previous chapters. The complete system enables users to synchronise configuration data, collected data and managed tasks. Users will interact mainly with the mobile application, which is therefore considered the most important element of the system. Users rely on the application to perform data collection tasks. In this chapter design elements related to the mobile application's considerations, structure and interfaces are discussed in detail.

Chapter 5: Mobile application design

Chapter 3 introduced a complete data collection and task management system, followed by a detailed application discussion in Chapter 4. This chapter discusses the integrated solution offered by the developed system in detail. The chapter discusses how various system components presented in Chapter 3 and Chapter 4 function together to deliver a range of outcomes.

Chapter 6: Implementation and case studies

The developed system offers a generic data collection solution that has the ability to address the data collection needs associated with a range of industrial activities. Provided discussions elaborate how the developed system conformed to the needs of various industrial clients and are presented as case studies. These case studies provide validation of the developed system. Special attention was paid to contributing novel elements and how it affected each particular case.

Chapter 7: Requirement and contribution evaluation

This chapter serves as a verification study of the developed system. Functionality of the individual components therefore has to be verified. Further evaluations prove that the six contributing components combine to form a novel system. Lastly, the contributing components are used to verify that the developed system aligns with system objectives.

Chapter 8: Conclusion and recommendations

This chapter provides a conclusion of the study. A review of forgoing chapters is provided and serves as a complete work summary. The final section of the document is used to provide recommendations for further study in this field.

Chapter references

Alsyouf, I. (2007). The role of maintenance in improving companies' productivity and profitability. *International Journal of Production Economics*, 105(1):70–78.

Alsyouf, I. (2009). Maintenance practices in Swedish industries: Survey results. *International Journal of Production Economics*, 121(1):212–223.

Australian National University Press (2015). *China's domestic transformation in a global context.*

Baglee, D. and Jantunen, E. (2014). Can equipment failure modes support the use of a condition based maintenance strategy? *Procedia CIRP*, 22:87–91.

Blignaut, J., Inglesi-Lotz, R., and Weideman, J. (2015). Sectoral electricity elasticities in South Africa: Before and after the supply crisis of 2008. *South African Journal of Science*, 111(9/10):50–56.

Brand, H. G. (2014). *An integrated sustainability framework for environmental impact reduction in the gold mining industry.* Phd thesis, University of North-West.

Cengel, Y. A. and Boles, M. A. (1989). *Thermodynamics An engineering approach 5th edition.* McGraw-Hill.

Centre for the Analysis and Dissemination of Demonstrated Energy Technologies (2001). Compressed air savings by leakage reduction and efficient air nozzles. *Caddet energy efficiency.*

Chamber of Mines of South Africa (2014). Annual Report 2013/2014.

Cloete, S., le Roux, D., and Buhrmann, T. (2013). Reducing Compressed Air Wastage By Installing New Technology in Underground Mines. *2013 Proceedings of the 10th Conference on the Industrial and Commercial Use of Energy.*

Daws, D. (2015). Scientists say there is no debate ' that SA is experiencing a water crisis '.

Deloitte (2012). The economic impact of electricity price increases on various sectors of the South African economy. page 108.

Department of Communications (2014). South Africa Yearbook 2013/2104 Mineral Resources. pages 301–311.

Donev, G., Van Sark, W. G. J. H. M., Blok, K., and Dintchev, O. (2012). Solar water heating potential in South Africa in dynamic energy market conditions. *Renewable and Sustainable Energy Reviews*, 16(5):3002–3013.

EYGM Limited (2016). Globalize or customize: Finding the right balance Global steel 2015-2016.

Groenewald, H. (2015). *A performance-centered maintenance strategy for industrial DSM projects*. Phd thesis, North-West University, Pretoria.

Groenewald, H., Kleingeld, M., and Vosloo, J. (2015). A performance-centred maintenance strategy for industrial DSM projects. *Proceedings of the Conference on the Industrial and Commercial Use of Energy, ICUE*, 2015-Septe:50–53.

Haley, U. C. V. and Haley, G. T. (2013). *Subsidies to Chinese industry : state capitalism, business strategy and trade policy*. Oxford University Press.

Hydro, M. (2000). Compressed air improvements save Tolko $125 000 a Year. *Power smart profiles*, 16(May).

Industrial Development Corporation (2013). South African economy: An overview of key trends since 1994. *Department of Research and Information*, (December):1–30.

Inglesi-Lotz, R. and Pouris, A. (2012). Energy efficiency in South Africa: A decomposition exercise. *Energy*, 42(1):113–120.

Kalin, M., Fyson, A., and Wheeler, W. N. (2006). The chemistry of conventional and alternative treatment systems for the neutralization of acid mine drainage. *Science of the Total Environment*, 366(2-3):395–408.

Khan, F. (2015). Capturing critical pipeline failure data for optimal maintenance management of a water supply network: a rand water proposition.

Kohler, M. (2014). Differential electricity pricing and energy efficiency in South Africa. *Energy*, 64:524–532.

Kotze, R. L. M. and Visser, J. K. (2012). An analysis of maintenance performance systems in the South African mining industry. *South African Journal of Industrial Engineering*, 23(3):13–29.

Lane, A., Guzek, J., and van Antwerpen, W. (2015). Tough choices facing the South African mining industry. *Journal of the Southern African Institute of Mining and Metallurgy*, 115(6):471–479.

Mabuza, P. F. and Gerwel Proches, C. N. (2014). Retaining core, Critical & scarce skills in the energy industry. *Indian Journal of Industrial Relations*, 49(4):635–648.

Man, M., Modrak, V., Dima, I. C., and Pachura, p. (2011). A theoretical approach to the job satisfaction. *Polish journal of management studies*, 4:7–15.

Maneschijn, R., Vosloo, J. C., and Mathews, M. J. (2016). Investigating load shift potential through the use of off-gas holders on South African steel plants. In *Proceedings of the 13th Conference on the Industrial and Commercial Use of Energy (ICUE)*, pages 104–111.

Moubray, J. (1997). *Reliability-centered maintenance*. Butterworth Heinemann.

Mudd, G. M. (2007). Global trends in gold mining: Towards quantifying environmental and resource sustainability. *Resources Policy*, 32(1):42–56.

Musingwini, C., Cruise, J. A., and Phillips, H. R. (2013). A perspective on the supply and utilization of mining graduates in the South African context. *Journal of the Southern African Institute of Mining and Metallurgy*, 113(3):235–241.

Newbold, J. (2006). Chile's environmental momentum: ISO 14001 and the large-scale mining industry - Case studies from the state and private sector. *Journal of Cleaner Production*, 14(3-4):248–261.

Popescu, G. H., Nica, E., tefnescu Mihil, R. O., and Lzroiu, G. (2016). The United States (U.S.) steel import crisis and the global production overcapacity till 2016. *Metalurgija*, 55(3):538–540.

Rand Water (2013). Rand Water Integrated Annual Report 2012-2013. *Rand Water Integrated Annual Report 2012-13*, (November):126–236.

Rasool, F., Botha, C. J., and Botha, C. (2011). The nature, extent and effect of skills shortages on skills migration in South Africa. *SA Journal of Human Resource Management*, 9(12).

Stanz, K. (2009). Factors affecting employee retention: what do engineers think? *Management Today*, 25(8):17–19.

Statistics South Afirca (2014). Youth employment, unemployment, skills and economic growth. *Statistics South Africa. Pretoria: Statistics South Africa.*

Stewart, T. P., Drake, E. J., Bell, S. M., Wang, J., Stewart, S., , and Scott Of, R. E. (2014). Surging steel imports put up to half a million U.S. jobs at risk. *EPI Briefing Paper*, 376.

Terera, S. R. and Ngirande, H. (2014). The impact of rewards on job satisfaction and employee retention. *Mediterranean Journal of Social Sciences MCSER Publishing*, 5(1):481–487.

Van Berkel, R. (2007). Eco-efficiency in primary metals production: Context, perspectives and methods. *Resources, Conservation and Recycling*, 51(3):511–540.

Van der Walt, F., Thasi, M. E., Jonck, P., and Chipunza, C. (2016). Skills shortages and job satisfaction - insights from the gold-mining sector of South Africa.

Van Tonder, A. J. M. (2011). Sustaining compressed air DSM project savings using an air leakage management system. *2011 Proceedings of the 8th Conference on the Industrial and Commercial Use of Energy*, (November):133–137.

Visagie, C. J. (2005). *Successful outsourcing of maintenance in the mining industry-methods and principles*. Maters desertation, University of Johannesburg.

Winkler, H. (2006). Energy policies for sustainable development in South Africa Options for the future.

Zeelie, L. E., Breytenbach, W. J. J., and Marais, J. H. (2015). Investigating the possibility of a cost saving intervention on a blast furnace cold blast system. In *Proceedings of the 12th Conference on the Industrial and Commercial Use of Energy (ICUE)*, pages 30–35. Cape Peninsula University of Technology, Cape Town, South Africa.

2

A review of existing data collection systems

Chapter one revealed the need for a unique data collection system. In chapter one, six software elements that contribute to the novelty of the system are discussed. These six elements are data verification, version control, calculation and data validation, task management, user restriction and assistance, as well as integration with support systems. In this chapter, existing data collection systems are considered. Literature findings relating to the six identified software elements are discussed. Lastly, existing commercial systems, are evaluated.

2.1 Industrial data collection systems

The previous chapter introduced the need for improved data collection in the industrial sector. In order to do so, the current economic environment surrounding South Africa's industrial sector was investigated. The investigation enforced the need for a cost effective data collection system. Data collection and management needs in multiple industries were consolidated and a problem statement was theorised.

Existing systems and methods were investigated to find solutions that address the identified data collection and management needs. No single system considered during the investigation was able to address all the requirements. Development of a novel system was therefore proposed. The proposed system offers advanced generic functionality capable of addressing the needs specified in the problem statement. The novel system combines the following six contributing components to produce a comprehensive solution:

1. Data verification structures
2. Data management and versioning structure
3. Calculation and data validation structure
4. Task management structure
5. User guidance and restriction structure
6. System integration and expansion structure

Other data collection and management systems were investigated to determine if a similar solution already exists. No system presented all the required features. However, the systems that were considered provided insight into one or many of the proposed system elements. Details regarding systems which were considered are discussed in this chapter. The chapter contains a general data collection system introduction, followed by discussions relating to the contributing components listed above. Commercial data collection systems are evaluated, followed by a summary of available systems.

Decision makers, senior operations managers and field workers require accurate and timely data to acquire relevant feedback and make informed decisions (Park, 2015). Park (2015) continues that the required data includes operational research, service delivery measurements and production efficiency recordings. The Society for Clinical Data Management (2014) elaborates on this by stating that industrial data collection systems are not only used for data entry, but for validation of data, document management and query creation and resolution purposes.

Industrial data collection systems have therefore evolved to more complex systems that surpass purely data collection tasks. Complex systems which are responsible for both design- and decision elements were considered by Pequito et al. (2016). In this study the structural design of the system was regarded as one of the most challenging issues. The following questions were therefore adapted from Skogestad (2004) to assist with the structural design.

1. Which variables must be measured?
2. Which variables must be manipulated?
3. Which feedback links should be incorporated between the variable sets stated in 1 and 2?

2.1.1 Automated data collection systems

According to Daneels and Salter (1999), large industrial activities frequently rely on sensor networks hosted by Supervisory Control And Data Acquisition (SCADA) systems. Daneels and Salter (1999) states that these SCADA systems are not full control systems by itself, but provides supervisory access to systems. SCADA systems are therefore purely software packages that provide access to underlying hardware such as Programmable Logic Controllers (PLCs), which are used to control specific systems.

Daneels and Salter (1999) further elaborates and states that SCADA systems can be divided into two basic layers, namely the client layer and the data server layer. Data servers contact field controllers such as PLCs at a user specified rate. These controllers collect sample values from field sensors and label captured values. These values are communicated to data servers when the controller is polled. Typically, these systems achieve scalability by linking multiple data servers to multiple controllers.

Agrawal (2015) identified the following benefits of using SCADA systems:

1. SCADA systems can record and store large amounts of process data.
2. Employees have real-time access to process data.
3. Simple interfaces offer great functionality due to strong development history.
4. A limited number of specific development needs to be performed by the end user.
5. SCADA systems are robust, due to implementation in critical industrial process environments where reliability and performance are essential.

SCADA systems offer extension opportunities by allowing easy integration through OLE for Process Control (OPC)(where OLE is Object Linking Embedding) interfaces. Enterprise Resource Planning (ERP) systems, which claim to assist organisations to become more productive, is one extension example (Park, 2015). However, Krasner (2000) argues that, although the integration of ERP systems may be beneficial, it still requires a large investment, and notes that effective implementation can take substantial time to achieve.

2.1.2 Manual data collection methods

Industrial organisations have a wide variety of data collection needs. These organisations typically rely on automatic data collection systems for operation-critical data collection. However, non-critical data collection needs exist, but do not validate the installation of expensive automated networks, especially not if the organisation is under financial strain. For this reason, manual data collection is widely implemented throughout the South African industrial sector.

Manual data collection is typically performed using a pen and paper approach. Lwin and Murayama (2011) indicates that traditional data collection is a laborious task. In addition to physical data collection, base maps must be prepared, supporting data must be collected and further form processing tasks must be performed. All the administrative tasks, including processing and analysing collected data, deems manual data collection inefficient and unsuitable for unpredictable response situations (Lwin and Murayama, 2011).

Manual data collection is burdened with extensive administrative tasks, including processing and analysing collected data (Schobel et al., 2014b). Park (2015) reinforces this by describing the following process: Data generated in production is recorded on paper sheets. The collected data is manually transferred to an ERP system or spreadsheet on a predefined time interval. Park (2015) further notes that this process restricts the opportunity for timely decision making and creates the risk that problems are not detected and properly recorded when they occur.

Additional shortfalls of manual data are explained by Schobel et al. (2014a) and InStream (2015). From a practical perspective, paper-based questionnaires require loads of space and cause logistical problems (Schobel et al., 2014a). InStream (2015) revealed that data collection systems that rely on paper-based forms are expensive to maintain on a large scale. Questionable accuracy and long turnaround times are again highlighted. Kinkade et al. (2008) raises the concern that manual data collection methods are prone to falsification.

Manual data collection methods offer simple and fast implementation. On the other hand, extensive overheads associated with handling paper-based forms in combination with large processing times are major concerns. Data falsification and absence of supporting data sources invalidate manual data collection for financial incentives or rebate programmes.

2.1.3 Mobile application based

Anandarajan et al. (2003) proposes that flexible mobile data collection is possible by utilising smart devices. Park (2015) explains that mobile data collection entails targeted collection of structured information on smart devices such as Personal Digital Assistants (PDAs), smart-phones, and tablet computers. Park (2015) further reasoned that the use of smart devices has become ubiquitous in everyday life. This dependency on smart mobile devices drives the need for mobile data collection solutions.

Smart devices contain an abundance of sensors and communication devices. Schobel et al. (2014b) suggested data collection by field sensors that communicate results to smart devices, while Pryss et al. (2013) proposed the use of smart form-based applications. On the other hand, Park (2015) noted that smart devices contain powerful embedded sensors that can be used for data collection. These embedded sensors include accelerometers, digital compasses, gyroscopes, GPS receivers, microphones and digital cameras.

The increasing use of mobile systems in business environments was observed by Pryss et al. (2013). These mobile systems were typically used for task management and location-based services. It was therefore noted that smart mobile devices offer promising mobile data collection opportunities. In addition to this, Schobel et al. (2014b) noted that the use of mobile data collection solutions relieves employees of costly manual tasks. Tomlinson et al. (2009) indicated that mobile systems allow real-time supervision and allows the detection of falsified data. These are major improvements over manual data collection systems.

CartONG (2011) investigated the use of mobile data collection systems in the manufacturing industry and found that this approach was seldom used. Schobel et al. (2014a) considered the possibility of developing a mobile data collection application. The results revealed that specific knowledge of mobile application development is required. Furthermore, specialist knowledge is required to generate an applicable application, but the application developers lack this expert knowledge. The typical work sequence of mobile data collection systems was described by Park (2015):

1. Create data collection forms.
2. Distribute forms to field devices.
3. Collect data using mobile devices.
4. Upload data to centralised database.
5. Process data immediately.
6. Provide output and reports.

In conclusion, mobile data collection offers an attractive alternative data collection system for industrial purposes. However, mobile systems have not been implemented on a large scale. Mobile systems offer great advantages over existing data collection methods. Implementation is simple and does not require large upfront investment. Various data quality improvements, rapid processing and supporting data management are included among the advantages of mobile systems.

2.2 Data verification structures

Data audits form an integral part of data collection. McKee (1993) argues that data collection without a well organised audit process carries no value. Furthermore, McKee (1993) suggests three audit types, namely routine audits, which focus on random data samples, structured audits and audits for cause. Rostami et al. (2009) found that a series of small audits produces higher quality results, by stating that traditional audits yielded an upward trend in error rates, while periodical statistical audits resulted in declining error rates.

Gómez-Rioja et al. (2013) stated that routine verification checks will aid in detecting transcription errors. To detect transcription errors, collected data must be compared with original source documentation (World Health Organization, 2003). In a study conducted by Mealer et al. (2013), an average transcription error rate of 9.8% was found. Periodical audits are therefore advisable to validate data and ensure a high quality of collected data.

Source document collection is essential to allow full data traceability options for audit processes. Macefield et al. (2013) emphasises that monitoring is required to ensure that collected data is accurate, complete and can be substantiated with source documentation. Table 2.1 was adapted from Zozus et al. (2014). The table details data quality dimensions with definitions and examples. Data quality and integrity problems can be detected and resolved by ensuring compliance with these three factors.

Table 2.1: *Data quality dimensions of research data*

Quality dimensions	Conceptual definition	Operational examples
Completeness	Presence of the required data	Presence of required data, percentage of records with sufficient data to calculate required outcomes, percentage of absent data.
Correctness	True value and data value is in close agreement	Percentage of data in error based on a set standard, percentage of data that do no conform to an expected range.
Consistency	Uniformity in data	Comparable proportions of relevant diagnoses, comparable proportions of documented order fulfillment.

On-site data monitoring offers the benefit of detecting and correcting data errors before test conditions change. However, Macefield et al. (2013) cautioned that on-site monitoring presents various logistical and financial challenges. In similar work, Mealer et al. (2013) reinforced that remote verification is an expensive task, but continued that more frequent monitoring has a positive effect on safety and data collection accuracy, because errors can be detected and rectified at an early stage.

Source document verification entails comparison of recorded data with original or certified copies of data sources to ensure that the collected data values are accurate, complete and verifiable (Houston et al., 2015). Mealer et al. (2013) and Zozus et al. (2014) implemented source document verification processes in practice and compared reported values with original documentation. This shows that continuous data verification can be a useful tool if it is implemented correctly.

The modern alternative to paper-based source documents are electronic source documents. Electronic source documents offer significant benefits on both logistical and financial fronts. The Center for Biologics Evaluation and Research et al. (2013) highlights that sources should still meet the same regulatory requirements for record keeping. Guidance for electronic source data is provided in Friedman et al. (2015). The guidance emphasize that the same principles apply for both physical and electronic source data. Data sources should therefore comply with the following five requirements:

1. Attributable
2. Legible
3. Contemporaneous
4. Original
5. Accurate

Other literature examples of data verification through auditing processes can be found in medical studies. McKee (1993) verifies this statement and continues that quality assurance audits within clinical settings are used to ensure generation of high-quality data. Park (2015) for example employed audits to evaluate document inconsistencies, service delivery and patient care.

2.3 Data management and versioning structure

Flexible software is required to produce tailored software solutions at a rapid pace. Software flexibility can be seen as variability without the need for extensive work. Riebisch and Brcina (2008) noted that adaptation can be achieved easily by selecting certain components instead of others. Moreover, such a structure can be provided through a plug-in architectural model that allows infrastructure changes during both the development phase and implementation phase.

Pohl et al. (1998) found that software changes are frequently brought forward by changes in customer requirements, technical platforms and environments. These changes drive the need for flexible software and have led to the development of software product lines. Pohl et al. (1998) describes these product lines as software that consists of a common core and various extension components. Specific products can then be configured by selecting appropriate components.

Although flexible software allows rapid adaptation and tailored outcomes, it leads to large amounts of additional work which may be hard to forecast (Pohl et al., 1998). Additional work is not limited only to development challenges, but includes added configuration overhead as well. Riebisch and Brcina (2008) warns that more chained components increase analysis complexity. Added complexity increases the risk of errors due to changes of features that interact with other components.

System maintainability is reduced by feature tangling and scattering. Sochos et al. (2006) suggests that variability points should be aligned so that each variable point is associated with a single optional feature to improve system flexibility. Tangling and scattering lead to multiple dependencies between software components. These dependencies have detrimental effects on configuration and development tasks, including program comprehension and impact analysis.

A thorough design is therefore required to support systems that allow high levels of variability. According to Gamma et al. (1995), good design include abstraction, conceptual integrity, encapsulation, modularity and separation of concerns. Additionally, a design method must be used to implement functional requirements, while meeting all the specified variability and quality requirements. Design patterns such as abstract factories and template methods can be implemented to increase run-time variability.

To manage configurations effectively, Gamma et al. (1995) recommends using a configuration tool, especially if the design is not optimised for configurability. A configuration tool will reduce the risk of missing variables associated with certain components, and therefore avoid problems caused as side effects, which will reduce overall software quality. Furthermore, complex configuration tasks increase the probability of mistakes. The effect of mistakes caused by complex configuration is exaggerated by large systems with many dependencies between components.

From a development perspective, change management is essential to have a working system available at all times. Mohan et al. (2008) defines the objective of change management practices as the process of systematic development, so that the system is continuously in a well-defined state, with accurate specification and quality variable attributes. Although this is focussed on development changes, the same principle applies to software configurations that were released to clients.

Configuration control is therefore implemented to maintain a record of consistent application states and provide structure to track changes. Nistala and Kumari (2013) describes two types of traceability actions, namely commute and conserve. Commute activities ensure that configurations are complete by passing existing elements to new configurations. Conserve activities are used to maintain a record of changes applied to elements.

Ren et al. (2010) promotes version history as a tool to review configurations. Problem sources can be traced using the history structures. Historic records must therefore contain the following elements: version identifier, time of version modification, modifier identification and a change description. Additional information can include support content such as version size and access properties.

2.4 Calculation and data validation structure

Friedman et al. (2015) states that variability reduces data patterns and causes difficulty in detecting changes. Knowledge and experience levels vary from person to person. Moreover, people perceive inputs and perform tasks in unique ways. As a result, these factors lead to inter-observer variability. Friedman et al. (2015) further notes that variations between users are not the only concern, because repeated measurements conducted by the same person often varies more than expected.

To obtain high quality data from field work conducted by persons, a formal monitoring system is required. Corrective action can only be taken once errors are found. Friedman et al. (2015) found that error screening and monitoring is most effective when conducted immediately. This enables personnel to take measures and perform corrective action as soon as errors or deficiencies are detected.

Prasad and Gaikwad (2015) classifies human errors into three types, namely: mistakes, slips and lapses. Mistakes occur when tasks are performed as intended, but the wrong approach is followed unknowingly. Slip is commission errors which occur when trivial tasks that do not require conscious thinking are performed. Lapses are similar to slip and are also associated with actions that do not require conscious thoughts and lead to omission errors.

Data quality is compromised when the mistakes discussed previously are committed while performing data collection tasks. Data validation is therefore required to mitigate the effect of human errors. Mealer et al. (2013) estimates a 10% error rate while transferring data from physical sources to electronic records. Human error should therefore be acknowledged and steps should be implemented to mitigate its effect.

Friedman et al. (2015) indicated that electronic data entry methods allow quality assurance checks at the time of initial data entry. Real-time data checking allows efficient resolution of discrepancies. Friedman et al. (2015) conducted a sensitivity analysis and showed that trail costs can be reduced in excess of 40% by reducing redundant data collection and verification tasks.

In addition to quality assurance tests, Friedman et al. (2015) investigated common data collection issues. Four data collection problems were identified, namely missing data, excess variability, incorrect data (including wrong and fabricated data) and delayed submission. Furthermore, Friedman et al. (2015) identified that other data collection facets can have a detrimental effect on data collection. These facets include too large data sets, excessive testing and too much testing of supplementary data.

Error rates associated with electronic data collection devices have been scrutinised by many researchers (Patnaik et al., 2009). These studies revealed an average error rate of less than 2% in programmes where users received 60 minutes of training. Patnaik et al. (2009) further acknowledged that studies related to data accuracy using mobile phones were lacking. Parikh et al. (2006) performed a study using a combination of camera-equipped mobile phones and paper forms. In this study, error rates of less than 1% were obtained.

Amin et al. (2016) investigated Data Verification and Reconciliation (DVR) technology. DVR relies on process information and mathematical methods to correct and supplement measurements in industrial processes. The aim of DVR is to close material balances where raw measurements are not available, or measurement noise corrupt readings. Additional DVR applications include gross error identification and error elimination. Systematic errors are flagged if measured values deviate too far from expected values. Additional studies based on DVR systems were conducted by Winget et al. (2005); Schmidt et al. (2005); Mitchell et al. (2005).

2.5 Task management structure

Task management opportunities are one of the attractive elements associated with electronic data collection. Modern electronic devices offer a wide range of communication options. These devices can therefore be used to enable communication with field operatives. In ideal conditions, data can be transferred in real time. This data is not limited only to the primary data collection objective, but can also contain configuration data and task information.

Park (2015) implemented a system that manages task distribution. The system consists of a web-based form builder and many remote clients. The form builder is used to create forms which resemble questionnaires. These forms are then distributed to enrolled members.

Operators receive notifications once the task has been created. The operator must use an appropriate mobile device to download and complete the form to complete the assigned task. Figure 2.1 provides a graphic representation of the task-handling process used by Park (2015).

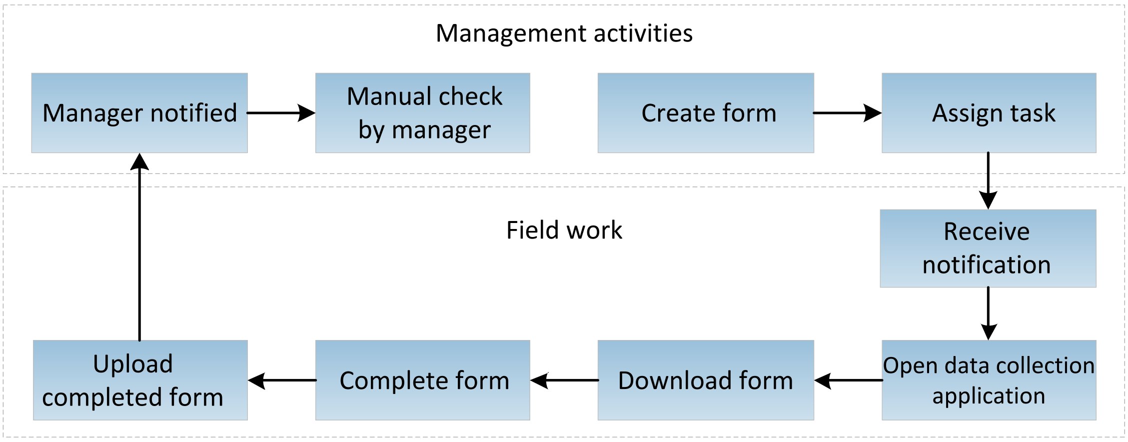


Figure 2.1: *Task handling process*

Task management forms a major part of programming. The large program task is separated into smaller conceptually separate tasks. Each task encapsulates a specific function which stems from the main branch at a specific reference state (Adya et al., 2002). Similarly, tasks performed by field operators serve a specific function. The data set state should be known before the task is performed. The result yielded by the task is appended to the known data set state upon completion of the task.

Adya et al. (2002) contrasted cooperative task management and serial task management. Cooperative task management was found to have advantages above serial task management. Tasks performed on a cooperative basis can be performed in parallel and are not reliant on other tasks to complete before a task can commence. However, the global state may change in such a manner that the global state may be invalid when a cooperative task completes, and won't be able to receive the result. State management is therefore an important factor to consider when implementing cooperative tasks.

An example of a mobile task management system was implemented at a hospital in New Zealand (Foo et al., 2015). Young staff adapted well to the system in concept and practice. The system had a positive effect on the working environment. Unnecessary tasks were avoided and communication among staff members improved. Two major advantages were time saving due to the ability to request action, and the ability to access results without transcription.

The system enabled seamless hand-over among staff members. The system furthermore offered functionality that is simply not achievable in a paper-based environment. Important factors that need to be considered when implementing a digital task management system were identified. Two important factors are full traceability of records, as well as unmistakable status and assignment flags.

2.6 User guidance and restriction structure

Mathauer and Imhoff (2006) considered Human Resource Management (HRM) and its effects in organisations. It was found that HRM influences management elements such as policies, practices and activities. Moreover, managers need to utilise these elements to obtain, develop, evaluate, retain and motivate a broad spectrum of employees to accomplish organisational objectives. HRM tools may have detrimental effects on employee attitude towards work if it is not implemented correct.

Non-financial incentives, in combination with HRM influences, are needed to motivate users and promote a positive attitude towards work. Correct implementation of tools will acknowledge professionalism of workers and promote personal development and desires related to career growth and further qualification. Reid (2004) conducted a study in South Africa and highlighted that non-financial incentives are required to extract optimum results from a workforce.

Although HRM tools will aid with creating a feeling of worth among employees, which will improve their willingness to perform tasks, employees still require adequate guidance structures. Guidance structures will enable employees to perform tasks with less direct management by superior workers. Moreover, tasks can be assigned to less reliable staff because modern systems offer support structures that will improve task execution accuracy and reduce errors.

Prasad and Gaikwad (2015) studied human error probability in a nuclear power plant setting. In the study, human errors are categorised as pre-initiators, initiators and post-initiators. Pre-initiators are actions associated with maintenance and cause system degradation which may lead to component failure. Initiators are actions that lead to plant transients and initiate events. Lastly, post-initiators are actions associated with operator responses to an incident. These actions include procedural safety actions, aggravating actions and recovery actions.

Friedman et al. (2015) suggests two types of training, namely general system training and specific task training. This will enable users to effectively use systems and help bridge the gap associated with unfamiliar tasks. Although training offers great advantages, effective system design will have positive effects on how users interact with a given system. Meinert (2012) offers the following guidelines that will improve user interfaces and help to guide users:

- Limit data fields displayed on the form.
- Limit available options.
- Restrict navigation until tasks are completed.
- Utilise intuitive data collection tools.

Standard features and protocols can be used as a tool to establish a feeling of familiarity among staff members (Woolf et al., 1999). This will also help users to perform correct procedures and actions. However, protocols complicate tasks and raise stress and apathy among workers. Fortunately, technological advances have been able to simplify the practical implementation of protocols (Morris, 2000). Panella et al. (2009) proposed that the new trend is to code organisational arrangements into systems as scheduling and workflow engines.

Schobel et al. (2014b) managed to demonstrate that electronic questionnaires relieve domain experts from costly manual tasks, like the transfer, transformation and analysis of collected data. In another study, Parikh et al. (2006) utilised a hybrid system in which paper forms are used for organisation, while phones are used for data collection. The system utilises cameras in mobile devices to detect printed codes. This reduced complexities of navigating electronic forms and therefore improved worker efficiency and accuracy.

Tomlinson et al. (2009) noted that immediate access to data offers significant data quality improvements. Furthermore, data collection can be guided by implementing advanced skip patterns based on entered values. Mobile devices such as smart-phones have hardware capable of providing validity and readability checks during data collection. This can be used to provide instant feedback to fieldworkers and can adapt forms to allow optimal execution.

In another study, González-Ferrer et al. (2013) developed a methodology to achieve the automated guideline-based generation of care pathways used for long-term patient care. Although this is in the medical sector, the same principles apply to user guidance. Obeid et al. (2013) considered the use of data dictionaries to provide further assistance to users. This system allowed users in linked teams to share information and access each other's work. However, this system required users with advanced training to manage data transfer.

2.7 System integration and expansion structure

Due to the popularity and widespread use of smart-phones, many people have access to devices suitable for mobile data collection purposes. Lane et al. (2010) confirmed that mobile phone users constantly have their devices with them. Moreover, this has led to the emergence of data collection on various personal and professional levels. Park (2015) noted that, although mobile systems are embedded in many economic sectors, it proves difficult to integrate with the manufacturing industry without integrating the mobile systems with legacy systems on site.

Collected data must be consolidated into a central repository to allow analysis of data (Schobel et al., 2014a). In addition to data analysis, a central repository is required to enable advanced functionality including system integration and distributed data management. Foo et al. (2015) depends on an integrated system to allow cooperation between mobile users. Furthermore, the managed data allows the implementation of seamless task hand-over capabilities, because the system is continuously in a consistent state.

A central repository connected to a system with processing capabilities can be used to integrate large systems. The central system can act as a consolidation platform which receives data, archives and translates the data, and interact with other systems to perform extended tasks. The Society for Clinical Data Management (2014) discussed the development of such a system for large medical trails. The main purpose of this system was to manage and direct data flow from various sources.

Communication between remote devices and central systems is an essential part of integrated systems. Data should be consolidated with secure systems as soon as possible to avoid possible data loss. Tomlinson et al. (2009) noted that regular automated data upload improves data security by reducing risks associated with damage to mobile devices or loss of mobile devices.

Although regular automated data synchronisation is ideal, it is not always possible. In many rural areas and industrial environments communication signals are weak or not available. Temporary storage on mobile devices is therefore required. Tomlinson et al. (2009) stated that systems with delayed upload capabilities allow field operators to perform tasks while not connected to the internet.

Shirima et al. (2007) also conducted work related to data synchronisation and noted that the cost of auxiliary field equipment could be reduced by communicating directly between field devices and a managed website. In the case documented by Shirima et al. (2007), communication-enabled devices therefore removed the need for expensive mobile computer equipment and offered significant cost savings.

Other benefits of a synchronised system is the ability to share data, and improved data quality. The Center for Biologics Evaluation and Research et al. (2013) noted how integration with electronic databases can reduce certain errors. Synchronisation functions allow system administrators to perform various comparisons between new data and existing data samples (Friedman et al., 2015). Data should be verified based on completeness and consistency with existing data. Consistency checks are focussed on certain variables, but can be confirmed using various source data verification techniques (Fda and Cder, 2013).

2.8 Related commercial systems

A study was conducted to establish if a single system with all the required capabilities is commercially available. A capability comparison was used to analyse similar systems to determine whether it can provide all the required functionality. Table 2.2 provides a summary of the systems by marking supported functions with '•' characters. The following 15 systems were included in the comparison:

- DeviceMagic (Magic, 2017)
- doForms (doForms, 2016)
- EpiCollectPlus (EpiCollect, 2016)
- FlowFinity (Flowfinity, 2017)
- Formitize (Formitize, 2016)
- GIS Cloud (Cloud, 2016)
- GoFormz (GoFormz, 2016)
- Keel (Keel, 2017)
- Magpi (Magpi, 2016)
- Momento (Momento, 2017)
- Momento Database (Memento Database, 2016)
- Nexticy (Nexticy, 2016)
- POI Mapper (Mapper, 2016)
- ProntoForms (ProntoForms, 2016)
- PushForms (PushForms, 2016)

Common generic capabilities were not included in this summary, however advanced features were considered. Advanced features were grouped according to the six categories associated with features that contribute to the novel capabilities of the developed system. The six categories are based on structures required to provide industrial clients with a single comprehensive data collection system. To achieve this the developed system makes provision for the following structures: data verification and archiving, configuration and version control, calculation and validation, task management, system restriction and user support, as well as data processing and integration.

Table 2.2: *Comparison of commercial data collection systems*

	Data collection systems	Device Magic	doForms	EpiCollectPlus	FlowFinity	formetize	GIS_Cloud	goformz	Keel	Magpi	Momento	Momento Database	Nextícy	POI_Mapper	ProntoForms	PushForms
Data verification and archiving structure	Secure database on central platform		●		●	●		●	●		●	●		●	●	
	Secure managed database											●		●		
	Geo location capture	●	●	●	●	●	●	●	●	●	●	●		●	●	●
	Photograph with annotations	●	●		●	●									●	
	Record system state with log															
Configuration and version control structure	Automated configuration synchronisation		●			●									●	●
	Data structure versioning													●	●	
	Auto update user configuration				●					●				●	●	
	Licencing and group authorisation		●		●	●								●	●	
Calculation and validation structure	Historic data access on device				●	●	●				●	●		●		
	Customisable data validation tests			●	●	●			●			●		●	●	●
	Validate according to historic data		●		●											
	Customisable summary							●			●				●	
	Offline calculations		●		●	●						●			●	
	Multiple variable calculations				●							●			●	
Task management structure	Manual task assignment	●	●		●	●		●	●	●	●	●			●	●
	Intelligent offline task generation															
	Task reminders					●										
	Automatic task closing															
	Multiple task types					●										
System restriction and user support structure	Authorised user linking	●	●		●	●			●	●		●	●	●	●	
	User access versioning															
	Code scanning	●	●	●	●	●	●		●	●		●			●	●
	User guidance on input form		●			●					●	●				●
	Automated data set detection								●							
	Review previous readings offline				●	●					●	●				
Data processing and integration structure	Customisable report integration				●	●	●	●	●	●	●	●		●	●	
	Data encryption	●			●	●			●	●	●	●			●	
	External system integration	●	●		●	●	●	●	●	●	●	●			●	●
	Immediate rule based notifications							●			●					

2.8.1 Most complete candidate systems

All the considered systems, summarised in Table 2.2, had unique elements that promote its use in particular cases, however no comprehensive system was found. The five most complete related systems were: DoForms, Flowfinity, Formitize, Momento Database and ProntoForms. The other systems had more significant shortfalls and are not discussed in more detail. The four most systems mentioned above are discussed in this section.

DoForms

DoForms offers a generic system aimed at replacing paper based forms with electronic forms. It is used in various environments including small- and medium sized businesses, large enterprises, government and education and healthcare industries. The mobile application allows users fill in forms using device data. Additional features include, basic form logic, data validation and data transfer options using a cloud service.

Although DoForms offer an extensive system, shortfalls were identified based on client needs in the South African industrial sector. The system does not offer an isolated database to store sensitive data. Another shortfall is limited calculation capabilities, which is largely caused by the absence of historical data on the device. The system also has limited task management options related to form completion.

Flowfinity

Flowfinity is aimed at developing business process workflow applications with a code-free editor. The system allows users to collect data, look up information and complete business transactions. Data is displayed using interactive dashboards. The system allows users to replace paper and spreadsheet systems with a maintainable without expert system knowledge.

Although Flowfinity offers comprehensive generic capabilities, it does not address all the requirements identified in the industrial sector. Flowfinity does not support task management and does not differentiate between data collection types. User support by automating decision making such as data set detection is not mentioned. The application allows users to create custom interfaces, however these interfaces do not follow the same pattern and may create the need for specialised training to complete each form. The marketing documentation indicates that Flowfinity is used in multiple industries there is little evidence of extensive implementation in the industrial sector and mining sector.

Formitise

Formitise offered the most comprehensive system in the investigation, however specialised client needs are not addressed. A form builder allows users to construct customised forms, suitable for a wide range of applications in multiple industries. These forms represent paper forms. The mobile application offers advanced off-line support with extended functionality including data validation and form logic operations. Lastly, Formitize offers secure data management through cloud services.

Although Formitize offers a powerful data management system certain client requirements could not be fulfilled by Formitize. Secure data storage is only offered in limited countries, where certain South African clients required centralised data storage. Another significant shortfall is routine task management. The system does not utilise existing data to perform off-line tasks such as data validation. A large shortfall is routine task generation, where the mobile application is not capable of generating user specific tasks based on historic data.

Momento Database

Momento database is a flexible mobile database manager. The applications interface can be customised to accept data based on 19 input types. The system offers data processing and display options. Basic data forwarding and integration options are made available. Momento database offers advanced security solutions including private server options.

However, Momento database is targeted at data management and does not offer and advanced user guidance and task management functionality. Task cannot be generated based on historic data. Furthermore, the application does not offer user guidance through intelligent actions such as data set detection or task generation. Data validation based on historic data is not supported and is a crucial element of this study.

ProntoForms

ProntoForms serves is another system targeted at replacing paper based forms with electronic alternatives. It offers advanced integration options between mobile devices and centralised services. Data can therefore be transferred back and forth to allow cooperation and ensure updated data sets. In addition to this, ProtoForms offer powerful calculation options on the mobile device.

When considered as a possible solution for the data collection need associated with this study ProntoForms did not address all the requirements. The most significant difference between ProntoForms and the developed system is mode types. ProntoForms rely on users to complete forms, but does not consider the recurring nature of certain tasks. Data validation based on previous data entries and task generation based on mode behaviour or previous data entries are not supported.

2.8.2 Summary of related systems

This study of related commercial systems show that no single comprehensive data collection and task management system exists. Furthermore if none of these systems were implemented in all the industrial activities covered by this study. No single system addresses all the requirements required by industrial applications. Common shortfalls areas include:

- Configuration version and system state recordings
- Data structure version
- Data validation based on previous records
- Customisable summaries on displayed during data collection
- Multiple variable calculations and off-line calculations
- Intelligent task generation
- Task reminders
- Automatic task closing
- Multiple task types
- User support including data set detection and proposals

This list indicates advanced needs required by industrial energy consumers stretches beyond basic data collection. User guidance is required to effectively utilise personnel. Traceability is restricted because forms do not track changes and cannot be linked to previous structures. Further, restrictions regarding historic data access prevent off-line data validation and calculation options, as well as intelligent task generation based on previous records. A single comprehensive data collection and management system is therefore required to address this combination of needs.

2.9 Summary of data collection systems

This chapter presented a literature study surrounding modern data collection systems. Automated, manual and mobile data collection systems were identified as the three current industrial data collection systems. SCADA systems offer the ideal solution for fixed measurements, but are expensive to implement and have restrictive hardware structures. Manual systems are inexpensive and offer easy implementation at first, but prove hard to maintain. Mobile data collection systems offer a flexible solution that allows collection of high quality data, without expensive infrastructure requirements.

Six categories were identified as parts of the ideal data collection system. These categories include structures that allow data verification and archiving, configuration and version control, calculation and validation, task management, system restriction and user support, as well as data processing and integration. Mobile systems from multiple industries were considered to learn more about each of the categories.

Finally, commercial systems were assessed, based on the same six categories, to determine if an existing solution can address the identified requirements. Each of the considered systems perform well in some selected categories, but no single system offered all the required capabilities. The findings of this chapter therefore enforce the need for a novel mobile data collection and task management system, due to the lack of a comprehensive alternative system.

Chapter references

Adya, A., Howell, J., Theimer, M., Bolosky, B., and Douceur, J. J. (2002). Cooperative Task Management without Manual Stack Management. In *USENIX 2002 Annual Technical Conference*, pages 289–302, Washington. USENIX.

Agrawal, D. K. (2015). Application of SCADA system in Steel Industries. *International Journal of Scientific and Research Publications*, 5(6):407–409.

Amin, A., Webb, R. A., Kalitventzeff, B., and De Vos, G. (2016). Application of Data Validation and Reconciliation to Production Allocation. *34th International North Sea Flow Measurement Workshop 25-25 October 2016*, pages 1–27.

Anandarajan, M., Anandarajan, A., and Srinivasan, C. A. (2003). Business Intelligence Techniques: A Perspective from Accounting and Finance - Google Books.

CartONG (2011). Analyses of existing mobile data collection against the requirement of organization working in the humanitarian context. *Mobile Data Collection in Humanitarian Context (NOMAD)*, pages 1–10.

Center for Biologics Evaluation and Research, Center for Drug Evaluation and Research, and Center for Devices and Radiological Health at the Food and Drug Administration (2013). Guidance for Industry Electronic Source Data in Clinical Investigations.

Cloud, G. (2016). Mobile Data Collection GIS Cloud, http://www.giscloud.com/apps/mobile-data-collection.

Daneels, A. and Salter, W. (1999). What Is Scada ? In *International Conference on Accelerator and Large Experimental Physics Control Systems, Trieste, Italy*, pages 339–343, Trieste.

doForms (2016). doForms — Features, http://www.doforms.com/wp-content/uploads/2016/05/doforms-over.

EpiCollect (2016). EpiCollect.net, http://www.epicollect.net/plus_Instructions/developers/default.html.

Fda and Cder (2013). Guidance for Industry Oversight of Clinical Investigations A Risk-Based Approach to Monitoring.

Flowfinity (2017). Knowledge Base — Flowfinity, http://www.flowfinity.com/kb/.

Foo, E., McDonald, R., Savage, E., Floyd, R., Butler, A., Rumball-Smith, A., and Connor, S. (2015). Mobile task management tool that improves workflow of an acute general surgical service. *ANZ Journal of Surgery*, 85(10):760–765.

Formitize (2016). Full Feature List — Formitize, http://formitize.com/en/features/full-feature-list.

Friedman, L. M., Furberg, C. D., DeMets, D. L., Reboussin, D. M., and Granger, C. B. (2015). Data Collection and Quality Control. In *Fundamentals of Clinical Trials*, pages 233–253. Springer International Publishing, Cham.

Gamma, E., Helm, R., Johnson, R., and Vlissides, J. M. (1995). *Design Patterns: Elements of Reusable Object-Oriented Software*. Addison Wesley.

GoFormz (2016). GoFormz Free Mobile Forms App and Platform is Easy to Use GoFormz, https://www.goformz.com/product/how-mobile-forms-work.

Gómez-Rioja, R., Álvarez, V., Ventura, M., Alsina, M. J., Barba, N., Cortés, M., Llopis, M. A., Martínez, C., and Ibarz, M. (2013). *Current status of verification practices in clinical biochemistry in Spain*, volume 51.

González-Ferrer, A., ten Teije, A., Fdez-Olivares, J., and Milian, K. (2013). Automated generation of patient-tailored electronic care pathways by translating computer-interpretable guidelines into hierarchical task networks. *Artificial Intelligence in Medicine*, 57(2):91–109.

Houston, L., Probst, Y., and Humphiers, A. (2015). Measuring data quality through a source data verification audit in a clinical research setting. *Driving Reform: Digital Health is Everyone's Business*, pages 107–110.

InStream (2015). The Problems of Manual Data Entry - Instream.

Keel (2017). Keel Solution, http://mobility.keelsolution.com/data-collector-app.

Kinkade, S., Verclas, K., and Org, M. (2008). Wireless Technology for Social Change: Trends in Mobile Use by NGOs. *Access to Communication Publication Series Volume 2*, 2.

Krasner, H. (2000). Ensuring e-business success by learning from ERP failures. *IT Professional*, 2(1):22–27.

Lane, N., Miluzzo, E., Lu, H., Peebles, D., Choudhury, T., and Campbell, A. (2010). A survey of mobile phone sensing. *IEEE Communications Magazine*, 48(9):140–150.

Lwin, K. K. and Murayama, Y. (2011). Web-based GIS System for Real-time Field Data Collection Using Personal Mobile Phone. *Journal of Geographic Information System*, 03(04):382–389.

Macefield, R. C., Beswick, A. D., Blazeby, J. M., and Lane, J. A. (2013). A systematic review of on-site monitoring methods for health-care randomised controlled trials. *Clinical Trials*, 10(1):104–124.

Magic, D. (2017). Mobile Forms Software — Powerful Features — Device Magic, http://www.devicemagic.com/mobile-forms-features/.

Magpi (2016). Magpi — Support, http://support.magpi.com/support/home.

Mapper, P. (2016). POI Mapper Features and Benefits, http://www.poimapper.com/benefits/.

Mathauer, I. and Imhoff, I. (2006). Health worker motivation in Africa: the role of non-financial incentives and human resource management tools. *Human Resource for Health*, 4(24):1–17.

McKee, M. (1993). Routine data: a resource for clinical audit? *Quality in health care : QHC*, 2(2):104–11.

Mealer, M., Kittelson, J., Thompson, B. T., Wheeler, A. P., Magee, J. C., Sokol, R. J., Moss, M., and Kahn, M. G. (2013). Remote Source Document Verification in Two National Clinical Trials Networks: A Pilot Study. *PLoS ONE*, 8(12):1–6.

Meinert, C. L. (2012). *Clinical trials : design, conduct, and analysis*. Oxford University Press.

Memento Database (2016). Memento Database, http://mementodatabase.com/.

Mitchell, R., Shah, M., Ahmad, S., Rogers, A. S., Ellenberg, J. H., and Interventions, A. M. T. N. f. H. (2005). A unified web-based Query and Notification System (QNS) for subject management, adverse events, regulatory, and IRB components of clinical trials. *Clinical Trials*, 2(1):61–71.

Mohan, K., Xu, P., Cao, L., and Ramesh, B. (2008). Improving change management in software development: Integrating traceability and software configuration management. *Decision Support Systems*, 45(4):922–936.

Momento (2017). Momento, https://momentoapp.com/features/.

Morris, A. H. (2000). Developing and Implementing Computerized Protocols for Standardization of Clinical Decisions. *Annals of Internal Medicine*, 132(5):373.

Nexticy (2016). Nexticy — Crossplatform app for Windows and iOS, https://nexticy.com/about.

Nistala, P. and Kumari, P. (2013). Establishing content traceability for software applications: An approach based on structuring and tracking of configuration elements. In *2013 7th International Workshop on Traceability in Emerging Forms of Software Engineering (TEFSE)*, pages 68–71. IEEE.

Obeid, J. S., Mcgraw, C. A., Minor, B. L., Conde, J. G., Pawluk, R., Lin, M., Wang, J., Banks, S. R., Hemphill, S. A., Taylor, R., and Harris, P. A. (2013). Procurement of shared data instruments for Research Electronic Data Capture (REDCap).

Panella, M., Vanhaecht, K., and Sermeus, W. (2009). Care pathways: from clinical pathways to care innovation. *International Journal of Care Pathways*, 13(2):49–50.

Parikh, T., Javid, P., and Ghosh, K. (2006). Mobile Phones and Paper Documents: Evaluating A New Approach for Capturing Microfinance Data in Rural India.

Park, J. (2015). Evaluating a mobile data-collection system for production information in SMEs. *Computers in Industry*, 68:53–64.

Patnaik, S., Brunskill, E., and Thies, W. (2009). Evaluating the accuracy of data collection on mobile phones: A study of forms, SMS, and voice. In *2009 International Conference on Information and Communication Technologies and Development (ICTD)*, pages 74–84. IEEE.

Pequito, S., Kar, S., and Aguiar, A. P. (2016). A Framework for Structural Input/Output and Control Configuration Selection in Large-Scale Systems. *IEEE Transactions on Automatic Control*, 61(2):303–318.

Pohl, K., Böckle, G., and van der Linden, F. (1998). Software Product Line Engineering - Foundations, Principles, and Techniques.

Prasad, M. and Gaikwad, A. J. (2015). Human error probability estimation by coupling simulator data and deterministic analysis. *Progress in Nuclear Energy*, 81:22–29.

ProntoForms (2016). Mobile Forms App — Mobile Forms Software — ProntoForms, https://www.prontoforms.com/platform/mobile-forms-app.

Pryss, R., Musiol, S., and Reichert, M. (2013). Collaboration Support Through Mobile Processes and Entailment Constraints. In *Proceedings of the 9th IEEE International Conference on Collaborative Computing: Networking, Applications and Worksharing*, pages 178–187. ICST.

PushForms (2016). Mobile Forms, Surveys, Checklists, Audits for iOS, Android, PushForms, http://www.getpushforms.com/#features.

Reid, S. (2004). Monitoring the Effect of the New Rural Allowance for Health Professionals. *Health Systems Trust*, pages 1–7.

Ren, Y., Xing, T., Quan, Q., and Zhao, Y. (2010). Software Configuration Management of Version Control Study Based on Baseline. In *2010 3rd International Conference on Information Management, Innovation Management and Industrial Engineering*, pages 118–121. IEEE.

Riebisch, M. and Brcina, R. (2008). Optimizing Design for Variability Using Traceability Links. pages 235–244. IEEE.

Rostami, R., Nahm, M., and Pieper, C. F. (2009). What can we learn from a decade of database audits? The Duke Clinical Research Institute experience, 1997–2006. *Clinical Trials*, 6(2):141–150.

Schmidt, J. R., Vignati, A. J., Pogash, R. M., Simmons, V. A., and Evans, R. L. (2005). Web-based distributed data management in the Childhood Asthma Research and Education (CARE) Network. *Clinical Trials*, 2(1):50–60.

Schobel, J., Schickler, M., Pryss, R., Maier, F., and Reichert, M. (2014a). Towards Process-driven Mobile Data Collection Applications: Requirements, Challenges, Lessons Learned. *International Conference on Web Information Systems and Technologies*, pages 371–382.

Schobel, J., Schickler, M., Pryss, R., and Reichert, M. (2014b). Process-driven data collection with smart mobile devices. In *International conference on web information systems and technologies*, pages 347–362. Springer, Cham.

Shirima, K., Mukasa, O., Schellenberg, J., Manzi, F., John, D., Mushi, A., Mrisho, M., Tanner, M., Mshinda, H., and Schellenberg, D. (2007). The use of personal digital assistants for data entry at the point of collection in a large household survey in southern Tanzania. *Emerging Themes in Epidemiology*, 4(1):5.

Skogestad, S. (2004). Control structure design for complete chemical plants. *Computers & Chemical Engineering*, 28(1):219–234.

Sochos, P., Riebisch, M., and Philippow, I. (2006). The Feature-Architecture Mapping (FArM) Method for Feature-Oriented Development of Software Product Lines.

Society for Clinical Data Management (2014). eSource Implementation in Clinical Research : A Data Management Perspective. A White Paper. pages 1–30.

Tomlinson, M., Solomon, W., Singh, Y., Doherty, T., Chopra, M., Ijumba, P., Tsai, A. C., and Jackson, D. (2009). The use of mobile phones as a data collection tool: A report from a household survey in South Africa. *Globalization and Health*, 2(1):9.

Winget, M., Kincaid, H., Lin, P., Li, L., Kelly, S., and Thornquist, M. (2005). A web-based system for managing and co-ordinating multiple multisite studies. *Clinical Trials*, 2(1):42–49.

Woolf, S. H., Grol, R., Hutchinson, A., Eccles, M., and Grimshaw, J. (1999). Potential benefits, limitations, and harms of clinical guidelines. *BMJ*, 318(7182).

World Health Organization (2003). *Improving Data Quality: A Guide for Developing Countries*. World Health Organization.

Zozus, M. N., Hammond, . W. E., Green, B. B., Kahn, M. G., Richesson, R. L., Rusincovitch, S. A., Simon, G. E., and Smerek, M. M. (2014). Assessing Data Quality for Healthcare Systems Data Used in Clinical Research (Version 1.0). *National Institutes of Health (NIH) Health Care Systems research Collaboration*, pages 1–26.

3

A novel data collection and management system

In the preceding chapters a mobile data collection system was identified as the optimal solution. Existing mobile data collection systems were considered in detail to determine shortfalls and advantages. A novel data collection system was therefore designed with these considerations in mind. The development of the new data collection system and its unique components are described in this chapter.

3.1 Introduction

Modern industrial data collection and reporting needs were introduced in Chapter 1. Chapter 2 presented a critical review of existing data collection systems. Data management standards and practices utilised by organisations were also considered. The review revealed various shortfalls with existing data collection systems. A new mobile data collection system was therefore conceptualised and developed to address the identified requirements.

The system was developed as a support system offered by an Energy Services Company (ESCO). According to IDC (2013), the role of ESCOs in the South African market is to identify key challenges in market barriers from a financial, technical and regulatory point of view. In addition to this, ESCOs recommend instruments and strategies that can be implemented to address the identified challenges.

The ESCO is involved with multiple industrial organisations. This exposure to a wide range of industries revealed similarities and specialised data requirements. These similarities led to the conceptualisation of a generic system capable of addressing multiple data management needs. Specialised components required to address data needs in specific industries were developed and allow other industries to benefit from experience gained elsewhere.

This chapter presents an overview of the developed system. The developed system offers a generic mobile data management solution. At its core, the system relies on a mobile application with specialised structures and components. The mobile application is supported by support systems which assist with synchronisation, consolidation and integration tasks.

3.2 Requirements and considerations

3.2.1 Design considerations

The economic conditions discussed in Chapter 1 have a profound impact on the industrial sector. Effective resource management offers cost-saving opportunities with minimal input cost. A cost-effective data collection and management platform is therefore required to address data needs associated with identified opportunities. The primary focus of the system is the collection and management of data samples and support data.

Mobile devices such as smart-phones were identified as potential tools to collect and manage the required data. These modern mobile devices offer calculation capabilities, large storage facilities, communication options, as well as various hardware components and sensors. Mobile devices therefore offer a cost-effective platform to host the resource management system.

In the industrial sector, workers and equipment are often exposed to harsh environmental conditions like wind, moisture, dust, extreme temperatures and humidity. As a result, rugged devices have been developed. These devices offer protection against drops, as well as ingress protection from water and dust. Selected mobile devices are certified for use in potentially explosive environments. These rugged devices typically utilise either Android or Windows Mobile operating systems.

Standard mobile devices such as Apple iPhones are popular devices in South Africa. However, Apple does not offer rugged devices developed for use in harsh conditions. Apple devices were therefore deemed unsuitable for an industrial mobile solution. According to IDC (2016), Android dominates the smart-phone market with 86.8% in comparison with IOS at 12.5% and Windows Phone at 0.3%. Android was therefore chosen as the preferred platform for the development of the mobile application.

3.2.2 System requirements

The parameters shown in Table 3.1 were derived from the problem statement discussed in Section 1.3. These parameters where used to conduct a critical review of existing data collection applications in Section 2.8. The review revealed that no single system has the ability to address all the stated parameters. The same list was therefore used as a requirement specification to develop a novel data management system, tailored according to industrial consumer needs.

3.3 Logic hierarchy

The developed system offers users a generic platform to construct data structures suited to their particular needs. The logic structure shown in Figure 3.1 shows the logic hierarchy of the developed system. The developed system can be seen as the top node. *Groups*, *Configurations* and *Modes* form the remainder of the structure and will be discussed in more detail in the following sections.

3.3.1 Groups

The developed system is a cross-industry tool developed for an ESCO. The ESCO is associated with multiple organisations across South Africa, and therefore offers services to various industrial clients and has access to collected data. Each organisation or client is referred to as a *Group*. Group data is stored in private databases and is managed by the ESCO. The Group database is used to store all the configuration settings and collected data.

Table 3.1: *Comprehensive mobile data collection system requirements*

Category	Item
Data verification and archiving structure	Secure database on central platform
	Secure managed database
	Geo location capture
	Photograph with annotations
	Record system state with log
Configuration and version control structure	Automated configuration synchronisation
	Data structure versioning
	Auto update user configuration
	Licencing and group authorisation
Calculation and validation structure	Historic data access on device
	Customisable data validation tests
	Validate according to historic data
	Customisable summary
	Offline calculations
	Multiple variable calculations
Task management structure	Manual task assignment
	Intelligent offline task generation
	Task reminders
	Automatic task closing
	Multiple task types
System restriction and user support structure	Authorised user linking
	User access versioning
	Code scanning
	User guidance on input form
	Automated data set detection
	Review previous readings offline
Data processing and integration structure	Customisable report integration
	Data encryption
	External system integration
	Immediate rule based notifications

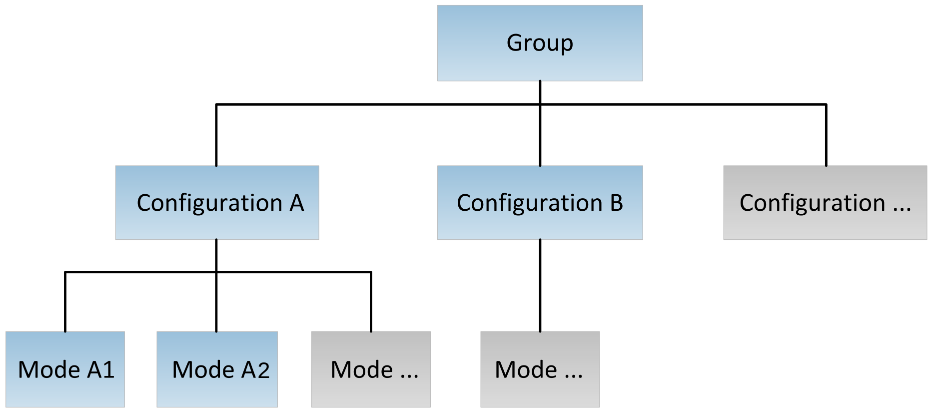


Figure 3.1: *Logic hierarchy*

3.3.2 Configurations

Multiple *Configurations* can be linked to each *Group*. These configurations are stored in the same database and belong to the same organisation, but function as separate units. Configurations can be used to define business entities according to user-specific needs. Configurations are subject to version control and store data, including devices, users, modes and user-mode-links.

3.3.3 Modes

Each *Configuration* may contain multiple *Modes*. Each mode can be seen as a specific questionnaire. Modes are used to collect a cluster of data. A list of input variables is defined for each mode. Appropriate data ingress interfaces are linked to the variables. When the mode is selected, the application constructs a form based on the mode specification and allows data collection through linked ingress interfaces.

Modes are classified as one of the following three types: routine modes, non-routine modes and status-tracking modes. Routine modes include activities such as meter readings, and occur on a scheduled basis. Non-routine modes are typically events which are logged and completed once. Lastly, status-tracking modes record the last known status of registered items and allow users to update the status on an ongoing basis. Mode types influence application behaviour during log creation and task operations and will be discussed in more detail in Chapter 4.

3.4 System architecture

The developed system consists of five interconnected divisions: *Mobile devices, Central services, Internal support systems, External support systems* and *Firebase cloud services*. Figure 3.2 provides a graphical representation of the system layout.

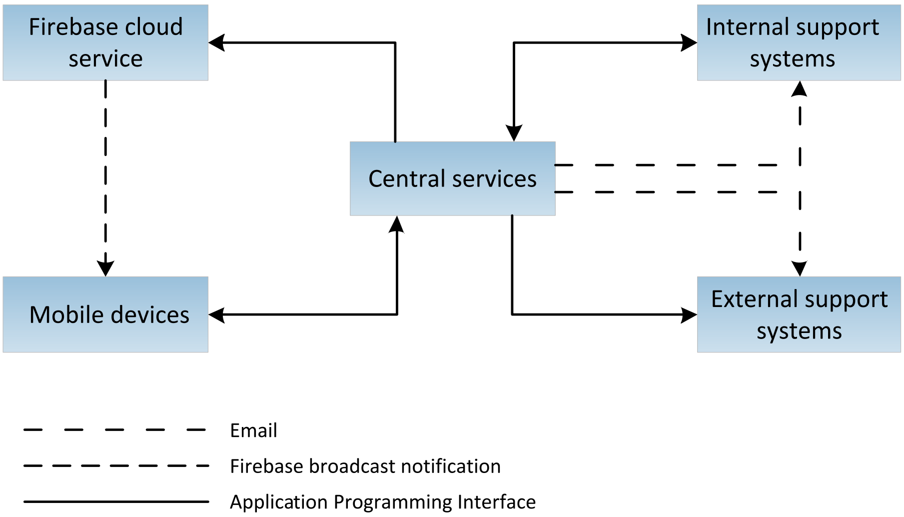


Figure 3.2: *Comprehensive mobile data collection system architecture*

3.4.1 Mobile devices

The network of mobile devices is the most important element of the system. A mobile application was therefore developed and is discussed in detail in Chapter 4. A mobile device can be registered as a member of a group. This grants the device access to group data. A partial copy of the group database is stored on the mobile device, depending on the configuration. This data is used to perform various off-line actions, including calculations based on historic values and task generation.

3.4.2 Central services

The central management system is part of a group of applications that run on a shared server. Separate database schemas are hosted for all registered groups. These databases are hosted on the central server and contain configuration settings and consolidated data. Group configurations are manipulated using a web-application. All configuration changes are recorded using version control structures. The active configuration version is synchronised with all the groups' devices.

The server also serves as a consolidation platform that receives data recordings from mobile devices. The received data is stored in the appropriate group database and synchronised with other linked devices. In addition to this, the server is used as a central platform to manage communication with support systems. This provides developers access to a complete dataset from which data can be exported and forwarded to other systems. This process is managed on the server and does not influence mobile users.

3.4.3 Internal support systems

The ESCO that funded the development of this system has a range of software systems used to interface with clients. Two of these systems offered suitable reporting platforms. The developed system was therefore integrated with both these systems. The first system is used to compose custom reports. The second system is an interactive website. The website has the ability to display data and perform additional tasks, such as raw data exports.

3.4.4 External support systems

External support systems are client systems. The developed system was integrated with client systems to generate automatic work orders. By using the developed system, complete and accurate data was captured and consolidated by the developed system. The consolidated data was reformatted and exported to the client systems in appropriate formats. Changes in communication standards are maintained through the central management system.

3.4.5 Cloud services

Firebase cloud services offer many web services to software developers. Firebase Cloud Messaging (FCM) is defined as a cross-platform messaging solution that enables cost free, reliable message delivery to mobile devices (Firebase Cloud Messaging, 2017). This forms a crucial part of system synchronisation. Upon receiving new data, the central server sends a notification to the linked devices via the FCM service. Cloud communication therefore enables the transmission of command messages and supports automated synchronisation among linked devices.

3.4.6 Communication

Three communication mediums are used to link the system components. The lines in Figure 3.1 indicate active communication channels. The three communication channels are FMC, Application Programming Interface (API) requests and e-mail messages. FCM is used to send notifications from the server to mobile devices. Internal API requests transfer configurations and data updates between the central server and mobile devices. Lastly, the central server allows communication with support systems, using API requests, and e-mail messages.

3.5 Data structures

One of the developed system's primary objectives is to manage collected data and support evidence. Careful consideration went into developing a scalable configuration and data management structure. The structure accounts for version control structures to manage configurations and support collected data.

Storage on both the server and mobile devices are managed using databases and supporting folder structures. Data transfer between the mobile devices and server relies on web requests through the developed API. Data is packaged as JavaScript Object Notation (JSON) packets and attached to requests. Both systems have data handlers that process the received JSON packets and save the results in the relevant structures.

An basic instance of the database is replicated and configured according to the unique requirements of each group. The developed relational database structure consists of six divisions. Each division contains a group of tables which are linked to keys in adjacent tables. The developed database divisions and their functions are discussed in the following sections.

3.5.1 Fixed values

The fixed value collection of tables provides structure to the system. These tables contain references to program extensions and are therefore populated at design time. These tables provide developers with a platform to add additional software features and options without fixed references. The fixed value collection comprises the following tables:

- Input types
- Activities
- User access levels
- View groups
- Tests
- Test parameters
- Log status
- Application modes
- Task types

3.5.2 Configuration management

The configuration management tables are used to define and manage configuration settings which were introduced in Section 3.3. Each group may define multiple sub-groups. These sub-groups are referred to as configurations and can be used to divide the group into manageable sections, based on geographic location or application types. Registered devices, users and modes are linked to configurations. Figure 3.3 provides a visual representation of the configuration management structure.

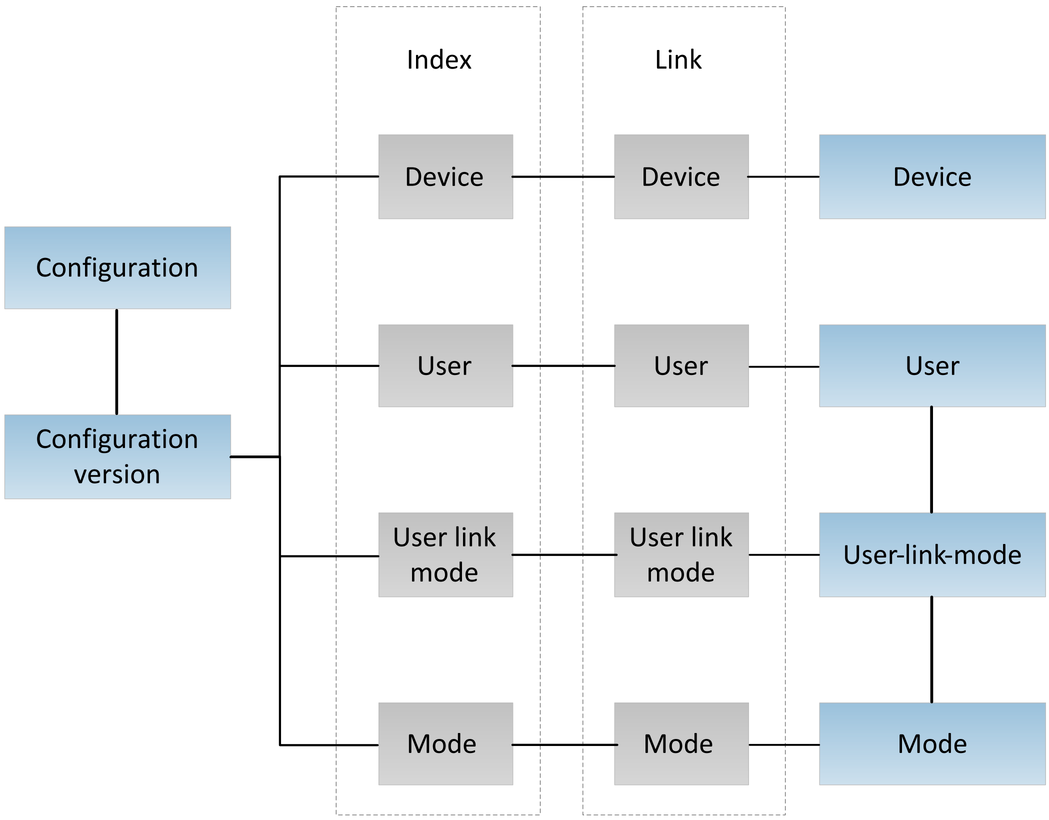


Figure 3.3: *Configuration management structure*

Configuration changes are stored in the configuration management structure. A new configuration version is created every time changes are applied to *Devices, Users, Modes, or User-mode links*. System administrators have access to manipulate the groups' configuration or revert to a previous stable configuration at any time. Changes are performed on the central system. Devices are notified of the changes and request updates from the server via the API.

3.5.3 Mode management

The mode management structure is similar to the configuration management structure discussed in the previous section. Each mode is linked to a specific configuration and can be seen as a specific questionnaire. The mode management structure provides a version control structure of the mode contents. Figure 3.4 provides a visual representation of the mode management structure.

The tables included in Figure 3.4 define the contents of the specific questionnaire or data collection form. The *Data field* table is the core of the mode structure. Every data field can be seen as a question on the form. The Data field table contains links that describe the heading, support text, data ingress interface and status of the data field.

The other tables in the structure extend the data field. Data field extensions are used to identify data fields used for display and identification purposes. *Data field relation* table entries link parent data fields and children data fields to allow form logic operations. The *List option* table contains possible options that are displayed if the ingress interface assigned to the connected *Data field* is a list selection interface. Chapter 4 provides additional information with regard to these interfaces.

Assigned test and *Test parameter* tables contain settings related to data validation tests and calculations. These tests are performed by the mobile application during data collection. A variety of tests have been developed and is discussed in detail in Chapter 4. Some tests utilise historic data entries to determine the validity of new data, while other tests have the ability to calculate values based on multiple data fields.

Mode management is also performed by system administrators. Current and historic states are stored in the database. Administrators have the ability to create new instances or revert to previous states. Mobile devices receive notifications if updates were made. These notifications prompt the devices to synchronise with the main database to obtain the latest configuration. Furthermore, the configuration is logged with every data recording, ensuring full traceability of collected data.

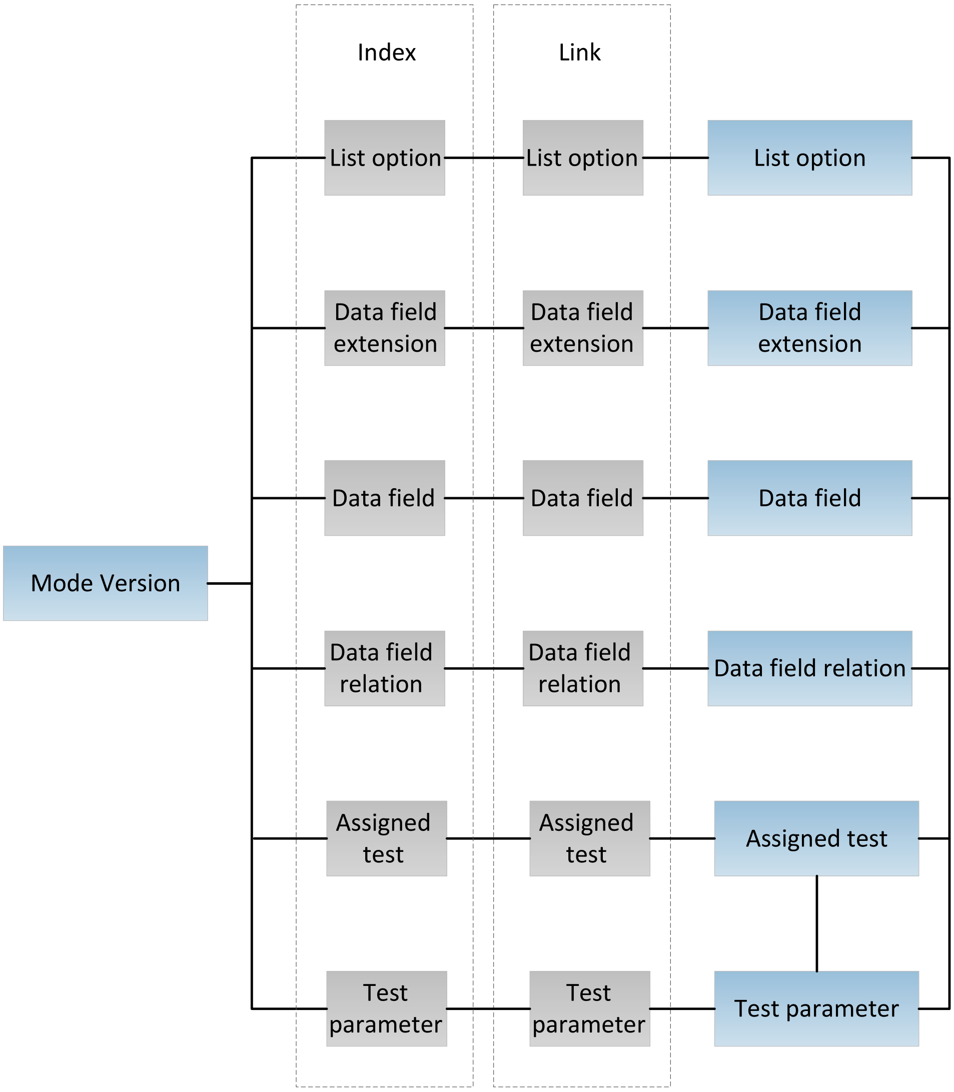


Figure 3.4: *Mode management structure*

3.5.4 Data handling

Existing data logs are stored in the data handling tables. Figure 3.5 shows the data handling structure. The *Data entry* table is at the core of the structure. Every record in the Data entry table contains the same base data, which includes a user identifier, time stamp, GPS location, active mode version and log status. In cases where a log builds on previous logs, a reference to the previous log is created.

Data fields linked to the active mode version are displayed on the data collection form. These data fields are not fixed and therefore require a flexible storage structure. The *Data detail* table provides a flexible structure to store log details. Every data field linked to the active mode version is stored as a record in the *Data detail* table, with a link to a parent log in the *Data entry* table. An additional entry in the *Data image* table is created in cases where the data field is linked to an image data type.

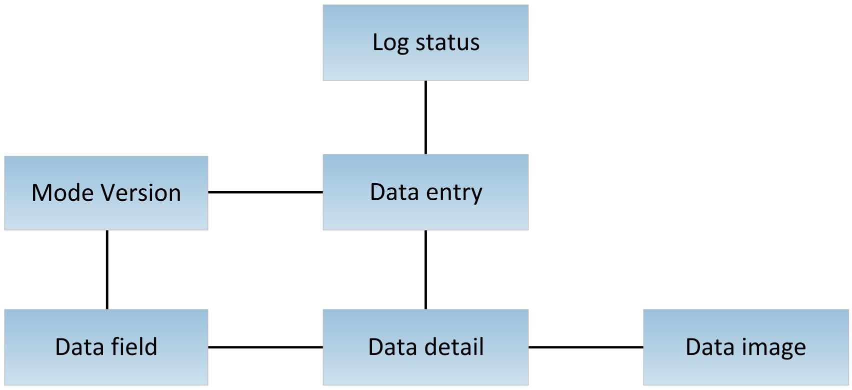


Figure 3.5: *Data handling structure*

3.5.5 Task management

The task management structure is shown in Figure 3.6 and is used to guide users. In order to complete a task, the user must create a log entry. The system will assess entered data and close the task if all the requirements are fulfilled. Entries in the *Task* table are dependent on two factors, namely *Mode type* and *Task type*. Tasks are divided into routine, follow-up and assigned tasks. Routine tasks only apply to recurring modes.

Follow-up tasks only apply to non-recurring modes. Assigned tasks are allocated to registered users and apply to any non-recurring and status modes. Follow-up tasks and assigned tasks are used to guide users to perform specific actions, or review conditions after a time period has elapsed. Recurring tasks are generated on the device to supply users with an action list. The task type influences application behaviour when completing tasks and is discussed in detail in Section 4.7

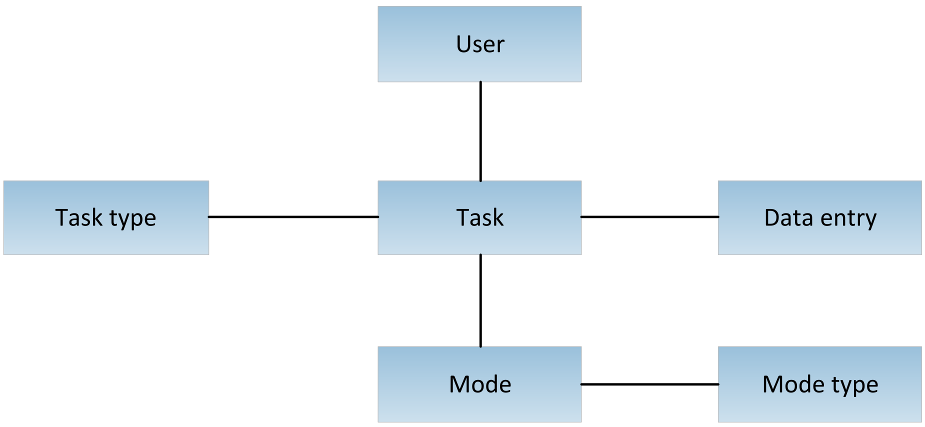


Figure 3.6: *Task management structure*

3.5.6 Data consolidation and processing

The developed system has the ability to process synchronised data and provide a range of outputs. Figure 3.7 shows the database structure used to configure advanced system output options. Every *Data entry* is associated with a *Mode version* for traceability purposes. The *Mode version*, in turn, is related to a specific *Mode*. Output options can be specified and linked to applicable modes.

Processing functions form part of the software package on the central platform. Each processing function serves as a process type and is used to construct a particular output. Additional variables associated with the process type are stored in the Process type parameter table. *Process types* and *Process type parameters* can be linked to *Modes* using the *Mode link process type* table.

This structure enables system administrators to develop structures that can be used to construct output files suitable for processing by external systems. Relevant data can be received, reformatted and forwarded to linked systems. This enables the system to integrate with client systems. Users can therefore be trained to use the only mobile system developed in this study, instead of multiple systems, while still having the ability to utilise advanced functionality of the respective systems.

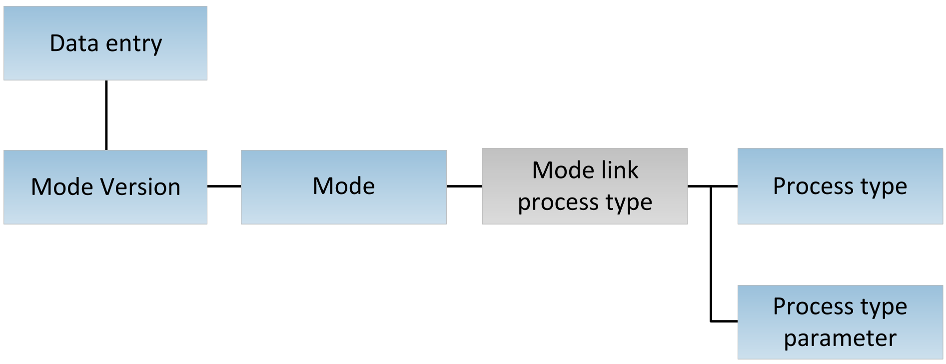


Figure 3.7: *Advance system output structure*

3.5.7 Instant e-mail notifications

The instant e-mail notification structure stems from the Process type property table which was introduced in the previous section and serves as an extension of the processing structure presented in the previous section. This structure is used to construct rules that will enable intelligent classification and personalised output options. Figure 3.8 shows the interactions between the tables that form the e-mail notification structure.

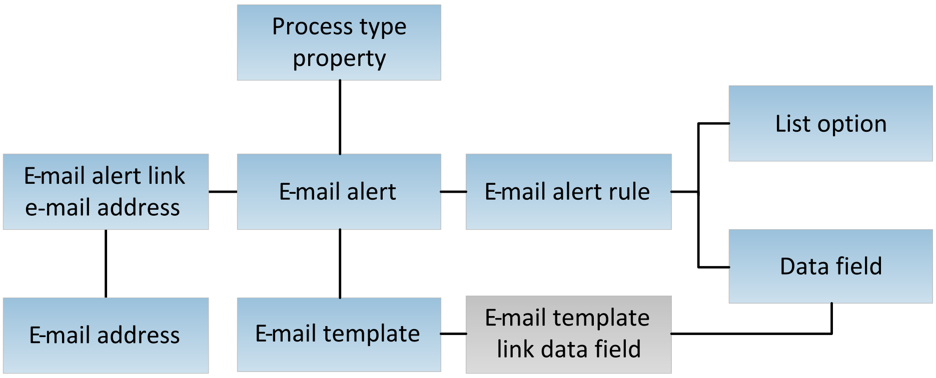


Figure 3.8: *E-mail notification structure*

Various *E-mail alerts* can be created and linked to an entry in the *Process type property* table. The system will attempt to construct *E-mail alert* when the system receives a log entry linked to the e-mail notification process type. In order to create an alert, all the rules associated with the alert must be met. The *E-mail alert rule* table contains the list of links and conditions.

The e-mail alert rule conditions rely on *List options* which are defined as part of the configuration process. An alert rule consists of a *Data field* part and a *List option* part. The rule dictates that, if a list option associated with a data field is selected, the result is positive. If all the rules associated with an alert has a positive result, an e-mail will be created and distributed to linked users.

3.6 System overview summary

In this chapter, system requirements and various design considerations are discussed. The values used to measure the capabilities of commercial data collection systems were used as a platform to construct a list of requirements. A novel data collection system was developed accordingly. Important design elements and concepts are introduced.

A logical structure is used to arrange group data into substructures. Most important elements to note are that every client has an isolated database with an identical base structure. Moreover, each client's structure is divided into multiple isolated configurations. Each configuration contains multiple modes. These modes can be seen as questionnaires and are customisable to address the most unique data collection needs.

Various system structures were presented and provide information related to core components used throughout the study. Key structures include the logic hierarchy, data structures and the system architecture. The logic hierarchy shows how groups, configurations and modes integrate. Data structures, used to form the database on the central server and mobile devices, are discussed in detail.

The physical application structure consists of five physical parts, namely Mobile devices, Centralised services, Internal support systems, External support systems and Cloud services. These components are interconnected and form a system capable of addressing the set requirements. Mobile devices are used to host an application developed as part of the system. The application is the most crucial element in the combined system, and will be considered in more detail.

Chapter references

Firebase Cloud Messaging (2017). Firebase Cloud Messaging — Firebase, https://firebase.google.com/docs/cloud-messaging/.

IDC (2013). Developing a vibrant ESCO Market -Prospects for South Africa's energy efficiency future, https://www.idc.co.za/images/geef-market-studies/.

IDC (2016). Smartphone OS Market Share 2016 Q3, http://www.idc.com/promo/smartphone-market-share/os.

4

A comprehensive mobile application

A data management system which consists of five distinct elements was presented in the previous chapters. The complete system enables users to synchronise configuration data, collected data and manage tasks. Users will interact mainly with the mobile application, which is therefore considered the most important element of the system. Users rely on the application to perform data collection tasks. In this chapter, design elements related to the mobile application's considerations, structure and interfaces are discussed in detail.

4.1 Introduction

The mobile application was developed and forms the core of the comprehensive mobile data collection and management system. The application consists of various software divisions. These divisions collaborate with one another to provide advanced functionality that is not possible in isolation. Moreover, factors that contribute to the novelty of the system were enabled by utilising the advanced functionality offered by the developed structure.

4.2 Mobile application architecture

The mobile application architecture can be described at the hand of seven software divisions. Each division is responsible for performing a specific function. Although certain tasks are performed by the division in isolation, many advanced functions rely on a combination of supporting factors from the other divisions. The system core provides a platform to link these divisions. The combined architecture and individual divisions are discussed throughout the remainder of this section.

A visual representation of the mobile application architecture is provided in Figure 4.1. The application core consists of *Logic controllers* and *Data holders*. This provides the system with structure to perform operations and manipulate data. Specific data handling structures supplement the core components and are indicated in the figure. These divisions include *Local storage* components, *Support services* infrastructure, *User interface* (UI) components, *Task management* structures, and *Calculation and validation* structures.

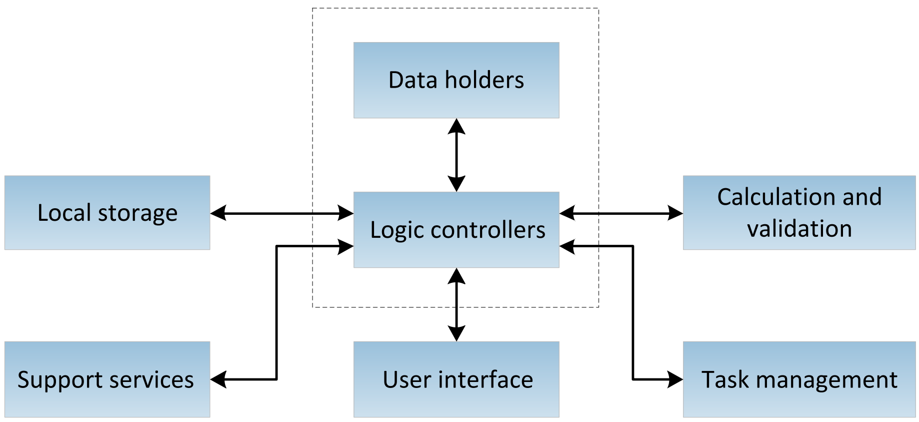


Figure 4.1: *Representation of application architecture*

4.2.1 Logic controllers and data holders

Logic controllers and data holders form the core of the mobile application. These controllers provide basic structure to the application and manage links between interfaces. Additionally, these controllers coordinate supplementary tasks such as user login, location tracking and synchronisation tasks. The logic controllers provide fixed flow to actions such as creating new logs, viewing existing logs and managing tasks.

The controllers are closely related to the user interface, for example, the main menu is populated based on user right rules according to fixed standards across all configurations. Equally, the view log and manage task interfaces have fixed items and options which are not configuration dependant. While certain displayed elements have fixed positions and functions, the majority of the displayed content is dynamic. Logic controllers interact with data holders to perform dynamically selected actions.

While the logic controllers enable links, the data holders are used to pass and convert data and settings. Many different data holder classes were developed to provide back-end structure to the system. Structure provided by these holders include:

- holders for interface components;
- log data holders;
- task holders; and
- synchronisation object holders.

The modular nature and widespread use of the data holders enable developers to edit a single piece of software to have that functionality available throughout the entire application. This allows easy expansion with respect to functions and stored data variables. Furthermore, these data holders can be created dynamically during runtime and enables the generic functionality of the system.

4.3 User interfaces

The mobile application was developed as a tool to support users to perform tasks and record information. The system therefore requires human interaction to perform the majority of possible actions. As a result, the user interface is one of the most important aspects of the developed system. Two key design factors were considered, namely operation factors and generic capability.

Optional factors are dictated by the harsh environment in the industrial sector. Harsh conditions are a concern when selecting equipment. Employees, notes and devices are often exposed to water, sunlight, wind, noise and other adverse conditions. The following factors that will influence user interaction were identified:

- sunlight readability
- large, easy to read text
- visual aids such as images
- large interaction controls
- basic interface components
- visual familiarity
- a logic systematic flow

From a developer point of view, user interface components must allow effective code reuse options. Effective code reuse reduces code complexity and application size. Limited reusable interface components were therefore selected as the preferred interface approach. In addition to development advantages, effective design of interface components form the foundation for a dynamic interface.

4.3.1 Card components

Four card components were developed and were reused across all application interfaces. Figure 4.2 through 4.5 show the design template of the card components. The respective card components are *Content cards*, *View cards*, *Extended view cards* and *Image cards*. The cards provide visual- and text- based user guidance through primary text, secondary text and image options where applicable. The card type provides additional clues as the card type presents the same behaviour throughout the application.

The cards are linked to data holders, as discussed in Section 4.2.1. These data holders contain structures that store data and provide *read functions* and *write functions* to manage the data. Data holders therefore serve as a back end, while the card components serve as a graphical front end. All the data stored in the data holder is not displayed, but assists with support activities, such as navigation to linked interfaces.

The content cards design shown in Figure 4.2 is the most widely used card component. These cards provide user guidance through *Primary text* and *Secondary text* labels. The cards can be identified by its large size, as well as the large image on its left. Visual guidance is provided by the images, as they show logos and images that hint which interface or detail will be revealed by selecting the card. Further visual aid is provided by the exclamation icon on the top left of the card, and is used to highlight a card if the item it refers to requires additional attention.

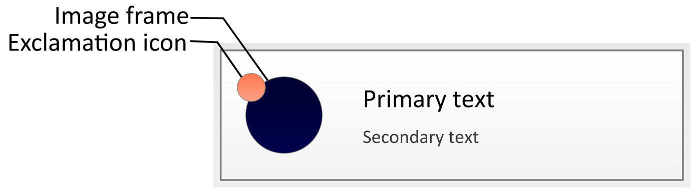


Figure 4.2: *Content card design*

View cards, as shown in Figure 4.3, are used purely to display text data to users. These cards are used to display collected data and task details on summary interfaces. These interfaces will be discussed in more detail in Section 4.3.2. View cards can be identified by their narrow profile. Furthermore, view cards are not designed to handle user input and therefore perform no action other than display data.

Figure 4.3: *View card design*

Figure 4.4 shows the design of extended view cards. Similar to view cards, the primary purpose of extended view cards is to display text-based data to users. Extended view cards show the data visible on view cards, as well as additional details. The resemblance of the two card types are similar, with the exceptions that extended view cards contain additional text fields with exclamation flags, and that the card background is highlighted in blue. The additional text fields are used to display test and validation data. The exclamation flags are displayed in cases where text or validation data exceed allowed limits.

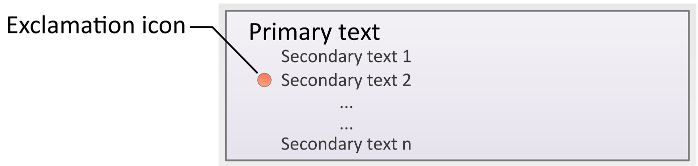


Figure 4.4: *Extended view card design*

The design of image cards are shown in Figure 4.5. These cards have a basic layout. The entire card surface is consumed by a large frame to contain images. The card does not have any particular features, but relies on the same structure as the other cards. These cards promote reusability and support development by following known patterns, consistent with the other interface components.

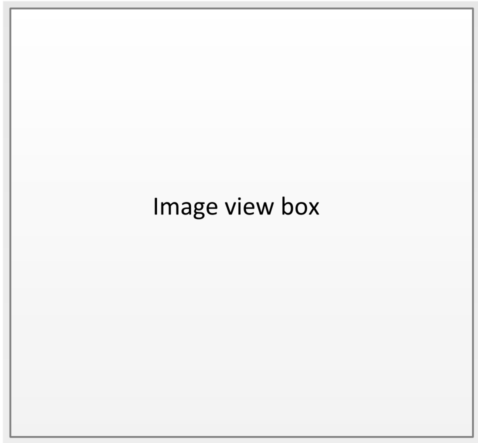


Figure 4.5: *Image card design*

4.3.2 Structural interfaces

Views provide structure to the application and assist with navigation. These views are predefined interfaces with both fixed elements and holders that are dynamically populated. Views define the application style by providing a light background on which appropriate card elements are displayed. The remainder of this section will discuss the structure and layout of the following core views:

- Main menu
- Mode selection
- Create entry
- Log summary
- Review log
- Review log menu
- Task management menu
- Task summary
- Synchronise menu

Main menu

Upon launching the application, the main menu is displayed. The main menu provides the links to application functions: create new entries, review existing entries, manage tasks, synchronise requests and manage settings. Figure 4.6 shows the layout of the main menu interface. The layout contains a single large dynamic card holder which is populated with content cards. This provides developers and administrators with a generic scalable platform.

Permissions were defined during the development phase, and are stored in the database. The View and User access tables in the database contain allowed structure information. Users with full- or administrator access rights will be able to see all the options in the main menu, while general users are restricted and do not have management access. During execution, the main menu interface is created by populating the *Dynamic card holder* with relevant card components, based on the user access level.

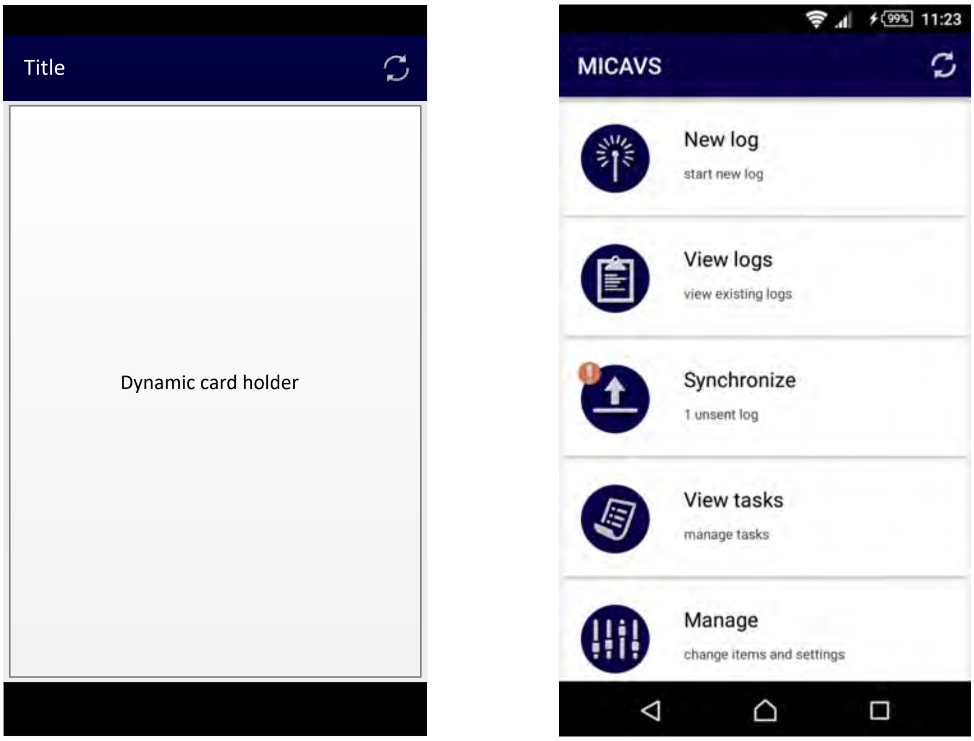


Figure 4.6: *Main menu interface*

Mode selection

New log is the first item shown on the main menu and is linked to the Mode selection interface, shown in Figure 4.7. In cases where the active user is linked to a single mode only, the application will automatically select that option and proceed to the next interface. This Mode selection interface allows the user to select a specific mode, which prompts the application to open the Create entry interface. This interface can also be used to scan a barcode which will automatically select the linked mode.

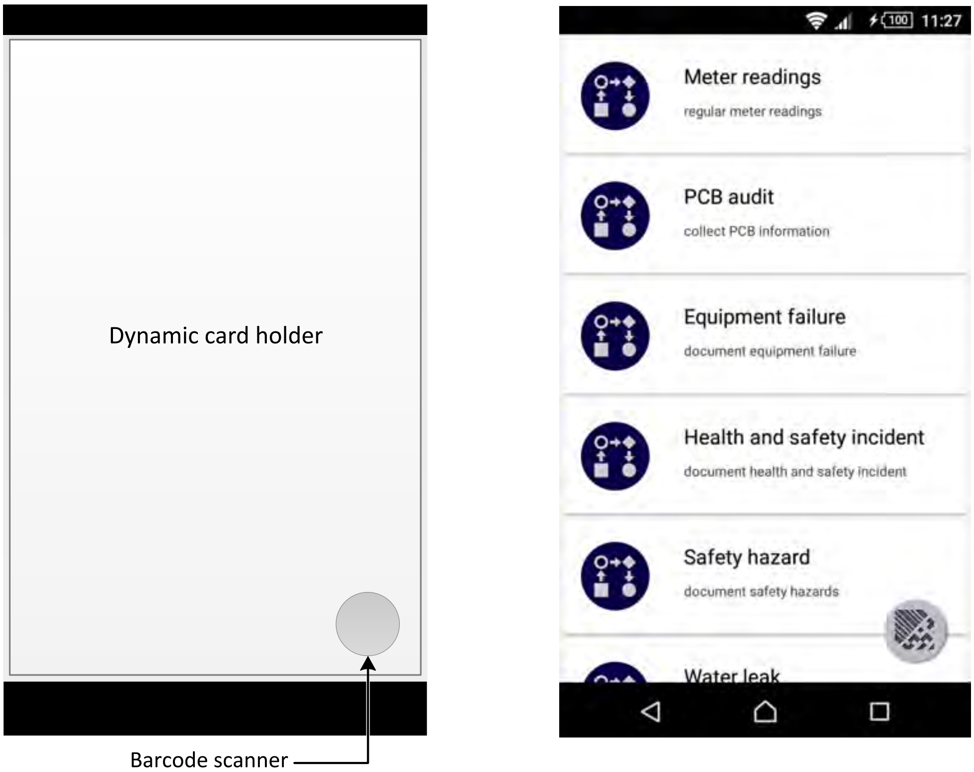


Figure 4.7: *Mode selection interface*

Create entry

The Create entry interface contains a *Dynamic card holder*, as well as a confirmation card holder that reads *'Finish'*, as shown in Figure 4.8. The card labelled 'Finish' is used to complete the log and navigate to the Log summary interface. The dynamic card holder is populated with card elements based on data fields. Data fields stored in the database are linked to modes and are used to form relevant questionnaires. Appropriate data fields are loaded based on the mode selected in the previous interface. Log entry creation process, as well as questionnaire population and functions, are discussed in Section 5.3.

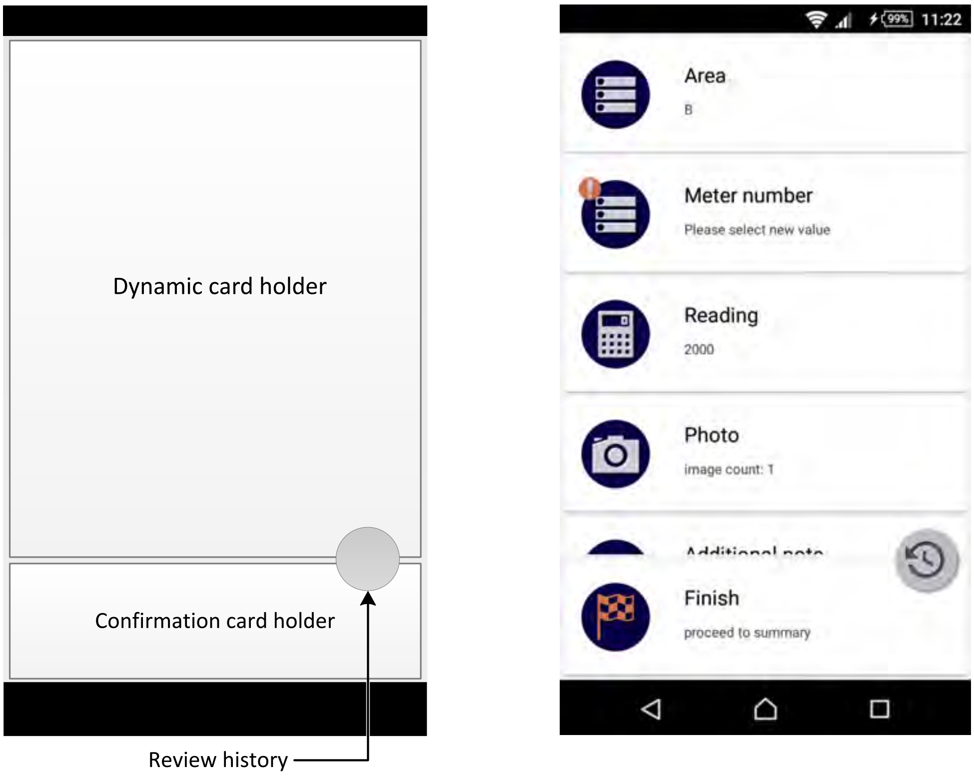


Figure 4.8: *Create entry interface*

Log summary

After completing all the required fields on the Create entry interface, the user will be allowed to proceed to the Log summary interface. This interface is used to review entries selected by the user. Data captured by background services such as GPS coordinates and time stamps are communicated to the user. Links to extension interfaces are provided by bullet components where applicable. Calculation and validation test results and flags are also displayed on this interface.

The Log summary interface, as seen in Figure 4.9, is divided into two sections. The top section of the interface is consumed by a large holder item. This holder is used to contain a dynamic list of view cards and extended view cards. The content of the displayed cards vary according to modes and individual log data. The second holder contains a highlighted content card labelled '*Accept*'. Unlike the summary cards, the content card reacts to input. By selecting 'Accept', the log is committed to the database and the user is returned to the main menu.

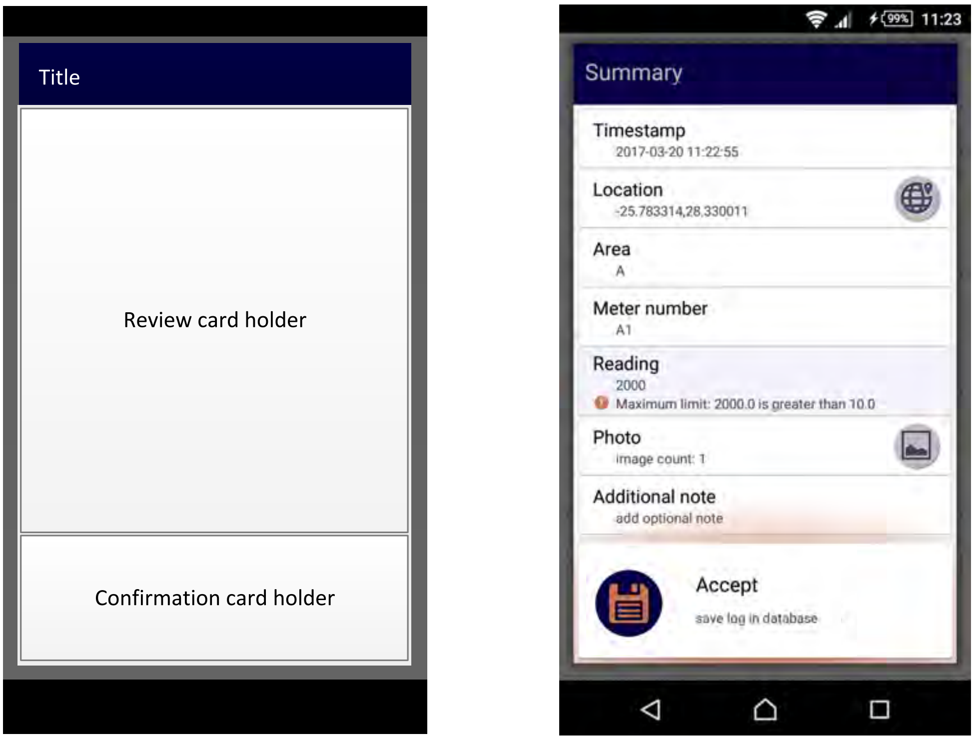


Figure 4.9: *Log summary interface*

Review log

The Review entry interface is a simplified summary interface. Figure 4.10 shows the interface, which only contains a single large card holder. All the data related to a specific log are displayed using multiple view cards. This is simply a view interface and does not permit any further actions. The Review log interface is used to display previous log information in two cases. Firstly, existing logs can be reviewed from the View logs menu discussed below. The second case allows users to review the previous entry related to a selected identifier during log creation from the Create log interface.

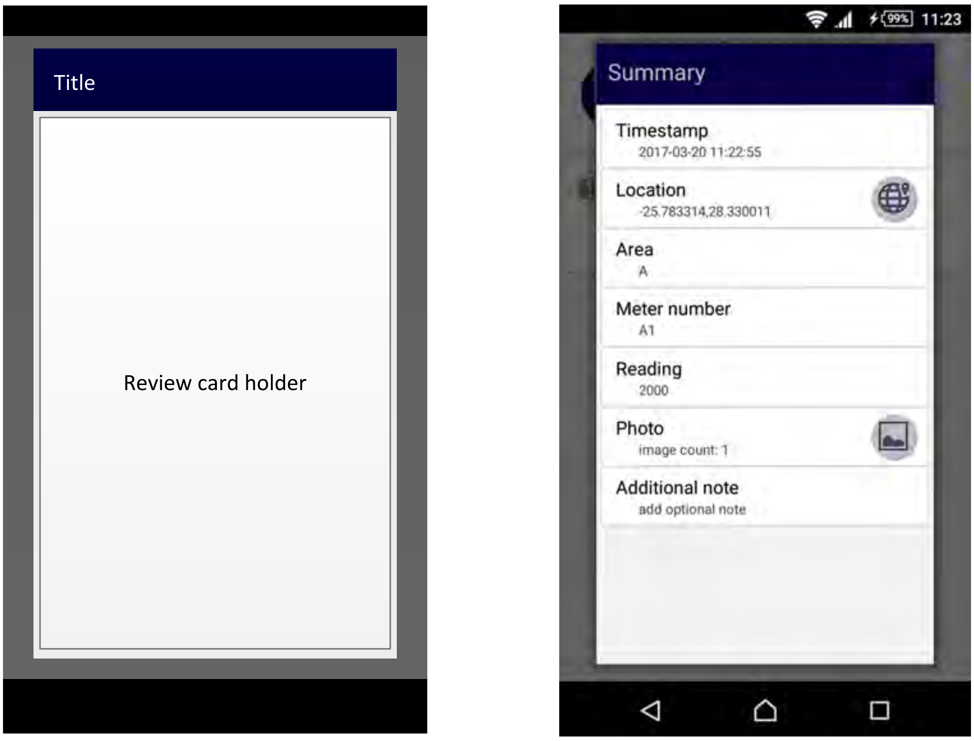


Figure 4.10: *Review entry interface*

Review logs menu

Figure 4.11 shows the Review entries menu interface. The purpose of this interface is to allow navigation to existing logs. Existing logs include log entries created on the device, as well as synchronised logs that were created on linked devices. The interface contains a highlighted card that opens a *Filter* view, which can be used to obtain a shortlist of logs. Logs are displayed on content cards. A time stamp is used as the primary text on the card. The displayed support text and image source are configurable variables. The exclamation icon is used to indicate unsynchronised logs.

Additional action is provided by pressing one of the log cards. A short press will display the log's details on a summary interface, while a long press allows the user to edit the log entry. An edit request will open the Create entry interface and populate the data fields with the values saved in the existing log entry. The user edits and saves the log, similar to creating a new log. Upon completion, a separate new log with a reference to the previous log is created. The old log is maintained for traceability purposes.

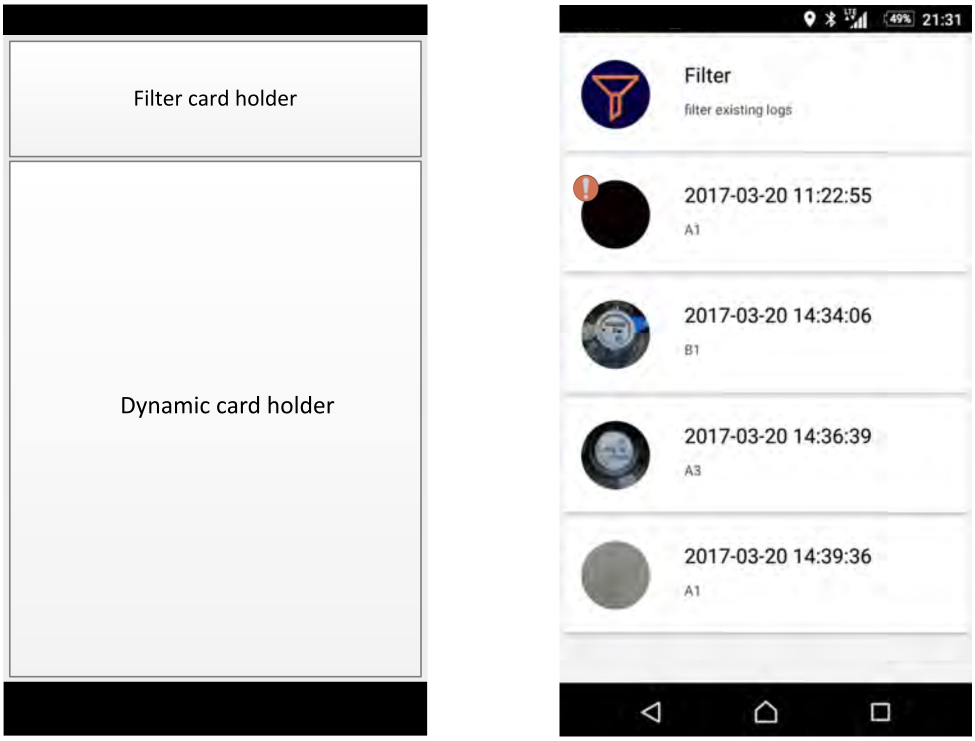


Figure 4.11: *Review entries menu interface*

Manage task menu

The Manage task interface is similar to the View logs interface discussed previously. A filter card and a single large card holder are displayed on the interface, as seen in Figure 4.12. The *Filter* functions can be used to find a short list of tasks. Tasks are represented by content cards and are displayed as items in the card holder. Task details are made available by touching the relevant card. Task details are displayed using an interface similar to the summary interface. The finish card in the Log summary interface is replaced with a complete task card. When the user selects 'Complete task', the Create entry interface is displayed with relevant data fields pre-populated. Upon completion of the log the task is marked as closed.

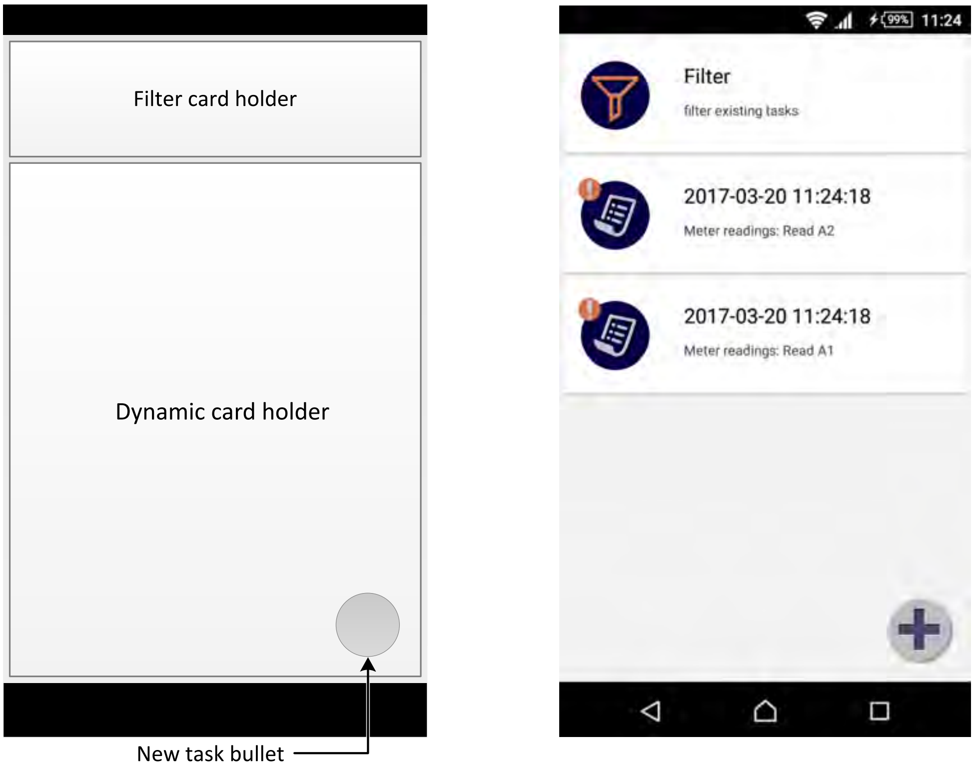


Figure 4.12: *Manage task interface*

Synchronise menu

Synchronisation detail information and request functionality are provided by the synchronise interface, shown in Figure 4.13. The interface contains a large card holder that contains three fixed card items, namely *Logs, Images* and *Tasks*. These cards display the number of unsynchronised items in the respective category. Unsynchronised items are indicated by exclamation icons.

The other item on the interface is a card that displays the *Sync all* command, as well as the last synchronisation date. Upon pressing the *Sync all* card, the application will contact the server with multiple upload- and download requests that will synchronise all application aspects.

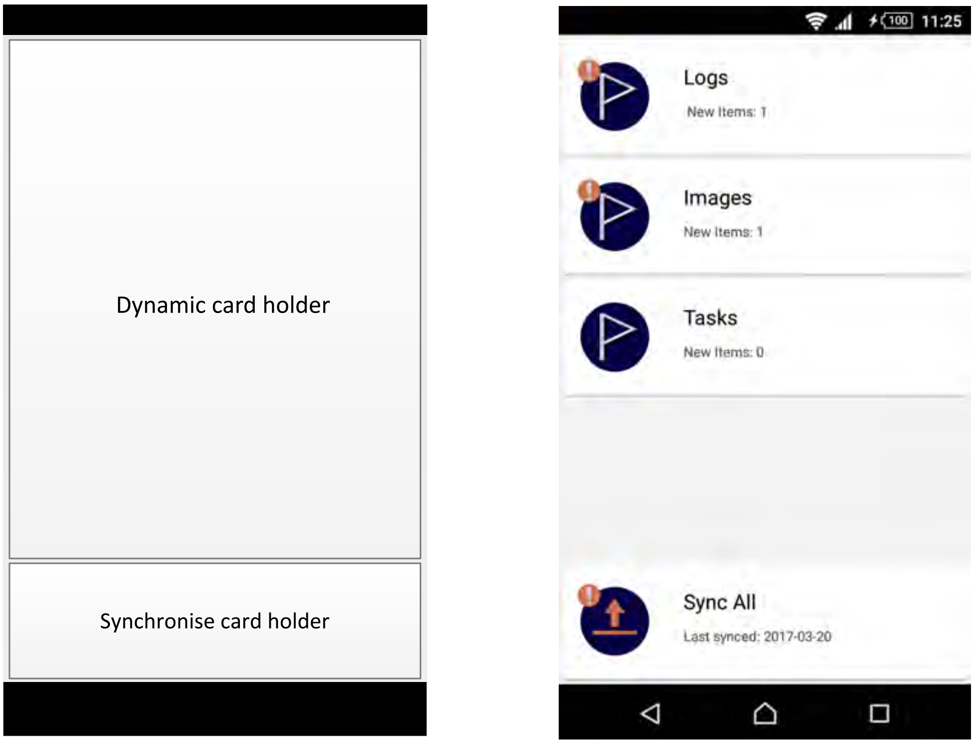


Figure 4.13: *Synchronise interface*

Interfaces summary

The interfaces discussed in this section provide structure to the application. In general, interface specific actions have fixed positions on the interfaces. In addition to fixed options, card holders are used to reserve space on interfaces to display card items. Card holders provide a dynamic structure to display a list of card items and form the core of the generic capabilities of the application.

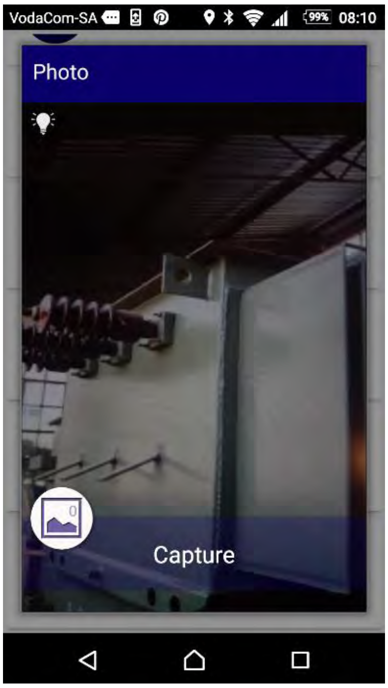
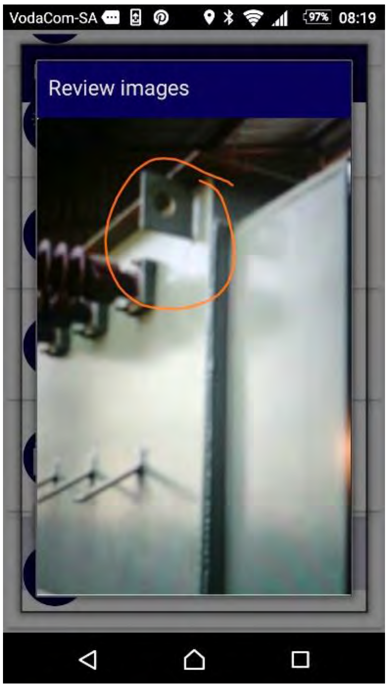
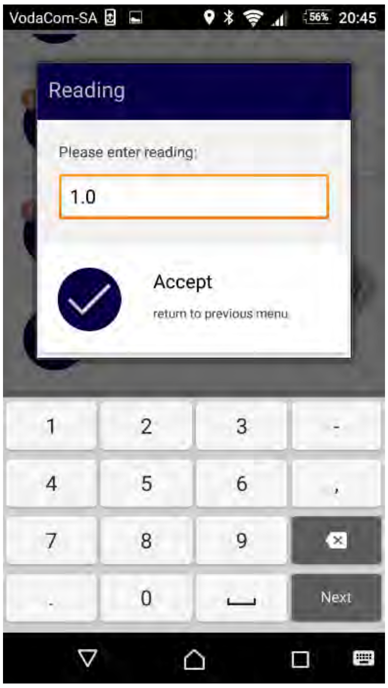
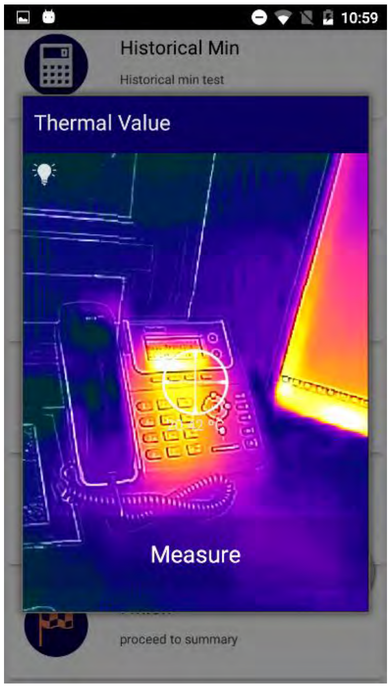
4.3.3 Data ingress interfaces

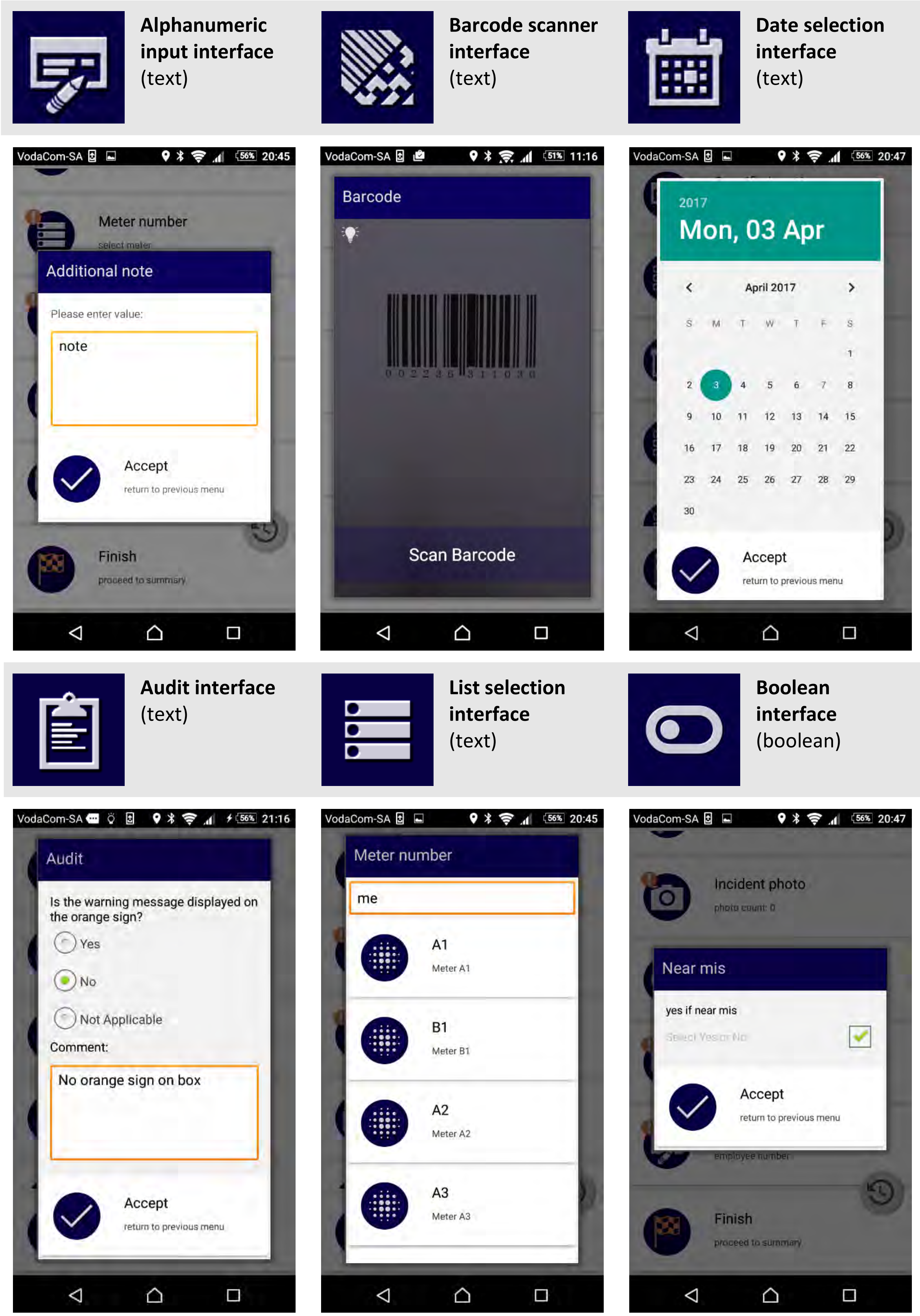
Data ingress interfaces are used to provide advance interfaces that allow efficient data collection. These interfaces are presented to the user as dialog items. The dialog interface guides users to perform desired actions. The dialogs further limit user actions and ensure that collected data conforms to desired formats and can be used to populate unique structures.

Multiple data ingress interfaces have been developed to address known data collection requirements within the industrial sector. Four data types were chosen as suitable output formats. The four output formats are: Text, Numeric values, Images and Boolean values. Each of the developed data ingress interfaces delivers an output in one of the four formats.

Table 4.1 shows the developed ingress components. Two unique interfaces were developed to harness the capabilities offered by FLIR systems (FLIR, 2017). These interfaces allow users to capture thermal images and numeric thermal values, using specialised smart-phone attachments.

Table 4.1: *Data ingress interfaces*

Camera interface (image)	**Annotation interface** (image)	**Thermal camera interface** (image)
		
Numeric input interface (numeric)	**Sound pressure level sample interface** (numeric)	**Thermal probe interface** (numeric)
		


Alphanumeric input interface (text)
Barcode scanner interface (text)
Date selection interface (text)
Meter number
select meter
Additional note
Please enter value:
note
Accept
return to previous menu
Finish
proceed to summary
Barcode
Scan Barcode
2017
Mon, 03 Apr
April 2017
Accept
return to previous menu
Audit interface (text)
List selection interface (text)
Boolean interface (boolean)
Audit
Is the warning message displayed on the orange sign?
Yes
No
Not Applicable
Comment:
No orange sign on box
Accept
return to previous menu
Meter number
me
A1
Meter A1
B1
Meter B1
A2
Meter A2
A3
Meter A3
Incident photo
photo count: 0
Near mis
yes if near mis
Accept
return to previous menu
Finish
proceed to summary

4.3.4 Notifications

Notifications are used to inform users of background task progress. Figure 4.14 shows the Android notification centre. The figure displays the active synchronisation tasks running on the mobile device. These requests are executed in the background and allow the user to continue using other applications while waiting for synchronisations tasks to complete. Upon completion, the background task will return a status to the data collection application, which will update status elements accordingly.

Figure 4.14: *Notification centre*

4.4 Local storage

The mobile application that was developed utilised local storage options on mobile devices to manage data. The system utilised three local storage options on the mobile device, namely database, physical storage and shared preferences. The database contains configuration data, log entries and tasks. Physical storage is used to store large files such as images and exported files. Lastly, operating system based storage is used to store various application variables and states.

4.4.1 Database storage

Database storage is the most important storage structure of the developed system. As stated above, it contains configuration data, log entries and tasks. During application registration and configuration, the appropriate database schema on the central server is contacted. Appropriate configuration data, historic data and tasks are then synchronised with the device's local database. This data is used to populate user interfaces, perform various tasks related to data verification, data review and task management.

The Android operating system supports SQLite databases. A MySQL database is maintained on the central server. The database on the server and the database on the mobile device have identical structures. The database structure presented in Section 3.5 therefore applies to both the central system and mobile application. This was chosen due to the large amount of corresponding tables required. Developers therefore only need to consider a single database structure when making changes.

4.4.2 Physical storage

Physical storage on the mobile device is used to contain large files such as images and exported data. References to stored files are saved in the database and are used to call external files for review and synchronisation activities. Physical storage provides access to files on the mobile device when connecting the mobile device to a computer. This enables administrators to export and pass data to and from mobile devices manually if mobile communication is not possible.

4.4.3 Operating system storage

Operating system storage is used to store application parameters and preferences. In the Android operating system, these variables are called shared preferences. This can be used to manage the application state and store small data items that are used throughout the application. The developed application uses this storage to manage session information and store small preference items that do not validate the use of database entries.

4.4.4 Storage management

Although mobile devices offer substantial amounts of storage space, resources are still limited. Small data items, such as text stored in the database, do not consume much space. However, large applications and files can fill the available memory quickly. Images are the largest space consumer in the developed system. A management strategy was therefore required to reduce the risk of overfilling the device storage space and to promote efficiency.

Two measures were developed as part of the storage management strategy. A unique clean-up period is configured for each device. When the application is launched, the application performs a clean-up task that deletes synchronised images which exceed the clean-up date limit. The second measure is a thumbnail service. The central server creates a low resolution copy of received images and sends it to the mobile systems. The thumbnail provides users with a resource-friendly copy of the actual image. Large files are requested from the server, but only when the log is viewed in detail.

4.5 Support services

Five support services have been developed. These services execute on separate processing threads from the main application. These services can therefore perform asynchronous tasks that have to wait for responses while the system remains available to the user. In addition to availability, this offers performance advantages, because the operating system allocates additional resources for each service. This results in less work on the main application thread, which improves the user experience.

The first two services are associated with the cloud notifications. Firebase cloud messages are used to broadcast messages between the central server and mobile devices. To enable Firebase communication, the device requires a unique token. A Firebase instance ID requests the token and processes the response. That second service is a Firebase listener service. The listener receives messages sent to the unique token and processes the results. This enables the central server to prompt action from remote devices.

Two data-related services were developed. The Data uploader packages log entries in a suitable format and sends it to the central server. Fixed log elements are stored in the Data entry table, while variable elements are stored in the Data detail table. These tables were discussed in Section 3.5.4. The Data image table in the same structure references files stored in the device's physical memory. The Image uploader service is tasked solely with uploading these files.

The final service is the Location retrieval service. The Location retrieval service is used to prompt location updates from the host system. Google Play services location APIs are the preferred method for creating location-aware applications (Android Developers, 2017). Google Play services manage power consumption by restricting accuracy and update intervals. This has a negative effect in areas with poor connectivity. The location service prompts continuous updates to ensure accurate location availability.

4.6 Data synchronisation

The system relies on the integrated system to perform various actions. The components and communication channels shown in Section 3.4 enables communication between system components. However, poor connectivity is common in areas where the system will be used. Local storage is therefore required to store new data entries. Local storage is also used to access historic data to perform calculations and other tasks, even when the system is offline.

Synchronisation between the mobile devices and the central database is an essential part of full system operation. In order to deliver optimal performance, the mobile system must have an up-to-date copy of relevant configuration data. A universal structure is required to allow synchronisation and collaboration. Configuration management and Mode management groups within the database are used to store a reference data structure which is used as a common ground between linked devices and support systems.

4.7 Task management

Task management relies on the task structure that was introduced in Section 3.5.5. Three task types were created: assigned tasks, follow-up tasks and recurring tasks. Another application structure is the mode structure, which contains three possible mode types: recurring, non-recurring and status tracking. The respective mode types influence application behaviour and dictate applicable task types. The remainder of this section will provide more detail surrounding the task management process.

Assigned tasks can be assigned to a specific user and will require that user to complete a log entry linked to a particular mode. To complete the task, the user must navigate to the task in the task menu, as shown in Figure 4.15(a), and select the appropriate task. A task summary will be shown, along with a complete task card, on the bottom of the dialog, as shown in Figure 4.15(b). The complete task action will open the Create entry dialog and load the data fields associated with the specified mode, as well as a task closing description option. Once the log is completed, the application automatically updates and closes the task.

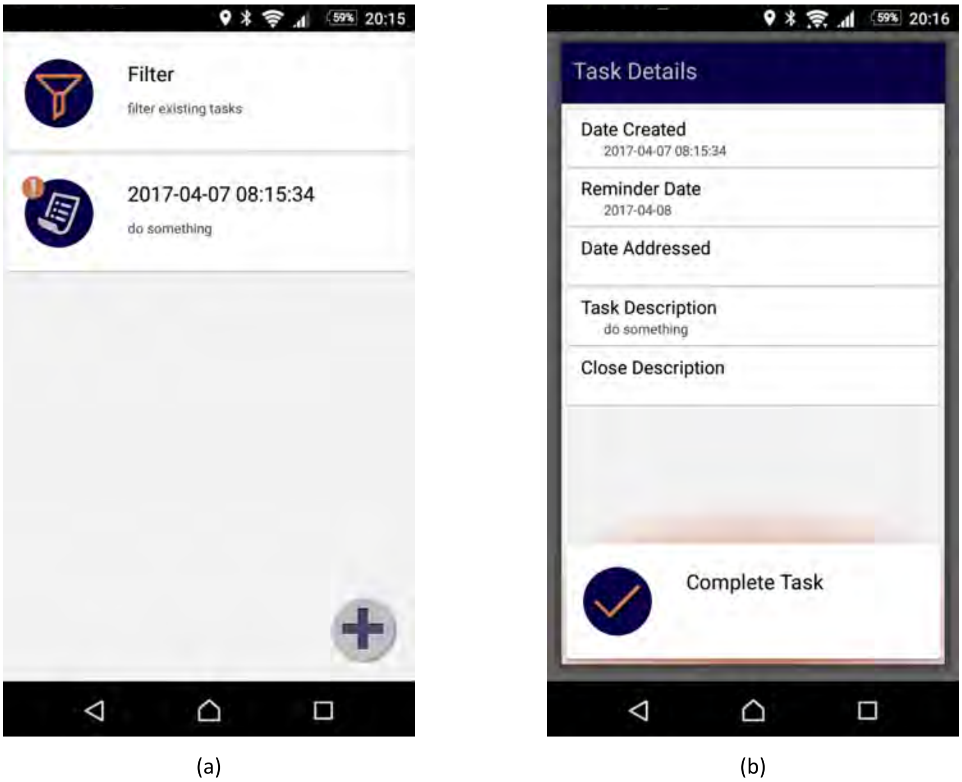


Figure 4.15: *Task interfaces*

Follow-up tasks are used to prompt additional action based on a previous log. After log data has been entered and 'Finish' is selected, a log summary is shown. If the active mode is linked to either the non-recurring or status tracking type, a task creation option is shown. Upon selection, the user will be prompted to enter a task message and a follow-up date. The follow-up task can be closed by editing the existing log, or by navigating to the task and selecting 'Complete task'. Figure 4.16(a) shows the summary interface with the task creation button visible, as well as the task detail input in Figure 4.16(b).

Recurring tasks can be created for recurring modes. Typically these modes will be used to perform routine actions such as monthly meter readings. Users can use this functionality to construct a list and run through a routine operation. This is especially useful in cases where teams collaborate. If a team member is unable to conduct his usual inspection round, another user can use the application to construct a task list customised according to the usual team member's habits.

Routine tasks can be generated in the application by selecting the *New task bullet* shown in Figure 4.15(a). A task creation dialog will be displayed where the user must select a user and mode to consider. The system considers historic logs based on the mode and user. Entries within the last three time-out periods are considered for example, if meter readings are conducted on a weekly basis, a 21-day period will be considered. Only items recorded by the user within the 21-day period will be added to the to-do list. The list therefore adapts according to tasks performed by the user.

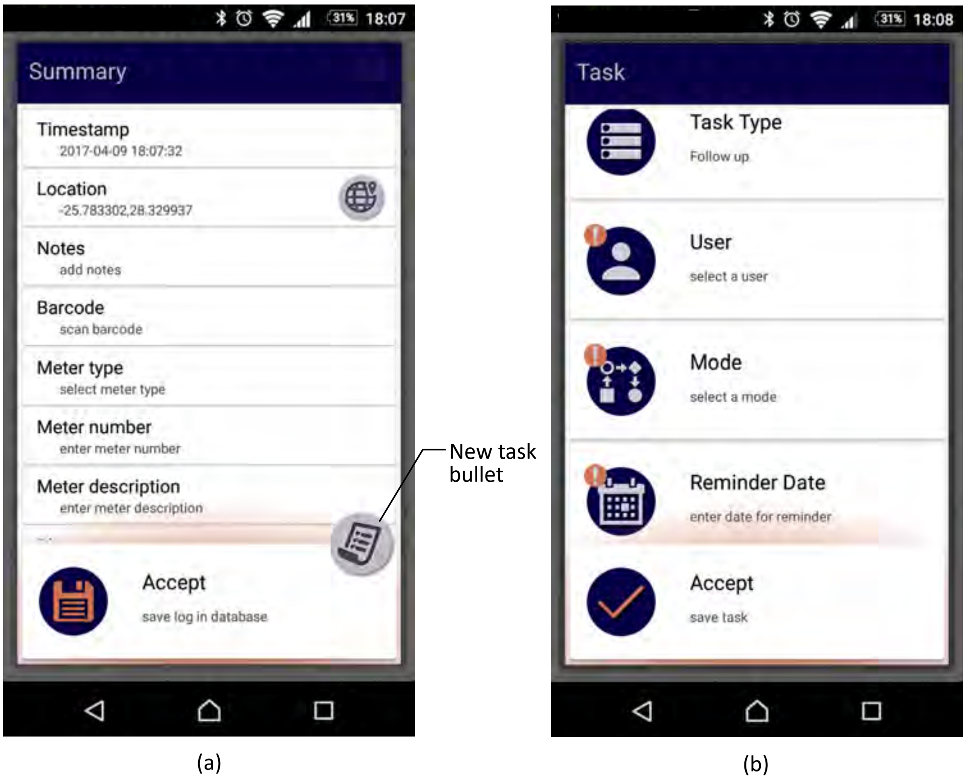


Figure 4.16: *Task creation*

4.8 Mobile application summary

This chapter provided a detailed discussion of the mobile application. The mobile application architecture was presented. Mobile system components include Logic controllers and Data holders, Local storage components, Support service infrastructure, Task management structures, User interface components, as well as Calculation and validation structures.

System interfaces are generated dynamically, based on entries stored in the database. The interfaces use four card components to populate dynamic content holders. Card contents and associated actions are managed by data holders. These components enable generic functionality and scalability while providing visual guidance to users.

Other application processes, including storage options and management, support services, data synchronisation and task management services, are introduced. Details surrounding this element and the mobile application are discussed. Full operation of these structures is provided in the following structure.

Chapter references

Android Developers (2017). Making Your App Location-Aware, https://developer.android.com/training/location/index.html.

FLIR (2017). The World's First Thermal Imaging Smartphone, http://www.flir.com/home/news/details/?ID=74197.

5

Integration of the comprehensive solution

Chapter 3 introduced a complete data collection and task management system, followed by a detailed application discussion in Chapter 4. This chapter discusses the integrated solution offered by the developed system in detail. The chapter discusses how various system components that were presented in Chapter 3 and Chapter 4 function together to deliver a range of outcomes.

5.1 Introduction

The developed data collection system comprises of many interlinked components. The combination of components enables a unique set of features, compared to other mobile data collection and management systems. The individual components have been developed and offer certain functionalities. However, the system relies on the combination of components. The developed components must therefore be integrated to extract the full potential from the system.

This chapter provides insight into system processes, as well as the integration of various system elements that make the process possible. This chapter is structured according to a natural flow in which the system is used. The sections provide insight into how the system fits together. Detailed figures are utilised to illustrate the system processes. Finally, each section is analysed according to the six novel components.

5.2 Configuration management

The developed system offers generic capabilities and can therefore be implemented to address the needs of clients across multiple industries. To allow this, the developed system isolates each client's data in a separate database. The database is used to store a full history of configuration data, as well as a full record of collected data. The system relies on the configuration stored in the database to manage system behaviour, user restrictions, data collection options and processing options.

System configuration is performed on the web interface, which is hosted on the centralised server. The configuration process can be divided into two parts, namely group configuration and management, and mode configuration management. Both these divisions are discussed in detail in the following sections, followed by a discussion of the Version management interface. This interface is used to publish both of the aforementioned divisions.

5.2.1 Group configuration management

Group configuration management tables are used to store information related to users, devices and data collection structures. Figure 5.1 shows the interface used to manage group configurations. Sections that can be edited are *Device, Mode, User, User Modes* and *Versions*. Each of these sections is managed by a similar interface, consisting of six actions and a table. Possible actions are indicated by the circular bullets above the table. These functions are, from left to right:

- Add new entry
- Delete selected entries
- Save changes
- Reset unsaved changes
- Download template
- Upload template

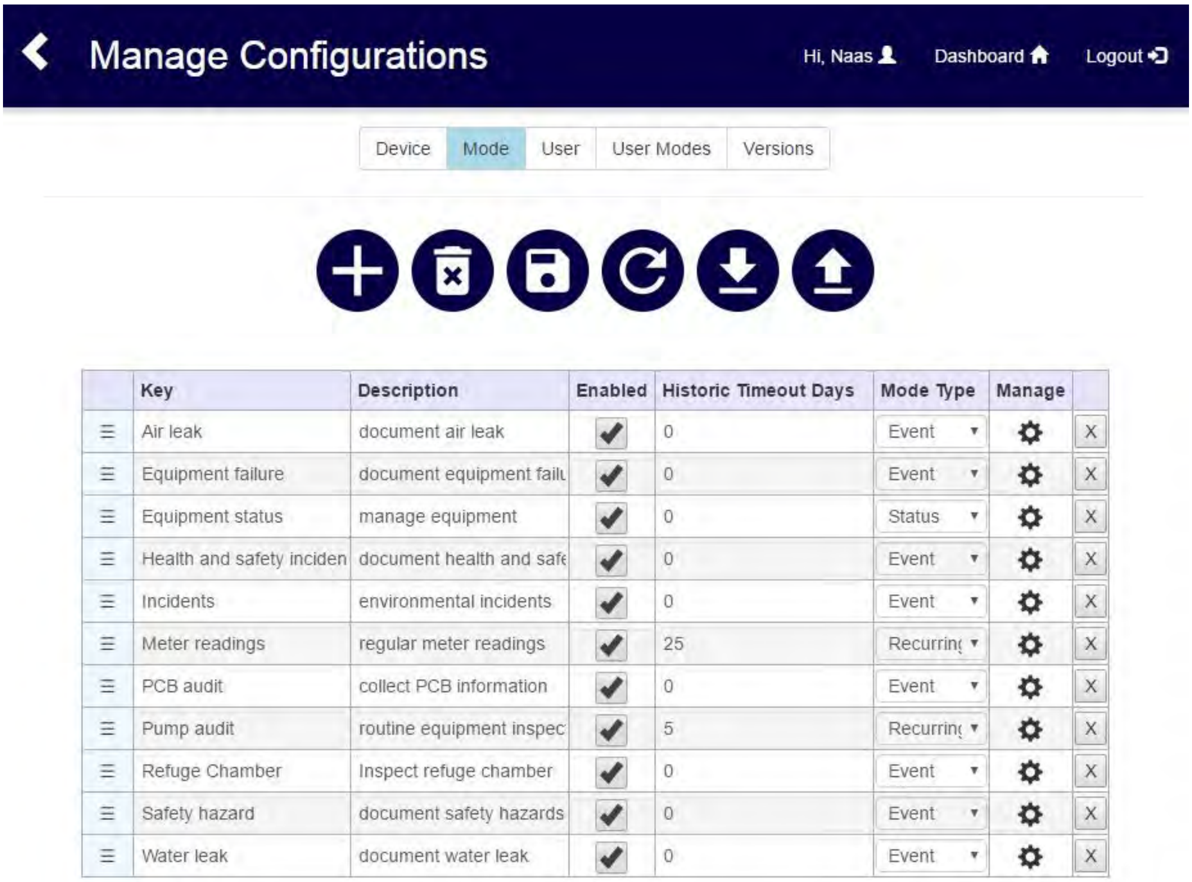


Figure 5.1: *Group configuration management interface*

The device section allows the user to manage devices permitted to access and manipulate data for a particular configuration. New devices can be registered and modified at any time. Parameters that can be adjusted are: Device name, Enabled flag, Data clean-up date, Automatic synchronisation flag and Associated licence. The administrator is granted the ability to generate and update licence keys which are formatted as Quick Response (QR) codes. The licence can be generated and sent to the user via an e-mail, using the interface shown In Figure 5.2.

The mode section is shown in Figure 5.1. Modes can be adapted in the same fashion as devices. Parameters available for adjustment are: *Key, Description, Enabled flag, Historic timeout day* count and a *Mode type* selection. Three items to note is the Mode type, Historic

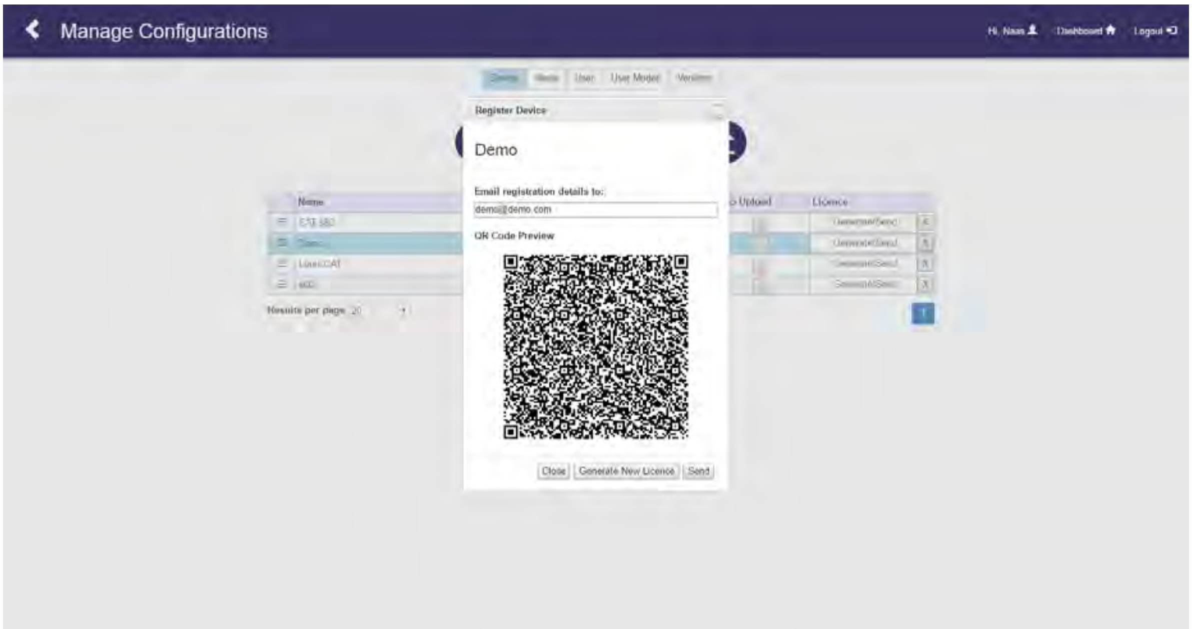


Figure 5.2: *Licence generation interface*

timeout day count and the Gear figure. The mode type can be selected as a recurring mode, non-recurring mode, or a status-tracking mode. The historic timeout count is used to set a period in which recurring actions are expected to take place. Lastly, the Gear figure can be used to jump to the mode configuration discussed in Section 5.2.2.

The group configuration is used to manage users. Users can be added or removed from the configuration using the options provided by the six actions discussed earlier. User access rights can be assigned to manage user privileges such as access to management interfaces. In addition to managing user accounts, users can be linked to selected modes. This enables administrators to manage which users have access to which modes. Administrators can therefore have access to multiple modes and application functions, while general users have limited access.

5.2.2 Mode configuration management

The Mode configuration management tables are used to detail the data collection structure. Each mode can be seen as a questionnaire with advanced additional features. Figure 5.3 shows the Mode configuration management interface. Sections that can be modified include *Data fields, List Options, Tests, Versions* and *Processing.* These sections have sub-sections and will be discussed in detail in subsequent sections. The interface is similar to the Group configuration management interface, and offers six actions, as discussed previously.

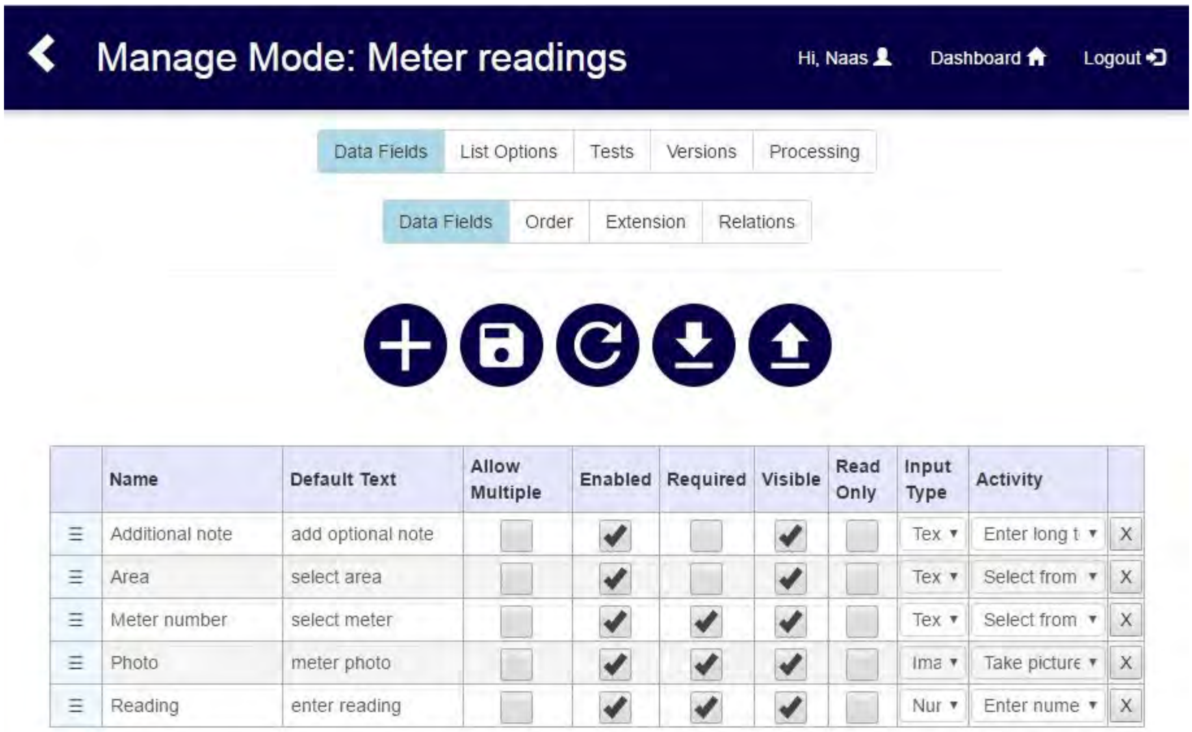


Figure 5.3: *Mode configuration management interface*

Data Fields are used to compose data collection interfaces and can be regarded as questions on a questionnaire. Properties that can be set include: *Name, Default text, Multiple allowance, Enabled flag, Required flag, Visible flag, Read-only flag* and, lastly, the assigned *Activity* which is filtered according to input types. Input activities dictate the logo that will be displayed, as well as the ingress interface that will be displayed when the data field is selected.

Additional sub-menu items associated with data fields are available and allow administrators to specify the data field order, data field with extended uses and relations between data fields. The *Order* option allows the administrator to move data fields up and down until a suitable display order is obtained. The *Extended* options dictate how data entries are displayed in review menus and is used to define identifying fields such as serial numbers that can be used for reference purposes. The *Relations* option is used to link parent and child data fields. Child data field behaviour can be controlled according to conditional parent data field values.

The *List options* section allows users to specify items that will be shown where lists are used within the application. List options are therefore linked to data fields linked with the list selection activity type. Sub-menu items in the list options sections allow administrators to manage list orders and list option relations. List relations extend data field relations. List options associated with a particular data field can be linked to list options associated with another data field. List options associated with a data field can be filtered, based on selected options in the other data field.

Tests are applied to data when a log is finalised for saving purposes. Possible tests are coded into functions. These functions require a particular set of parameters. References to possible tests and their associated parameters are stored in the database. Two test formats are available. A test can be linked with a data field. The result will be appended to that data field during the summary display. The second option allows execution of tests based on multiple parameters and will display the result on a free-standing card if no data field is assigned.

When a test is linked to a mode parameter, references are automatically created. The administrator must then link data fields to the parameters. These input parameters will be substituted into mathematical functions during test executions. The system must be populated with default values to account for missing data fields, or to add fixed values. These tests are executed by the mobile application and displayed to assist the user during the data collection process.

5.2.3 Version management

A Version management structure has been implemented on both the Configuration management structure, as presented in Section 3.5.2, and the Mode management structure, as presented in Section 3.5.3. The structure keeps track of changes made to the applicable structure's contents. The system state can therefore be tracked to reference historic states.

Figure 5.4 shows the Version interface. A table containing a full record of published versions is displayed on the bottom of the page. The table shows a time stamp, indication of which mode is currently active on the system, as well as a change description. When changes have been made to the system, the administrator must type a reference message and can then select the *Publish Current Version* option. This saves the changes and notify mobile devices of the updated system state. In return, the mobile devices will send requests to access the updated data.

5.2.4 Device registration process

The developed application restricts access to licensed users only. Licences are generated and distributed to users permitted to access a client group's data. The licences are distributed in the form of QR codes that was shown in Figure 5.2. To use the developed application, users must download and install the application on an Android enabled device. Android versions ranging from version 4.3 and upwards are supported. After installation, the device must be registered to link the device and load configuration data.

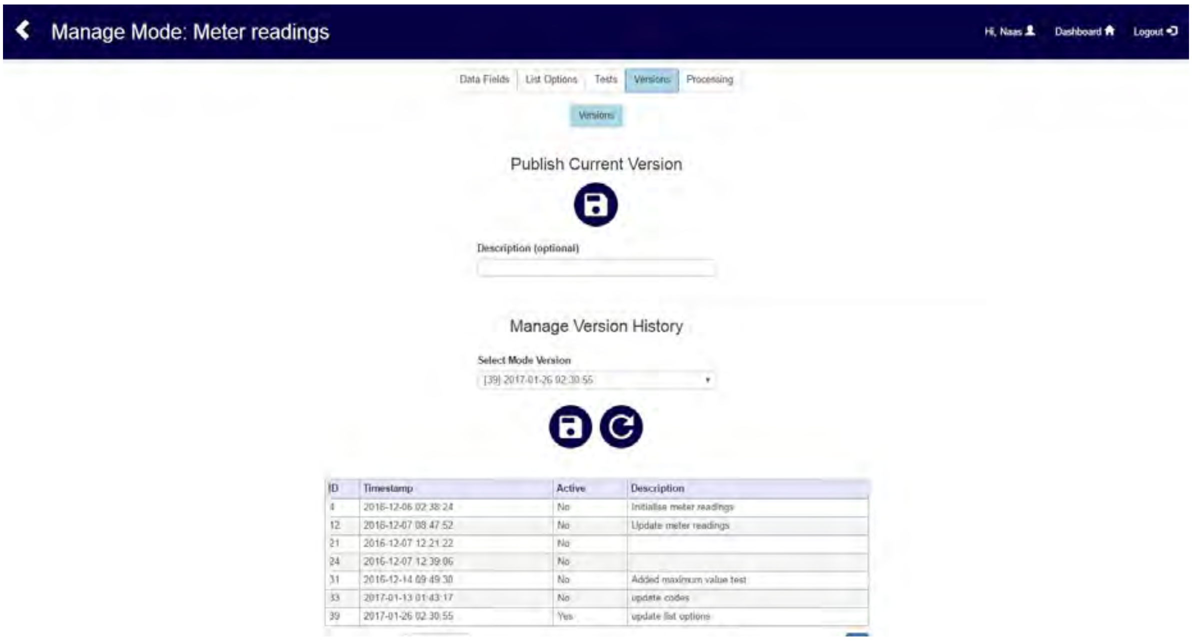


Figure 5.4: *Version interface*

When the application is executed for the first time, the application will perform the Device registration process shown in Figure 5.5. During the registration process the device will attempt to obtain a unique communication token used for FCM services. This key is sent to the server and will be used as an identifier for all future communication between the device and server. Once the device has been registered, the application downloads configuration data and existing log entries.

5.3 Log creation and extended processes

5.3.1 New log process

New log entries can be created using the mobile application. When creating a new log, users must first select the mode that will be used. To simplify the process, barcodes can be added to identifying elements. When a barcode is scanned and a linked item is found, applicable modes are detected. If multiple modes are found, the user must select a mode to complete from a shortlist. The application will respond by opening the Create log interface that was introduced in Section 4.3.2. If an item was identified using the barcode scan operation, the associated data fields will automatically be completed.

Remaining data fields must be completed by selecting the content cards from the Create log interface. Data is entered using data ingress interfaces linked to the data field. Required data fields are indicated by an exclamation icon. Once all the required data fields have been completed, the system will allow the user to complete the log. To complete the log the user must select *Finish*. The application will respond by preparing a log summary and displaying the entered values and test results. If the user is satisfied with the displayed summary, the log can be saved by selecting *Save log*. The new log process is shown in Figure 5.6.

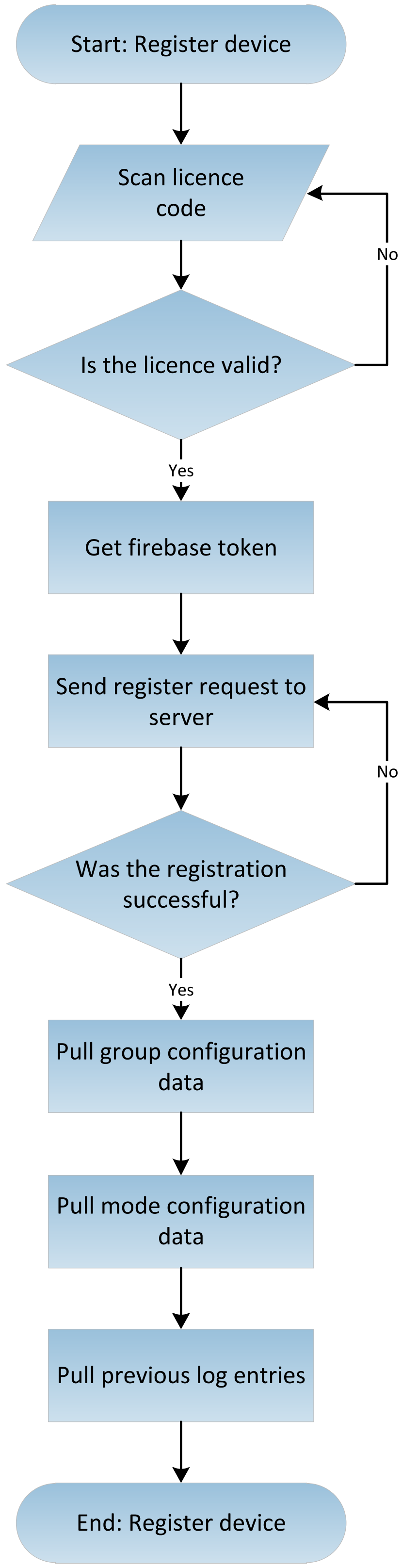


Figure 5.5: *Device registration process*

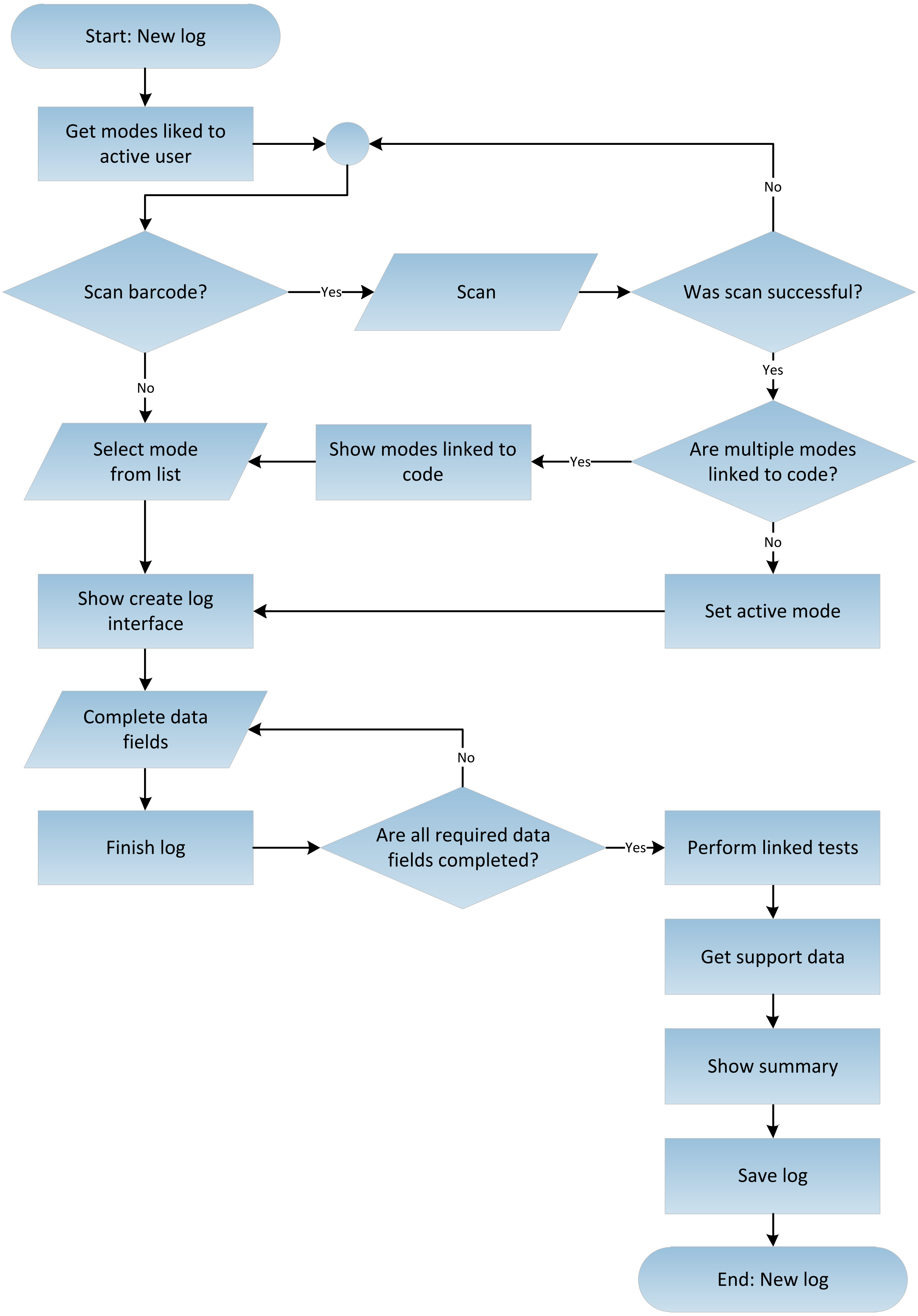


Figure 5.6: *Log creation process*

5.3.2 Calculation and validation process

The calculation and validation process, as shown in Figure 5.7, is performed when a log summary is compiled. Tests linked to the active mode are executed using the collected data. Test parameters linked to specific data fields will replace default parameter values with recorded values. The results are displayed by extending view card contents, or by creating additional view cards that supplement collected data. In cases where test values exceed specified tolerance levels, the test will be marked with an exclamation icon. Possible tests and calculations developed to date include:

- Compare value with historic average;
- Compare increment with historic average;
- Compare value to historic maximum value;
- Compare value to historic minimum value;
- Compare value to fixed maximum value;
- Compare value to fixed minimum value;
- Compare current GPS location with historic GPS locations;
- Calculate financial cost of air compressed air leaks; and
- Calculate financial cost of water leaks in mines.

5.3.3 Log entry synchronisation process

A log entry is created and stored on the mobile device when data collection takes place. If automatic upload is enabled on the device, the application will immediately try to synchronise the collected data with the central system. If automatic synchronisation is turned off, or the mobile device cannot establish a connection with the central server, the log will be marked as unsent. An exclamation icon will be shown in the main menu, indicating that synchronisation is required, until all the unsent logs are marked as sent.

During synchronisation the central server receives an upload request from the mobile device. The server decrypts the payload contained in the request and creates a copy of the log in the consolidated database. A unique identifying key is generated when creating the log entry. The identifying key is returned to the device that uploaded the log, which updates the original log to reference the remote key. Figure 5.8 provides a graphical representation of the data synchronisation process.

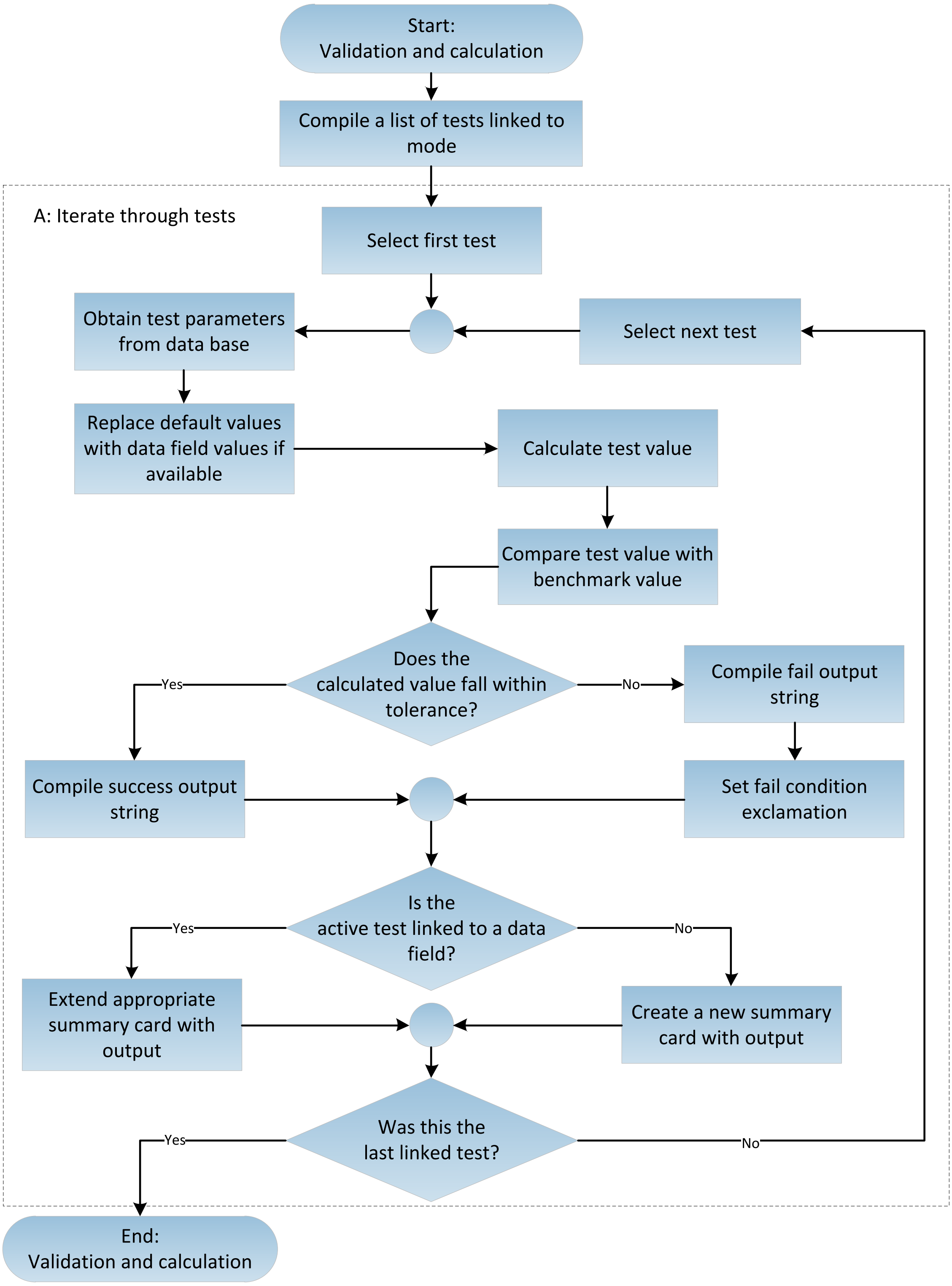


Figure 5.7: *Validation and calculation process*

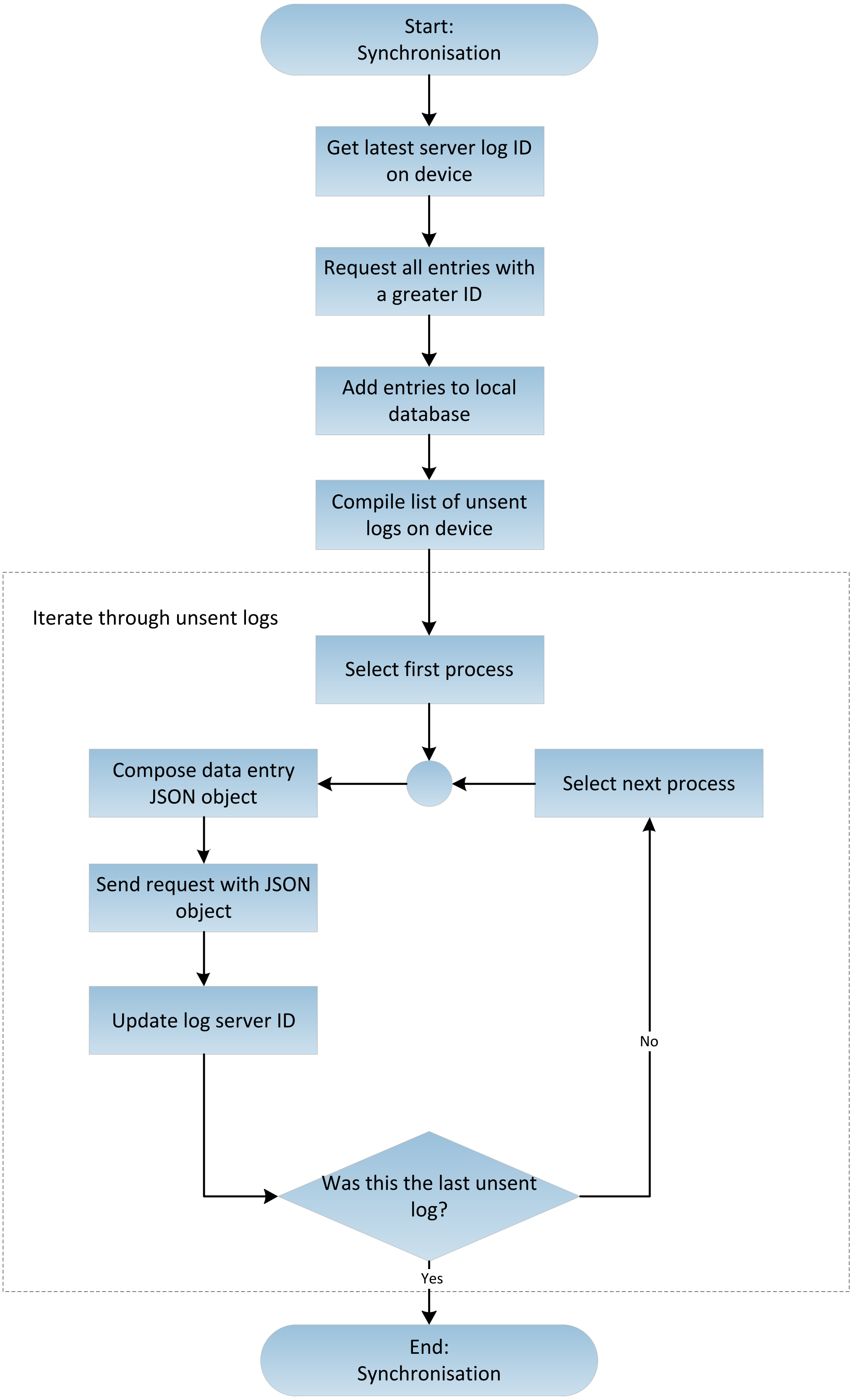


Figure 5.8: *Synchronisation process*

5.4 Task management

5.4.1 Task completion process

The three available task types are recurring tasks, follow-up tasks and assigned tasks. Recurring tasks guide users to perform routine tasks by compiling a list of expected logs based on previous log entries. Follow-up tasks remind users to re-evaluate a recoded item and are not available for routine tasks, because they are revisited on a continuous basis. Assigned tasks can be used to direct users to perform actions and create specific logs.

Task management options provided by the developed system can be used to guide users to perform data collection tasks. The task completion process is indicated in Figure 5.9. Recurring tasks, Follow-up tasks and Assigned tasks have different applications and therefore require different approaches to close tasks. However, all tasks are finally closed by creating a suitable log entry.

5.4.2 Task generation process

Tasks are synchronised among linked devices. Users can therefore create tasks and allocate other remote users to perform actions. Log entries used during task generation consider all synchronised data collected by the entire group. This is especially useful when users perform tasks generally addressed by co-workers.

Task generation is a special feature offered by the developed system and is shown in Figure 5.10. This feature focusses on recurring data collection tasks such as meter readings or similar work that repeats after fixed time intervals. A specified interval period must be specified for routine data collection tasks. To generate tasks, the system considers actions performed by a specific user for a specific mode.

The system narrows the list by ignoring tasks that were performed prior to three time intervals, and removes log entries that have been taken within the last timeout period. The result is a list of tasks that have been performed in the last three time intervals, but have not been completed within the last time interval. Other users can make use of this to take over outstanding tasks that colleagues have not performed yet.

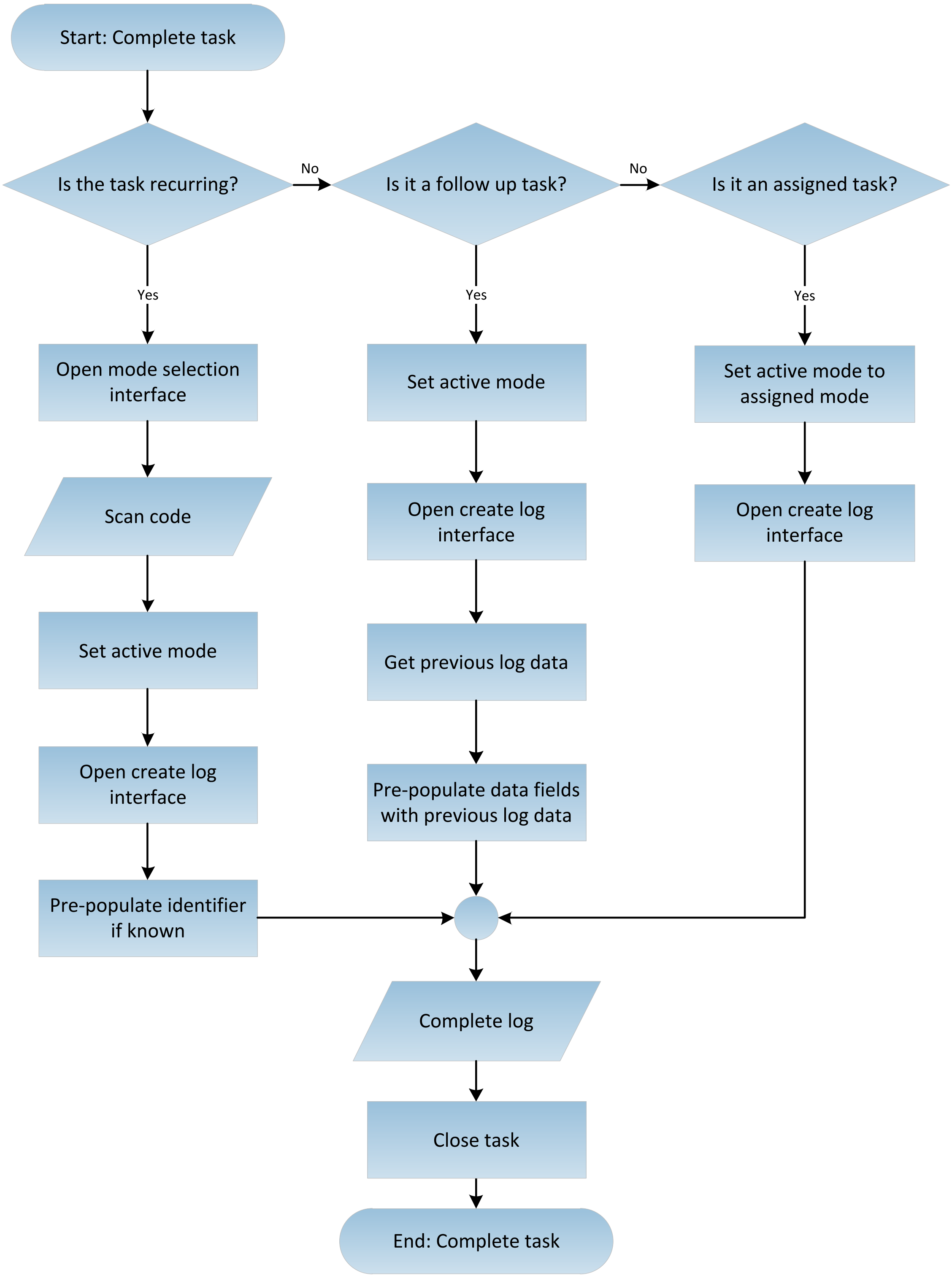


Figure 5.9: *Task completion process*

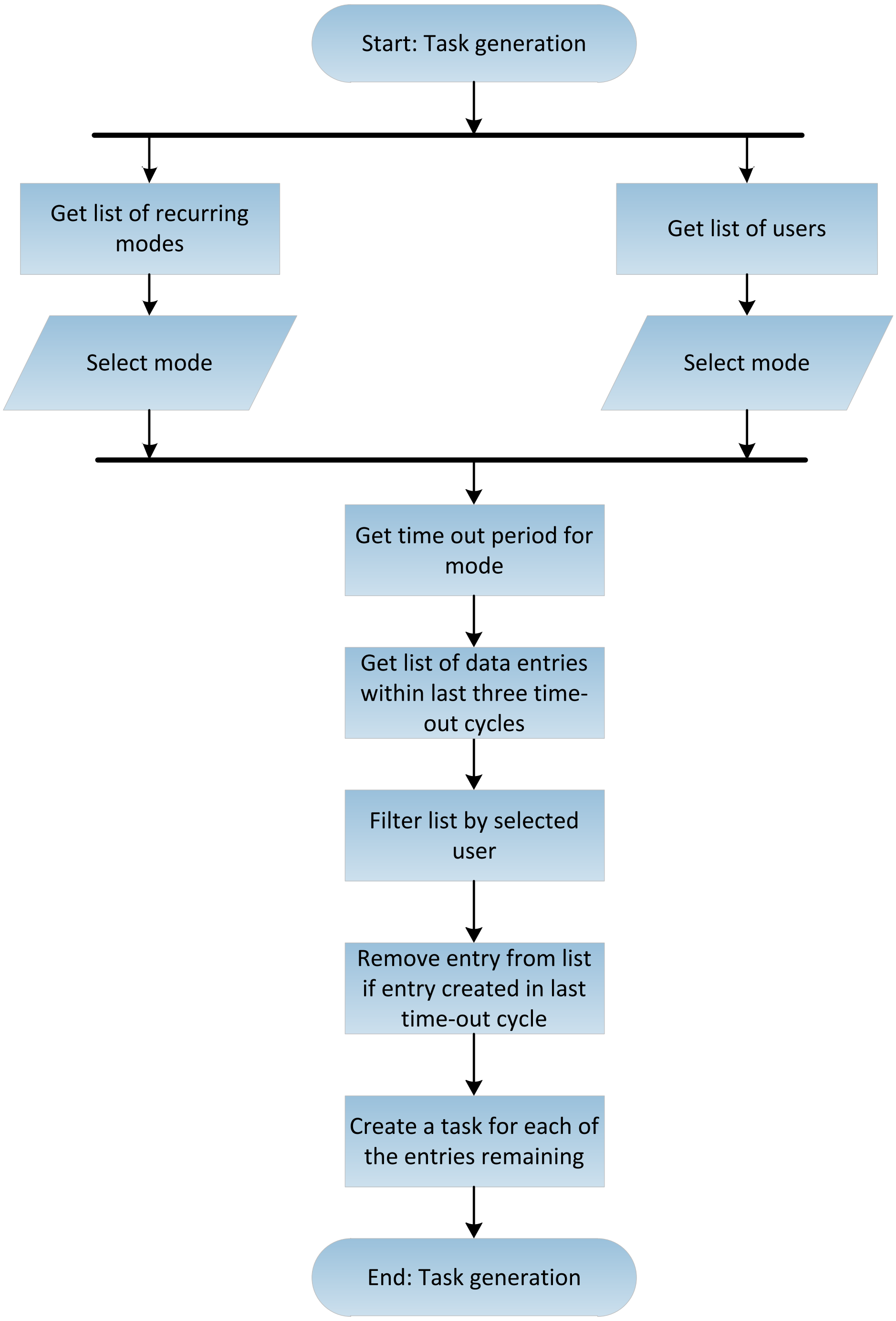


Figure 5.10: *Task generation process*

5.5 Data consolidation and processing

5.5.1 Data consolidation and processing

The developed system offers extensive data consolidation and processing options via the centralised server. Data collection and data transfer functions between the server and mobile application utilise generic structures. Unique specialised processing takes place on the server. Changes can take place on the server without distribution issues associated with updating multiple mobile devices.

All received logs are processed and consolidated with the group's database. When an entry has been added to the central database, the server sends the identifying key to the uploading device. A broadcast notification is sent to all linked devices to notify that new data is available. If other output options are associated with the mode, relevant files are created and distributed based on the predefined outcomes. Figure 5.11 provides a graphical representation of the data consolidation and processing process.

5.5.2 E-mail notification process

E-mail notifications are a specific data processing and forwarding function offered by the developed system. Instant e-mail notifications can be linked to modes. When a data entry is received for that mode, the e-mail notification process is triggered. The system iterates through e-mail alerts and tests the log entry to establish which action to execute.

Each alert can have multiple rules assigned to it. Rules are based on data fields linked to list selections. This restricts system behaviour to known states. If the selection for the data field in the new log entry matches the list option specified by the rule, the result is successful. If all the rules linked to an alert return a true value, an e-mail notification is prepared and distributed.

E-mail notifications contain generic body messages and file attachments that contain log data. The attachment content is managed by the template and data fields linked to the template. Linked e-mail addresses are added to the distribution list and the e-mail is sent. Figure 5.12 shows this process graphically.

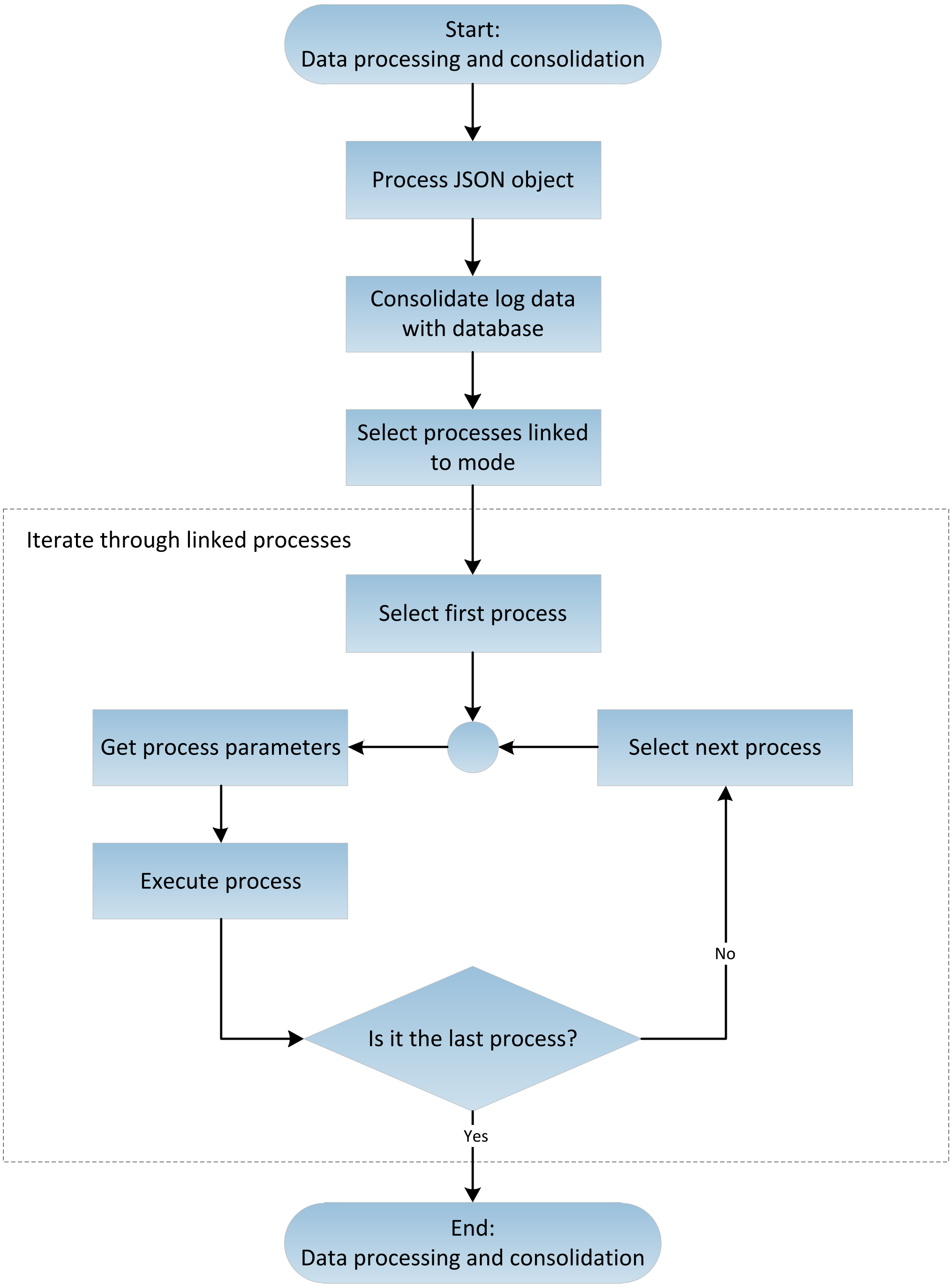


Figure 5.11: *Data processing and consolidation process*

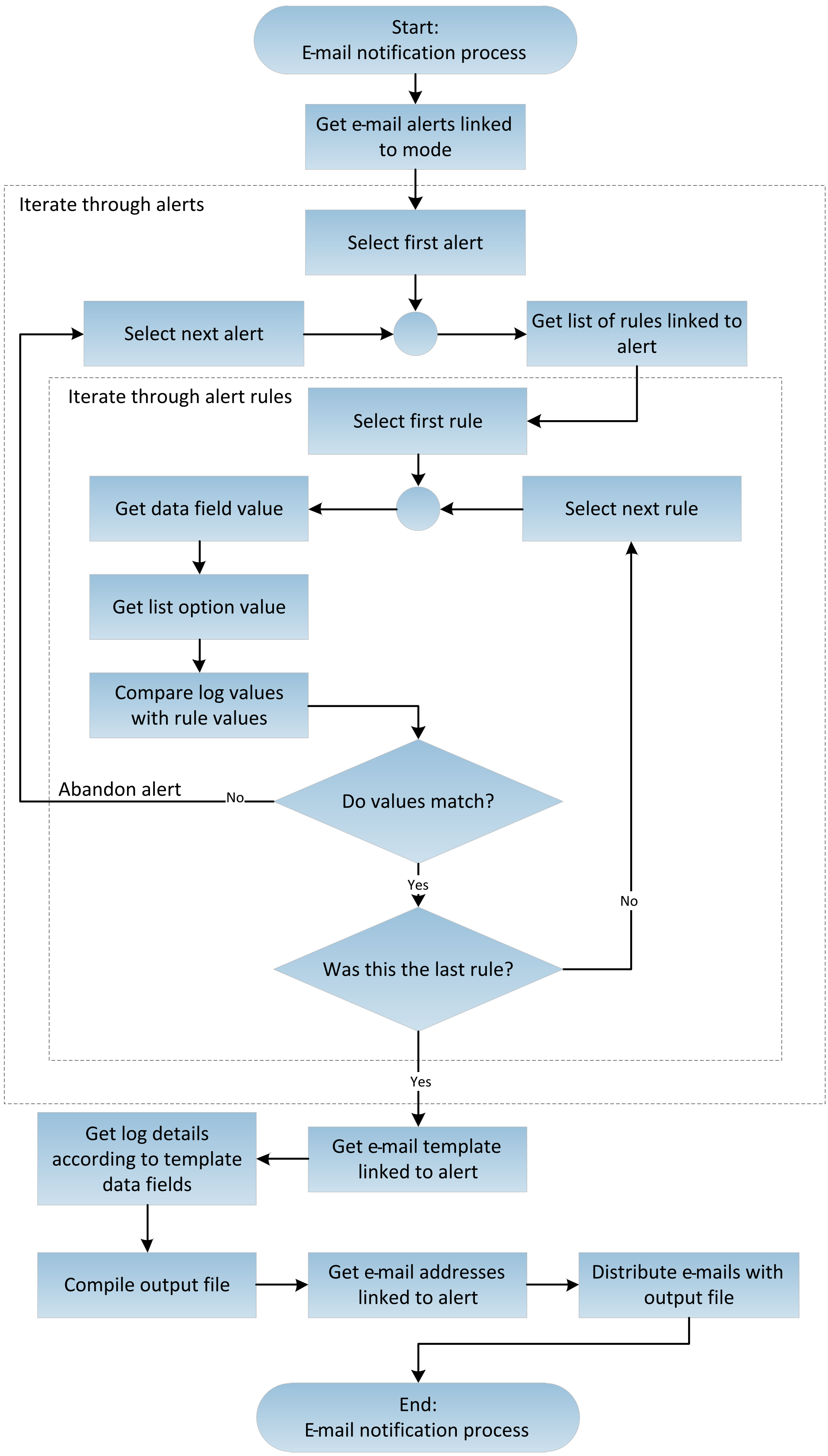


Figure 5.12: *E-mail notification process*

5.5.3 Information extraction and display

Integration with internal reporting systems offer web-based reporting options. The central server makes data available via various APIs. Various extension interfaces have been developed for a web-based energy system. This web-based system is used by clients and can be used to navigate to data collected by the mobile data collection system.

A generic table view, as shown in Figure 5.13, offers access to data entries and allows users to download the raw data in Comma Separated Values (CSV) file format for further processing. Figure 5.14 shows a detailed interface that was created to display specific information and allow the clients to see processed results. Lastly, specific entry details can be viewed by selecting a particular data entry. This interface displays collected data, including images and GPS locations as pins on a map, and can be seen in Figure 5.15.

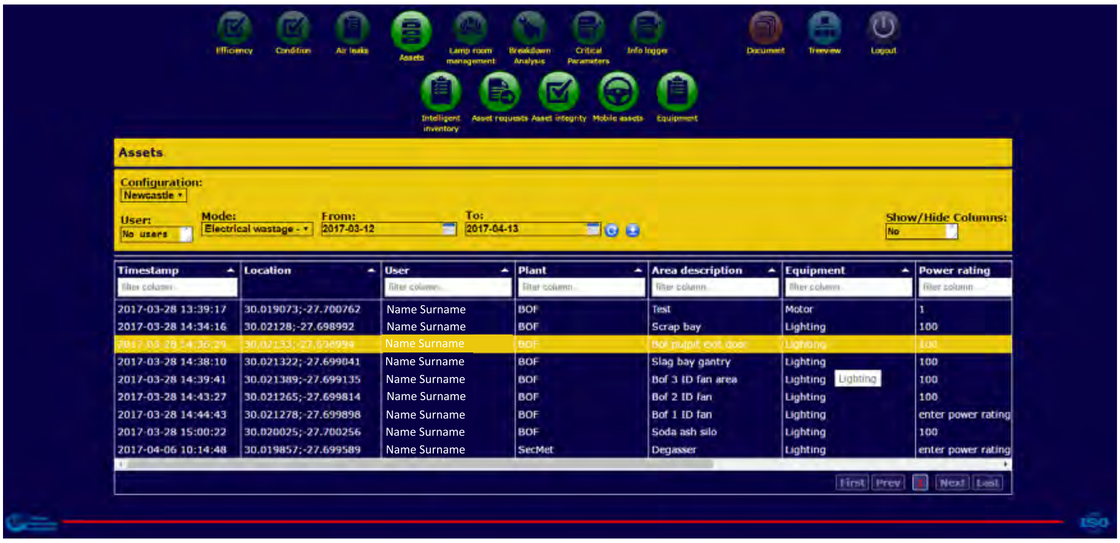


Figure 5.13: *Generic interface*

Figure 5.14: *Specific information interface*

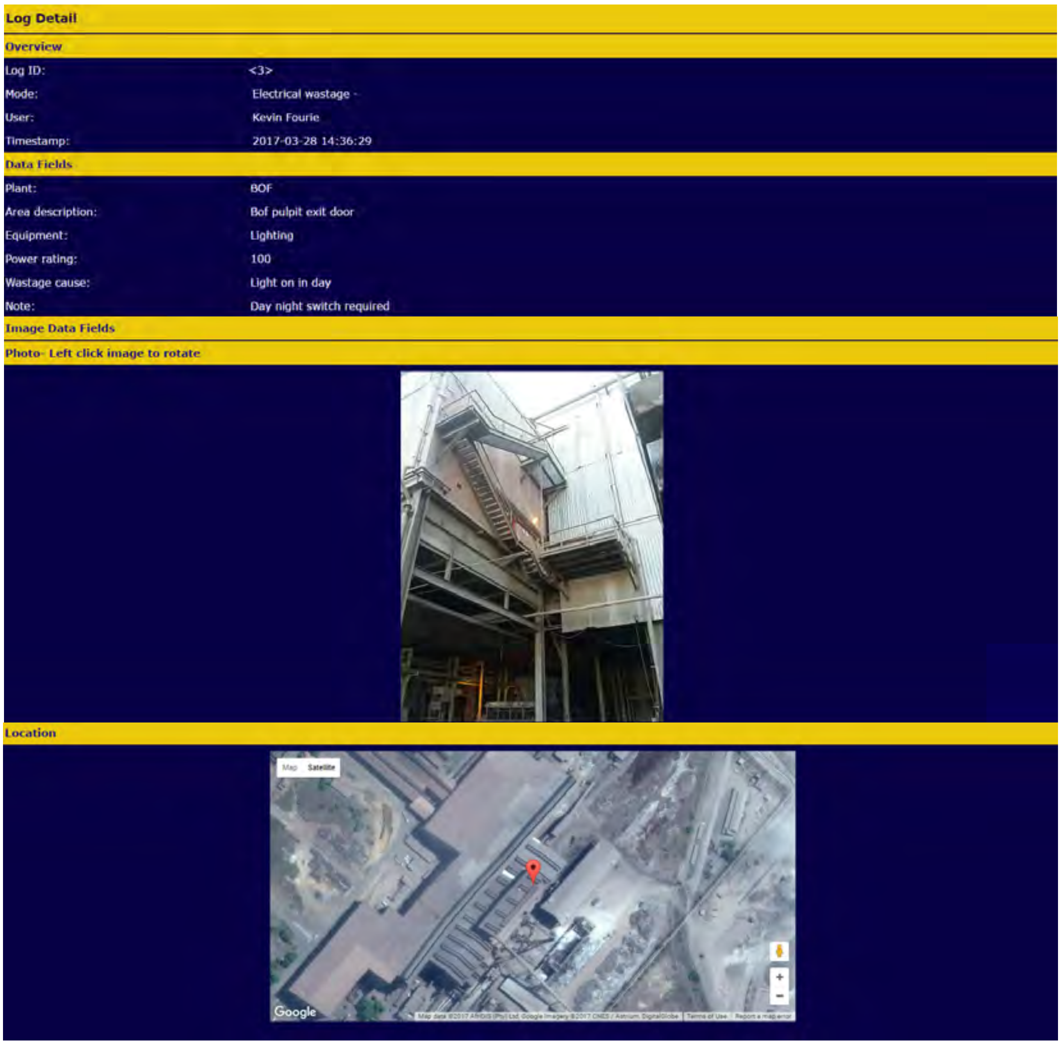


Figure 5.15: *Detailed log review interface*

5.6 Integration discussion

This chapter presented the integrated solution offered by the developed system. The section was divided into four sections namely Configuration management, Log creation and Extended processes, Task management and Data consolidation and processing.

Each of these sections described how system components interact to produce the desired outcomes. Flow diagrams were used to visually illustrate processes discussed in the text. This chapter proves that the developed system relies on interaction between various components to enable advanced functionality.

6

System implementation in the industrial sector

The developed system offers a generic data collection solution that has the ability to address the data collection needs associated with a range of industrial activities. Case studies presented in this chapter shows how the developed system conformed to the needs of various industrial clients. These case studies provide validation of the developed system. Special attention was paid to contributing novel elements and how it affected each particular case.

6.1 Introduction

The first two chapters of this document studied current economic conditions surrounding South Africa's industrial sector, and data collection systems respectively. This study revealed that no single mobile data collection system meets all the identified needs surrounding data collection and task management requirements in the industrial sector. A new data collection and management system was therefore developed to address the identified needs.

A new mobile data collection and management system was proposed. Chapter 3 introduced a system capable of addressing the identified requirements. An overview of the entire system was provided, while Chapter 4 provided details related to the mobile application. The integrated system and comprehensive solution was discussed in Chapter 5.

The developed system has generic capabilities that allow it to conform to the needs of various industrial applications. Five case studies are presented to validate the developed system at the hand of actual implementations in the South African industrial sector. Specialised interfaces and functions were utilised to address the diverse range of needs associated with these applications. The following sections present the five case studies.

6.2 Case study 1: Meter readings

6.2.1 Background

Industrial data collection is typically focussed on systems that directly influence production and is therefore associated with significant financial implications. Due to the lack of financial motivation, auxiliary data including safety inspections and environmental values are often neglected.

In recent years, higher reporting standards and legislative requirements have created the need for additional reports and higher accuracy. In most cases reported data must be substantiated with source documentation or other evidence. Handwritten notes used to collect data for reporting purposes are therefore insufficient and must be replaced by traceable systems.

Although advanced systems exist and are implemented at many industrial sites, it is not feasible to automate systems that do not directly influence production. Therefore, data associated with numerous industrial activities are collected using manual methods. Park (2015) elaborates that manual data collection is reliant on paper forms, which relate to high and long turnaround times. In addition to this, Vecellio et al. (2015) and Park (2015) both note that data accuracy associated with handwritten notes is a concern.

Data collected using manual methods is susceptible to human errors when reading the meter, writing down the reading and during the transcription of notes. If an error was made at a remote location and is detected later on, no remedial action can be taken. Many data collection tasks occur outdoors and therefore exposes the data collector and data collection equipment or notes to adverse weather conditions.

6.2.2 Needs

In this case, the developed system is used to collect meter readings. The first client collected water meter readings for a cluster of mines on a monthly basis. The meters are located over a wide area and are typically in places that are difficult to access. However, monthly meter readings do not justify the installation cost of automated meters with communication capabilities. The meters are therefore visited once a month and a reading is recorded using a pen and paper approach.

In the second implementation, a similar configuration was requested by another client with corresponding requirements. The second client uses the system to collect both water meter readings and electricity meter readings on a monthly basis. The readings are used for internal billing and GRI reporting and must therefore be verifiable. Data verification tests and reports are therefore required. As a minimum, collected data must include:

- Data collector identification
- Time stamp
- GPS Location
- Meter identification
- Meter reading
- Photographic evidence

6.2.3 Solution implementation

The developed system was subsequently implemented at the respective client facilities. The configuration was prepared according to the specific application. The configuration platform on the central system was used to configure the various application structures. A central database with a full history of configuration changes and historic data is stored on the central server and used to synchronise data with field devices.

Figure 6.1 shows the interface that handles the active version and change logs. System administrators can revert the system configuration to previous states or save stable versions. This also keeps a history of configuration changes. Linked devices are notified when changes are saved and a version is published. The devices download new configurations when notifications are received or on the next application launch, provided that an internet connection is available.

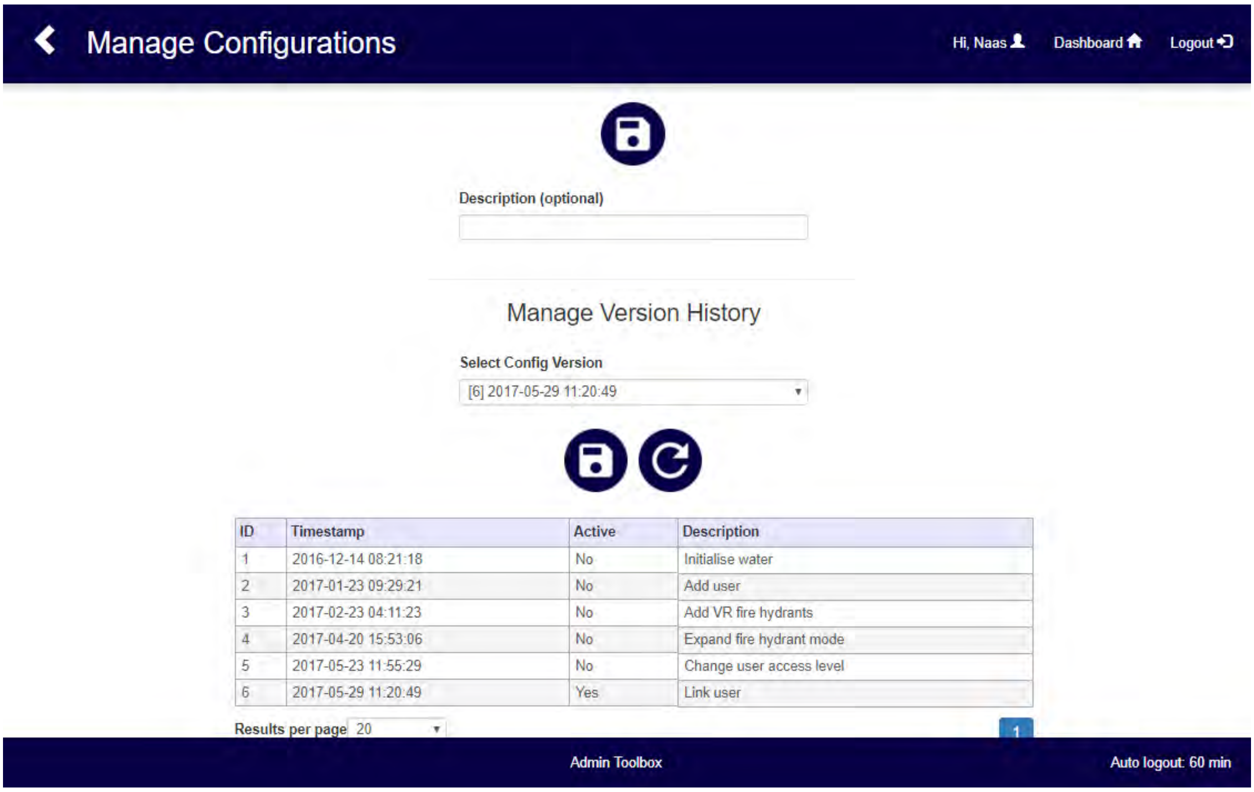
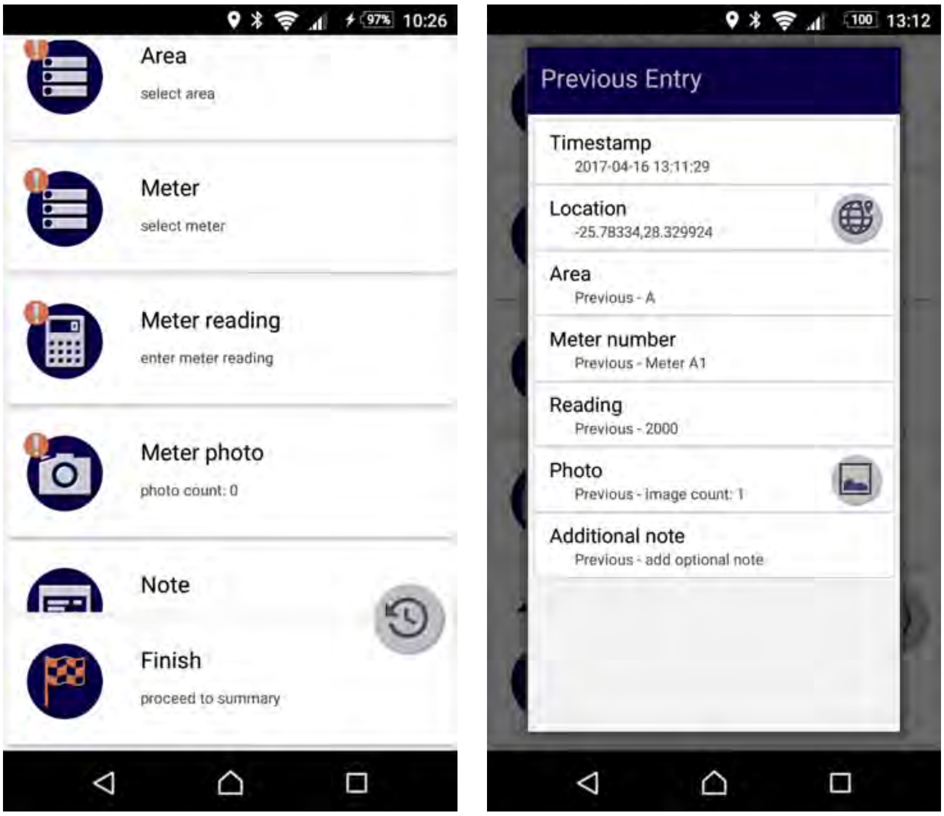


Figure 6.1: *Version management interface*

The initial configuration only included the meter reading data set. This data set was configured as a recurring mode. Figure 6.2 (a) shows the interface displaying the custom data set that was defined for this application. Entries pertaining to *Area* list and *Meter* list data fields were predefined. Data field relations were established between these two lists. The Area list was therefore used to enable form logic by providing a filter for the Meter list that shows only meters available in the selected area.

The Meter reading allows the user to enter a numeric value as displayed on the meter, and the Note data field makes provision for possible notes. The Meter photo data field is used to capture a photo of the meter display. This is used as proof documentation in combination with a time stamp, user identification and GPS coordinate, all of which is recorded in the background. Figure 6.2 (b) shows the customised summary that allows users to view the information gathered via user inputs and background services.



(a) (b)

Figure 6.2: *Create log interface*

At later stages a new user was added and an additional mode was created for fire hydrants, as was shown in Figure 6.1. These changes were performed online and stored in the central database. The new user was issued with a licence code. Figure 6.3(a) shows how the licence code is scanned using the mobile application. The application uses the contained information to contact the server to register the device, request configurations and request existing data as shown in Figure 6.3(b). All communication including configuration and log data is encrypted for added security.

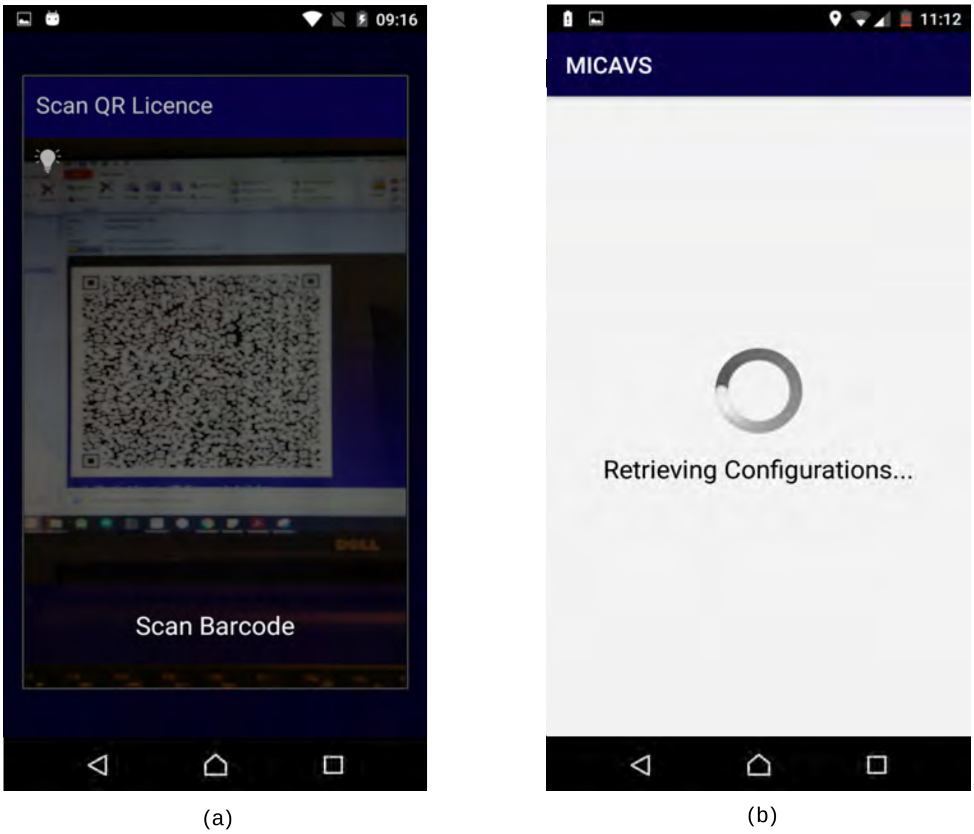


Figure 6.3: *Device registration*

6.2.4 Results

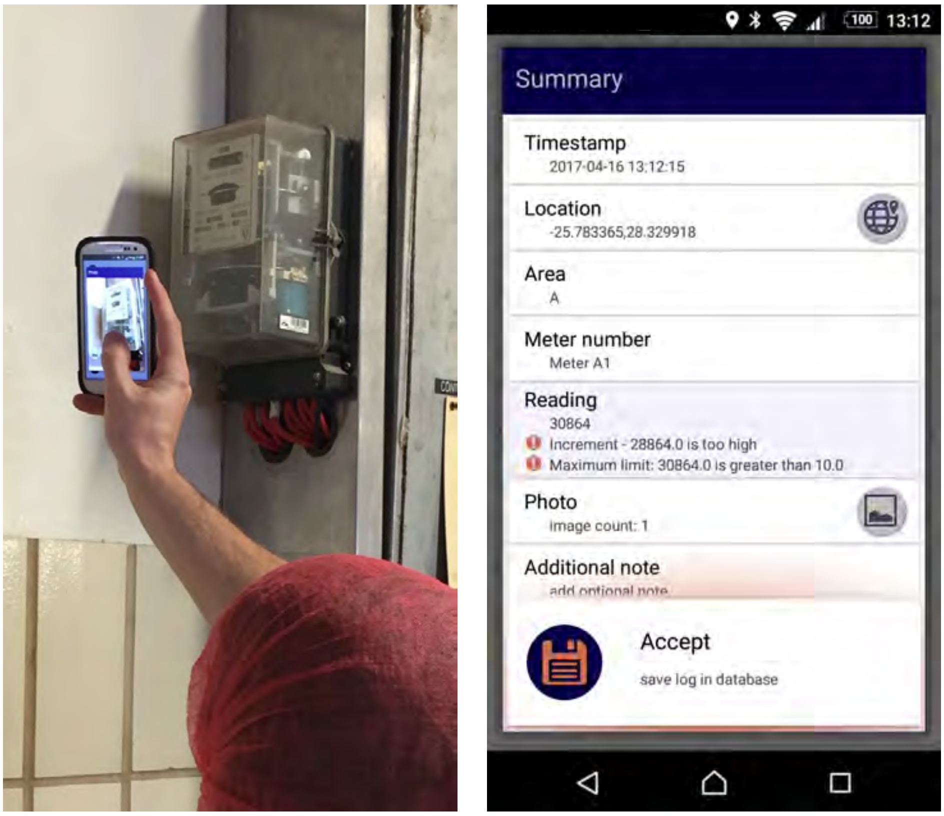
The first client marked more than 500 meters and water related items on the facility with barcodes. These codes were linked to meter numbers and fire hydrant numbers. When a code is scanned the system automatically detects and displays the appropriate mode. The detected meter and associated group is automatically selected. This improves accuracy, because the system and removes a possible region for human error. Figure 6.4 (a) shows an example of a user gathering data.

These configurations were specified as recurring tasks the system makes provision for tasks that utilise previously recorded data. Historic identifiers are assigned to recurring data collection tasks if possible identifiers can be defined. In these the cases meter number data field was selected to serve as the identifier. Previous readings can be recalled based on the historic identifier. The previous reading linked to a meter number can be viewed, during data collection, by pressing the 'review previous entry' bullet on the 'create log' interface, shown in Figure 6.2.

Real-time data validation was achieved by linking normalised average increment tests to the meter reading data field. The developed system is unique in the sense that this test can be performed offline, due to a complete historic data set on the device. The historic identifier, in this case the meter number, is used as a reference to select all previous readings associated with the selected item.

When performing the average increment test, a reference value is calculated by calculating the average daily increment between the first and last data entry. The comparative value is calculated as the average daily increase between the previous log and current log. If the two normalised values differ by more than the specified tolerance percentage, the meter reading is flagged in the customisable summary. Figure 6.4 (b) shows the summary interface that indicates two failed tests.

If the user is satisfied with the collected data a log entry can be saved. The collected data as well as substantiating evidence is stored on the device. The system records the active configuration version ID to enable full traceability of collected data. If the automatic upload setting was activated and the device has an internet connection, data will be synchronised with the server. Alternatively the log will be stored on the device until the user synchronises the collected data with the server using the option in the application's main menu.



(a) (b)

Figure 6.4: *Summary interface with failed increment test*

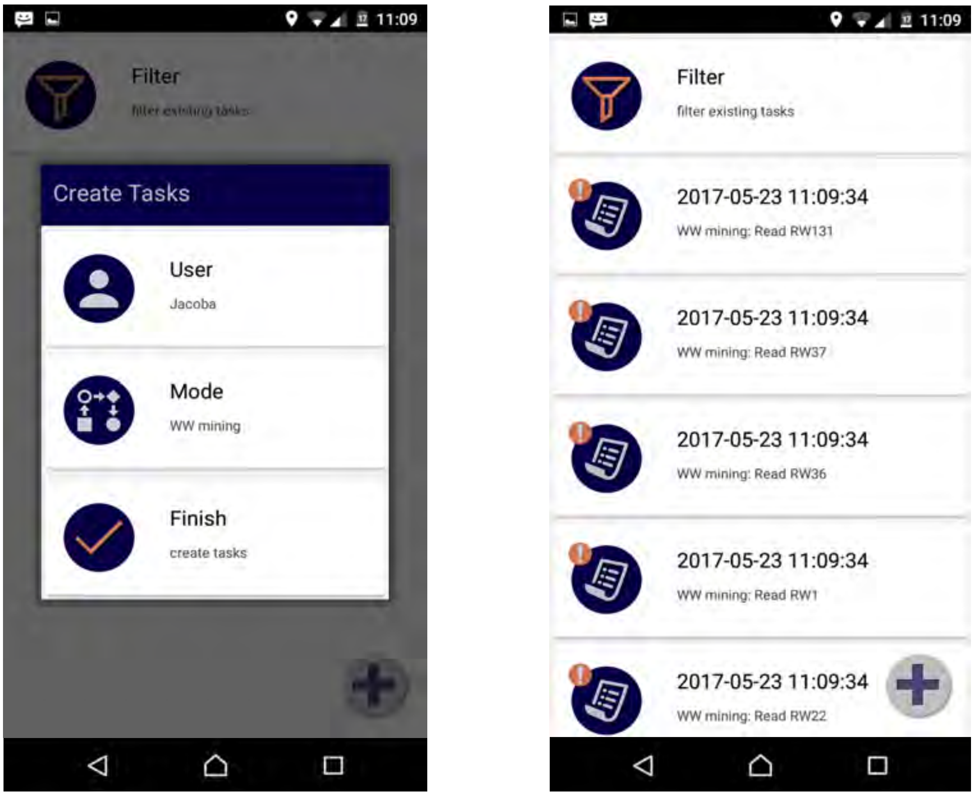
The first client has been using the system on a monthly basis for more than 12 months. Every month more than 80 routine readings are collected. Due to safety issues, all the meters cannot be accessed every month. A customised summary is displayed before log creation completes. The summary displays calculations performed on the device that indicate possible data errors, and alert the user of any discrepancies while still on site. The recurring task generation capability is functional and can be used by security-escorted personnel to collect critical data, if necessary. Furthermore, the collected data is stored in a traceable structure and can be used for reporting and auditing purposes.

In the second implementation, a similar configuration was used with the addition of a second mode. The two modes were used to separate the water meter readings and electricity meter readings. This also enabled user assignment to restrict users to allowed modes. Similar test and task generation capabilities were implemented successfully. This system has been in use for 6 months. Figure 6.5 shows barcoded electricity and water meters that are managed with the developed system.

(a) (b)

Figure 6.5: *Barcoded electricity and water meters*

When the mobile application is used to scan the codes shown previously, the appropriate mode is detected and meter is selected. Only users who are linked to detected modes will be able to create data entries for the detected item. If the user is linked to water meters the application will not show electricity meter options and oppositely. The detected meter is automatically selected in the data collection interface. Furthermore, the identified meter is used to access previous data entries. These data entries are used for validation tests, historic review and lastly task generation. Figure 6.6a shows the task generation interface while Figure 6.6b shows the generated task list.

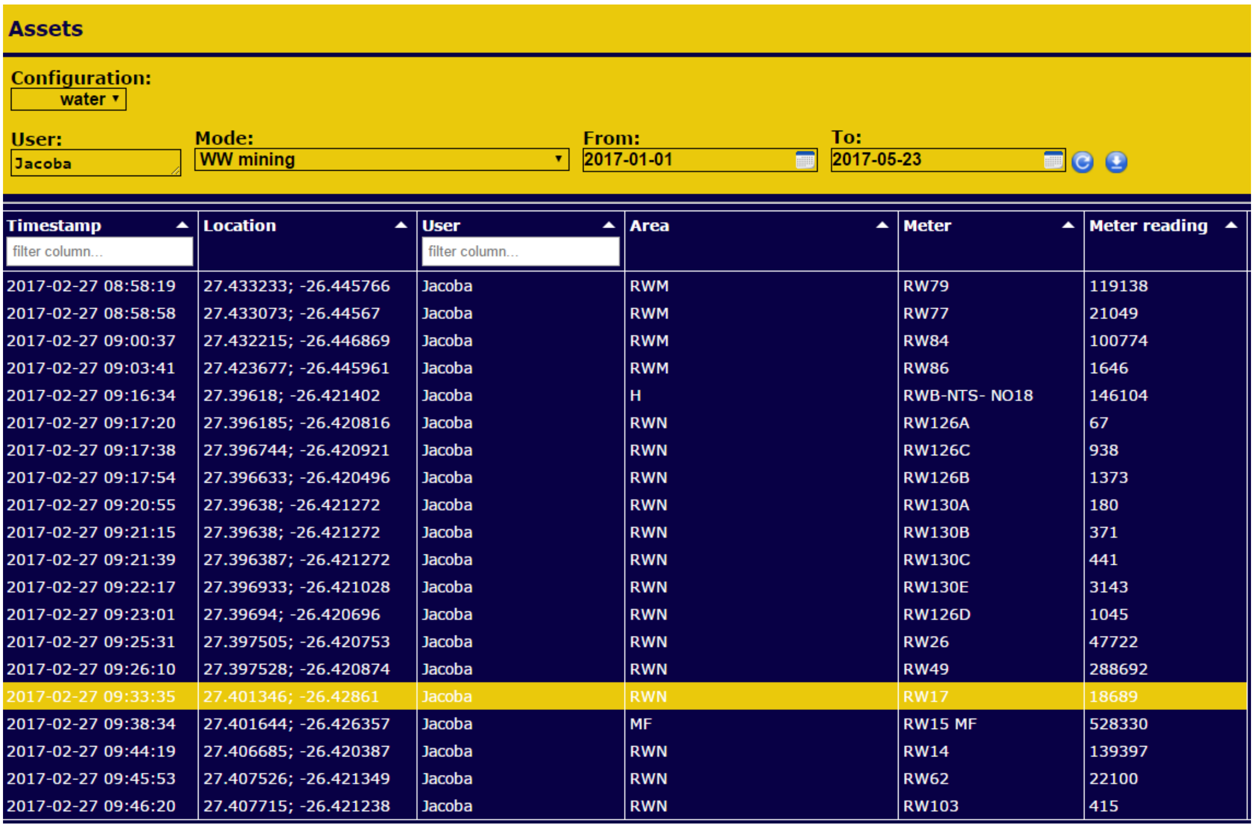


(a) (b)

Figure 6.6: *Task interfaces*

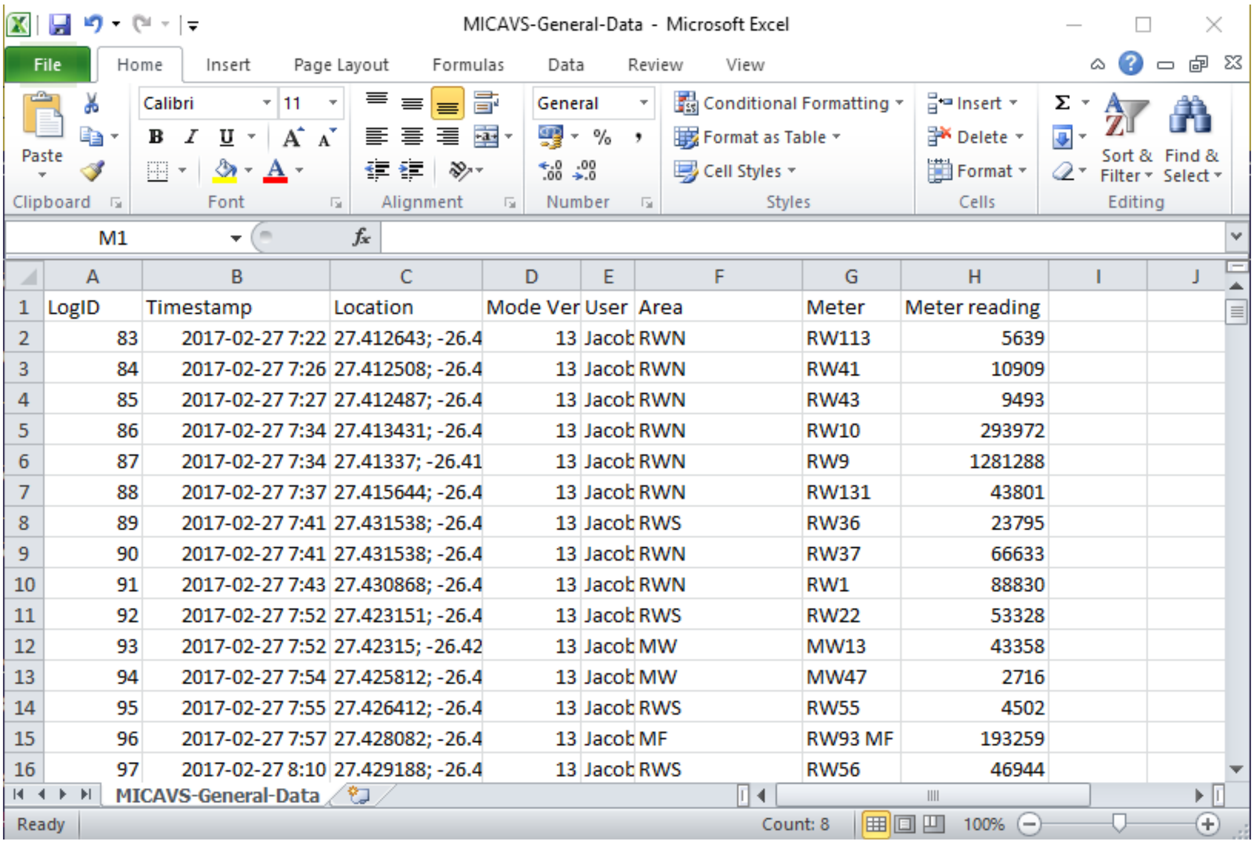
User based task generation is available and is used to assist with data collection. Data entries are linked to the users that created them. Logs created by all users are synchronised among all the linked devices in real time. In cases where a user has to stand in for another user the system can be used to generate a list of meters documented by the second user in the last three months. The system therefore ignores items that the second user has not access for three time-out cycles. If data entries are created or entries with dates that fall within the current time-out period, the task related to the relevant item is closed and removed from the list.

The recorded water and electricity meter readings are used to perform internal billing applications. Furthermore the consolidated total of these readings are used to calculate values that are presented in GRI reports. The reported values are calculated as the total amount that the organisation was billed minus the total consumption used by internal consumers. Figure 6.7 shows how the consolidated data is displayed an associated web-based platform, while Figure 6.8 shows the file obtained by downloading the displayed data.



Timestamp	Location	User	Area	Meter	Meter reading
2017-02-27 08:58:19	27.433233; -26.445766	Jacoba	RWM	RW79	119138
2017-02-27 08:58:58	27.433073; -26.44567	Jacoba	RWM	RW77	21049
2017-02-27 09:00:37	27.432215; -26.446869	Jacoba	RWM	RW84	100774
2017-02-27 09:03:41	27.423677; -26.445961	Jacoba	RWM	RW86	1646
2017-02-27 09:16:34	27.39618; -26.421402	Jacoba	H	RWB-NTS- NO18	146104
2017-02-27 09:17:20	27.396185; -26.420816	Jacoba	RWN	RW126A	67
2017-02-27 09:17:38	27.396744; -26.420921	Jacoba	RWN	RW126C	938
2017-02-27 09:17:54	27.396633; -26.420496	Jacoba	RWN	RW126B	1373
2017-02-27 09:20:55	27.39638; -26.421272	Jacoba	RWN	RW130A	180
2017-02-27 09:21:15	27.39638; -26.421272	Jacoba	RWN	RW130B	371
2017-02-27 09:21:39	27.396387; -26.421272	Jacoba	RWN	RW130C	441
2017-02-27 09:22:17	27.396933; -26.421028	Jacoba	RWN	RW130E	3143
2017-02-27 09:23:01	27.39694; -26.420696	Jacoba	RWN	RW126D	1045
2017-02-27 09:25:31	27.397505; -26.420753	Jacoba	RWN	RW26	47722
2017-02-27 09:26:10	27.397528; -26.420874	Jacoba	RWN	RW49	288692
2017-02-27 09:33:35	27.401346; -26.42861	Jacoba	RWN	RW17	18689
2017-02-27 09:38:34	27.401644; -26.426357	Jacoba	MF	RW15 MF	528330
2017-02-27 09:44:19	27.406685; -26.420387	Jacoba	RWN	RW14	139397
2017-02-27 09:45:53	27.407526; -26.421349	Jacoba	RWN	RW62	22100
2017-02-27 09:46:20	27.407715; -26.421238	Jacoba	RWN	RW103	415

Figure 6.7: *Consolidated data on web-interface*



	A	B	C	D	E	F	G	H
1	LogID	Timestamp	Location	Mode Ver	User	Area	Meter	Meter reading
2	83	2017-02-27 7:22	27.412643; -26.4	13	Jacob	RWN	RW113	5639
3	84	2017-02-27 7:26	27.412508; -26.4	13	Jacob	RWN	RW41	10909
4	85	2017-02-27 7:27	27.412487; -26.4	13	Jacob	RWN	RW43	9493
5	86	2017-02-27 7:34	27.413431; -26.4	13	Jacob	RWN	RW10	293972
6	87	2017-02-27 7:34	27.41337; -26.41	13	Jacob	RWN	RW9	1281288
7	88	2017-02-27 7:37	27.415644; -26.4	13	Jacob	RWN	RW131	43801
8	89	2017-02-27 7:41	27.431538; -26.4	13	Jacob	RWS	RW36	23795
9	90	2017-02-27 7:41	27.431538; -26.4	13	Jacob	RWN	RW37	66633
10	91	2017-02-27 7:43	27.430868; -26.4	13	Jacob	RWN	RW1	88830
11	92	2017-02-27 7:52	27.423151; -26.4	13	Jacob	RWS	RW22	53328
12	93	2017-02-27 7:52	27.42315; -26.42	13	Jacob	MW	MW13	43358
13	94	2017-02-27 7:54	27.425812; -26.4	13	Jacob	MW	MW47	2716
14	95	2017-02-27 7:55	27.426412; -26.4	13	Jacob	RWS	RW55	4502
15	96	2017-02-27 7:57	27.428082; -26.4	13	Jacob	MF	RW93 MF	193259
16	97	2017-02-27 8:10	27.429188; -26.4	13	Jacob	RWS	RW56	46944

Figure 6.8: *Consolidated data in exported file*

6.2.5 Contribution discussion

In this case the developed system was successfully implemented to address routine data collection tasks on two industrial facilities. This shows that the developed system can be adapted to conform to multiple client needs. Furthermore, useful structures developed for a specific application can be re-purposed to address similar needs elsewhere.

Automated functions such as mode and item detection based on barcodes improved the user experience and increased accuracy. Real-time test results further assist users to enter valid data. Table 6.1 provides an overview of the elements that contribute to the novel system at the hand of examples presented in this case.

Table 6.1: *Case 1 contributing elements*

Contributing element	Case example
Data verification and archiving structure	Collected data is stored in the centralised database and is used to present data to users while safeguarding copies for auditing purposes.
Configuration and version control structure	Configurations are managed from the web-interface. Users and data collection structures can therefore be updated and transferred to field devices at any time. Revert option and previous status reviews can be performed by using this structure.
Calculation and data validation structure	Calculation and data validation tests are used extensively to compare readings with historic readings associated with the same meter. The system therefore provides immediate notifications of anomalies and enables the user to perform corrective action while still at the meter location.
Task management structure	Task management options are used to generate task lists if the normal user is not able to perform routine readings. Team collaboration and immediate log synchronisation among devices allows users to generate a work lists generally performed by other users when assisting them.
System restriction and user support structure	Account based login is used to manage user access. Only users with administrator rights have access to manage menus. Furthermore, certain users perform limited tasks and therefore only have access to applicable mode options. Barcode tags assist users to select correct modes and meters.
Data processing and integration structure	When users upload logs the logs are synchronised with other registered devices. These values can be used by the other devices to view historic logs and generate tasks based on data collected by other users while offline.

6.3 Case study 2: Service network maintenance

6.3.1 Background

The mining industry relies on services that include compressed air and chilled water for many applications. Many South African mines are mature which have led to mining at extremely deep levels (Manzi, 2014). At these levels rock temperatures can reach up to 65 °C, with working conditions that are equally punitive on workers and equipment.

Special service networks have therefore been developed to enable operations. Chilled water and compressed air are two examples of widely used systems. However, the provision of these services are expensive and must therefore be used optimally. In a study of compressed air systems, Van Tonder (2011) reported that compressed air generation contributes to between 20% and 50% of a mine's electricity consumption.

6.3.2 Needs

Large energy efficiency improvements can be obtained by reducing wastages. ESCO services therefore include system audits on client premises, during which ESCO personnel identify inefficiencies, leaks and possible improvements. These findings need to be recorded accurately and processed in order to produce a system status report. Potential saving opportunities or maintenance requirements can be identified and prioritised, based on findings documented in these reports.

The developed system offers extensive off-line support including calculations and data review options. The calculations include real-time estimations of air leak cost implications. The results give users an indication of cost implications related to identified issues and assist with task prioritising. Accurate data is required to perform calculations and enable detailed reporting. To enable calculations and effective reporting the following data must be collected:

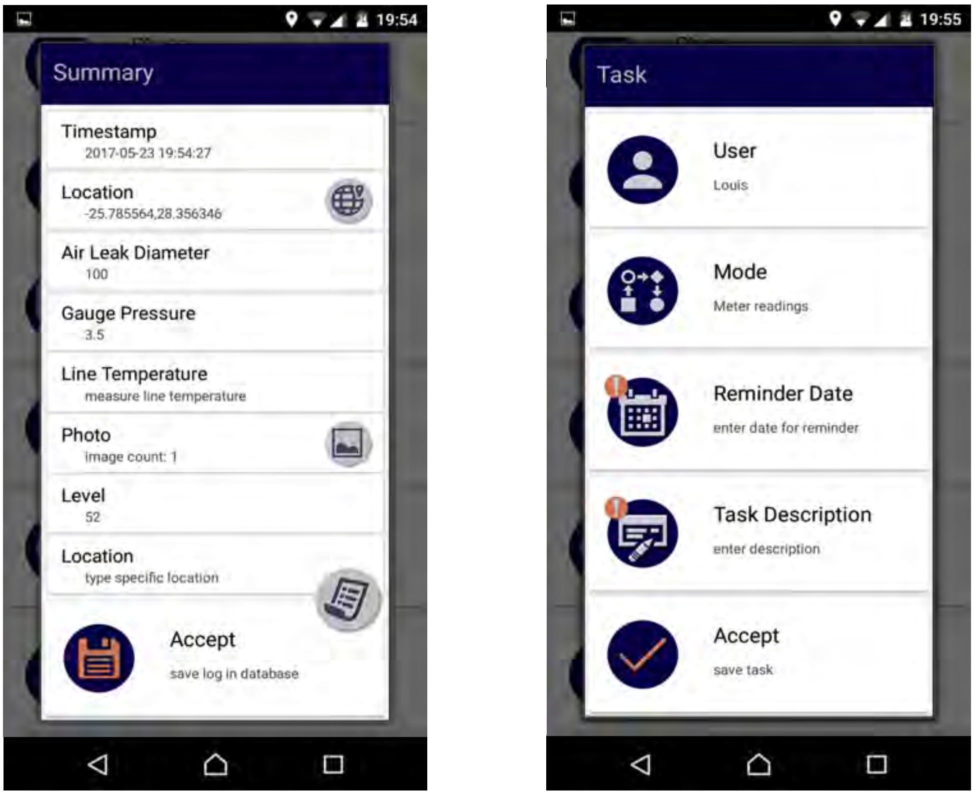
- User identification
- Location identification
- Pipe contents
- Supply pressure
- Pipe diameter
- Leak size
- Leak cause
- Leak description

6.3.3 Solution implementation

The generic platform offered by the developed system allowed ESCO personnel to configure client specific maintenance questionnaires. In three separate cases the developed system was used by ESCO personnel to conduct investigations on mining sites. The first two cases were performed underground and investigated chilled water system leaks and air leaks respectively. The other investigation utilised the system to conduct an air leak investigation on surface level.

In all three cases the configuration process was completed using the web application. Configurations such as service network maintenance are configured as event data collection modes. Data entries therefore do not reference previous values when performing data collection tasks, perform tests or create task entries. By selecting the non-recurring mode type the system restricts users and allows only relevant actions.

Task management related to non-recurring data collection modes presents users with specific options. After data collection, when the log summary is displayed, the user is permitted to create a new follow up task. The grey bullet shown in Figure 6.9(a) allows this action and is only displayed on log summaries related to non-recurring modes. Figure 6.9(b) shows the task detail interface where users can specify dates and other information regarding the follow up investigation. Tasks are automatically closed when follow up logs are created.

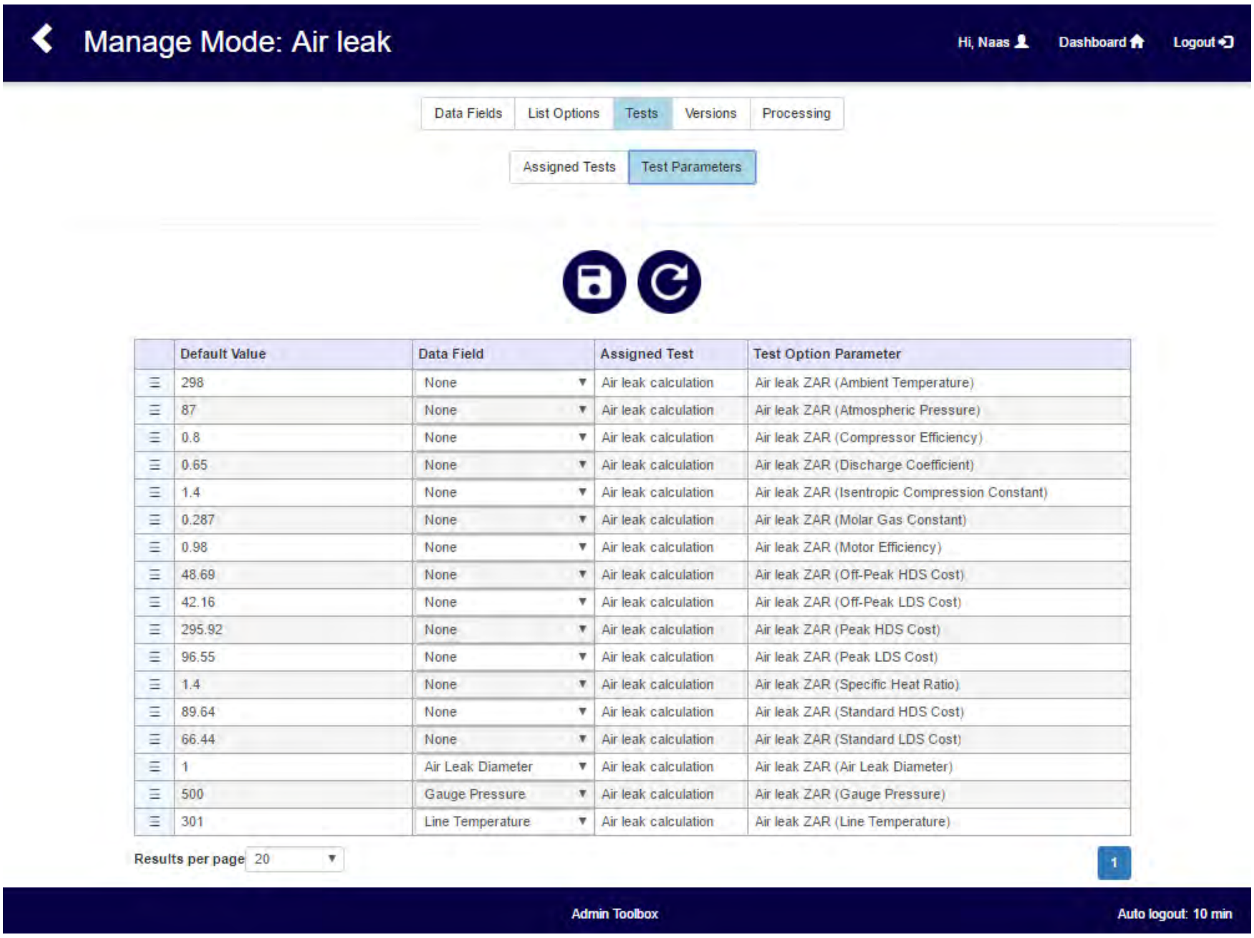


(a) (b)

Figure 6.9: *Non-recurring task generation interface*

The summary also offers customisable aspects. The system supports two test result options, results can be associated with a single data field, and alternatively test results can be displayed in isolation. The associated option works well in cases where single data fields are considered. When multiple data fields are used as parameters a free standing result provides a more clear result.

In one of the cases a compressed air leak cost estimation calculation was implemented. The formula considers 17 parameters. The configuration interface used to specify these parameters are show in Figure 6.10. Default values can be specified for each parameter. Furthermore data fields can be assigned to any of the parameters. The default values are used when the calculations are performed in the event where no data field is specified or the data field is empty.



	Default Value	Data Field	Assigned Test	Test Option Parameter
☰	298	None	Air leak calculation	Air leak ZAR (Ambient Temperature)
☰	87	None	Air leak calculation	Air leak ZAR (Atmospheric Pressure)
☰	0.8	None	Air leak calculation	Air leak ZAR (Compressor Efficiency)
☰	0.65	None	Air leak calculation	Air leak ZAR (Discharge Coefficient)
☰	1.4	None	Air leak calculation	Air leak ZAR (Isentropic Compression Constant)
☰	0.287	None	Air leak calculation	Air leak ZAR (Molar Gas Constant)
☰	0.98	None	Air leak calculation	Air leak ZAR (Motor Efficiency)
☰	48.69	None	Air leak calculation	Air leak ZAR (Off-Peak HDS Cost)
☰	42.16	None	Air leak calculation	Air leak ZAR (Off-Peak LDS Cost)
☰	295.92	None	Air leak calculation	Air leak ZAR (Peak HDS Cost)
☰	96.55	None	Air leak calculation	Air leak ZAR (Peak LDS Cost)
☰	1.4	None	Air leak calculation	Air leak ZAR (Specific Heat Ratio)
☰	89.64	None	Air leak calculation	Air leak ZAR (Standard HDS Cost)
☰	66.44	None	Air leak calculation	Air leak ZAR (Standard LDS Cost)
☰	1	Air Leak Diameter	Air leak calculation	Air leak ZAR (Air Leak Diameter)
☰	500	Gauge Pressure	Air leak calculation	Air leak ZAR (Gauge Pressure)
☰	301	Line Temperature	Air leak calculation	Air leak ZAR (Line Temperature)

Figure 6.10: *Test parameter configuration*

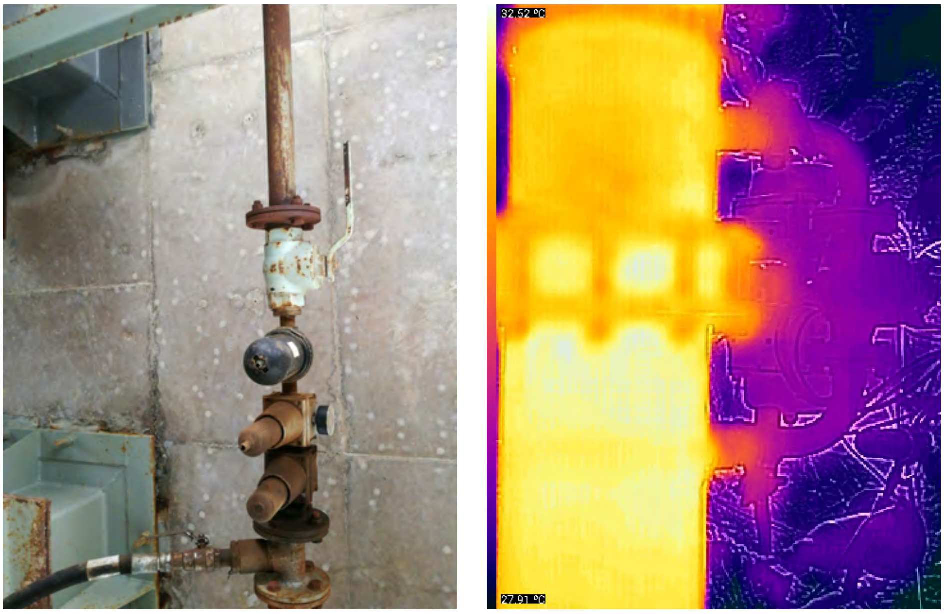
6.3.4 Results

Leaks in any of these systems have a major impact on system performance and induce significant cost implications. The system allowed the users to collect data on a single platform in harsh conditions, where paper based notes would not have been sufficient. Large electrical compressor systems, pumps and refrigeration systems can be used more efficiently if leaks are repaired. By reducing wastages, these systems can be optimised, resulting in reduced energy consumption and decreased electricity expenses.

Figure 6.11 and 6.12 show examples of leaks reported, using the system. Figure 6.12 shows an example of an infrared photo created by the system. Although other applications support multiple input types, none of the systems optimised for the industrial sector utilised this feature. This is partly because thermal image integration and the integration with mobile devices are still limited. Thermal imaging offers maintenance staff a powerful tool and the developed system allows users to utilise this functionality along with other features.

(a) (b)

Figure 6.11: *Examples of reported water leaks*

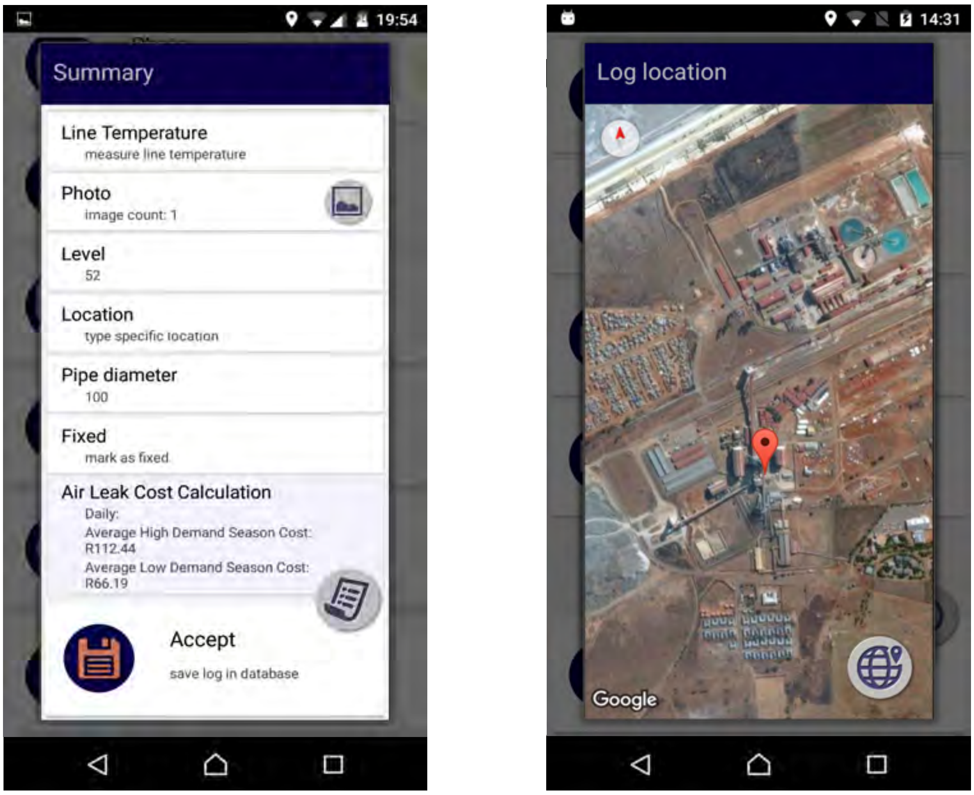


(a) (b)

Figure 6.12: *Examples of reported air leaks*

Once all the data fields have been completed, users can proceed to the summary interface. The summary interface presents users with a summary of collected data along with test results and data that were collected in the background. The compressed air leak cost calculations were performed and displayed as a component of the customisable summary. Figure 6.13(a) shows a summary interface that features the calculation results. Calculated values are shown for both summer and winter tariffs.

The system allowed the users to capture advanced data including GPS coordinates and thermal images that were not previously possible. Figure 6.13(b) shows the map interface that users can use to see GPS locations associated with logs. The buttons allows users to switch between satellite images and other standard map views.



(a) (b)

Figure 6.13: *Customisable summary results*

All the required data was collected using the mobile application and synchronised using the central system. This enabled users to download and view the data on the web-interface without having to manually consolidate or retype data. The developed system allowed the users to perform the complete range of data collection tasks on a single device that was not previously possible.

Multiple audits were of active areas were performed at various time intervals. The collected leak data was used to create maintenance reports. These reports provide leak details, evidence and indicate the severity. Maintenance staff can prioritise tasks based on this information. These reports also serve as a tracking mechanism to ensure that items identified in earlier audits are addressed.

6.3.5 Contribution discussion

In this case the developed system was used by ESCO staff to perform a range of data collection exercises. This illustrates the application's ability to conform to a wide range of requirements and allow the collection of a wide range of variables. Table 6.2 provides an overview of the elements that contribute to the novel system at the hand of examples presented in this case.

Table 6.2: *Case 2 contributing elements*

Contributing element	Case example
Data verification and archiving structure	Collected logs along with proof documentation including photos are stored on the system and can be used to maintenance reports. Log entries can be reviewed and updated to provide follow-up information. Both log entries are stored and can be traced during audit operations.
Configuration and version control structure	Configuration can be updated to add or remove data set entries. Historic log entries reference the active configuration number an can be used to verify the log against possible options at the time of creation.
Calculation and data validation structure	Special calculations were added to estimate the Rand value associated with air leaks. Various parameters can be selected form the data fields to improve calculation accuracy. The results are displayed
Task management structure	Follow-up tasks can be used to remind users to inspect recorded entries after a time period has elapsed. The user must create a follow-up log entry, that contains updated details and support documentation, to close the task.
System restriction and user support structure	Account based user access permits to see only available menu options and modes. Various visual support elements are provided by the application including test results and task notifications, which is used to assist the user to perform appropriate actions.
Data processing and integration structure	The data processing and integration structure is used to create a consolidated record of collected data. Maintenance reports can be created by exporting data from the comprehensive list. Furthermore, log entries are shared among linked devices and allow teams to follow-up on work performed by supporting teams.

6.4 Case study 3: Water utility network maintenance

6.4.1 Background

The water utility sector in South Africa is placed under various pressures. These pressures include restricted water supply, increasing electricity expenses and ageing infrastructure components which are prone to failure. Maintenance efforts are therefore required to improve operational efficiency and reduce wastage of limited water resources.

In a press statement, the Department of Water Affairs (2013) announced that a research study revealed that 36.7% of water delivered to municipalities are lost. Furthermore, pipe leakages account for 25.4% of the lost water. McKenzie et al. (2013) estimates a nominal production cost of R4.50 per Kl of water supplied. This relates to annual water loss to the value of R7.2 billion.

The water utility regarded in this case study relies on a pipeline infrastructure with a combined length in excess of 3600 km (Khan, 2015). The majority of these pipelines are underground and are subject to corrosion and other factors that decrease life expectancy of the pipelines.

According to Baird (2011), buried pipelines have a typical lifespan of 70 years. Khan (2015) reported that, most of the considered network's pipes were installed more than 50 years ago. The infrastructure can therefore be regarded as mature, and present an increased risk of failure. However, due to the scale of the network, it is impractical to replace extensive pipe sections purely based on age. It is therefore more important to identify high risk sections and implement preventative maintenance measures.

6.4.2 Needs

Two powerful systems were at the disposal of the client. However, the full capability of these systems was not utilised. The first system is used to manage maintenance tasks, while the second system has the capability of managing geographic information. Staff members of the water utility noted that these systems are not utilised to their full capacity. It was further noted that maintenance tasks can be executed with greater effectiveness if complete data sets with GPS coordinates are available when work orders are created.

The water utility therefore required a mobile data collection system. The goal of the system is to empower district supervisors to create accurate log entries that are consolidated with existing systems. In the long term collected data will be used as part of a maintenance plan to enable preventative maintenance measures.

6.4.3 Solution implementation

The developed system was implemented as a maintenance data collection system. The water utility acquired 26 smartphones and distributed it to district supervisors. These supervisors use these devices to capture data and send the captured data to the maintenance centre. Recorded data is used to create work orders and to analyse maintenance patterns to detect possible system weaknesses.

A fixed data set was identified by maintenance representatives of the water utility. The developed system was configured in alignment with this data field. The data set defined by the client consists of the following:

- User identification
- Site identification
- Pipeline name
- Account number
- Supervisor details
- GPS coordinates
- Time stamp
- Task priority
- Geographic description
- Failure details
- Work description

The developed system is used to capture and consolidate recorded data. When a new data entry is uploaded, the system translates the entry to the agreed upon format and sends the data via e-mail to a designated recipient. The client's systems are then used to process the email message, open work orders and distribute maintenance related information among the relevant systems.

6.4.4 Results

Khan (2015) stated that water loss figures between 4% and 5% were reported. This loss rate equates to a loss of 210 Ml of treated water on a daily basis, which in turn has a immense impact on environmental, technical, social and financial factors. The value of water lost on a daily basis can therefore be estimated at R945 000 per day, based on the R4.50 per Kl estimation provided by McKenzie et al. (2013).

Two tables were obtained from McKenzie and Lambert (2002). Table 6.3 shows basic information related to reported and unreported leaks. Table 6.4 provides information on the duration of reported bursts. The client in this case is a large water utility. A 'Transmission main' pipe, with a leakage rate of 30 Kl per hour is therefore considered. According to the time estimation in Table 6.3, total duration of such a leak will be 24 hours. A single leak will therefore relate to a loss of 720 Kl of water at a cost of R3 240.

Further perspective can be provided by considering the lost water. McKenzie et al. (2013) states that the average amount of water consumed per capita is 273 l. The leak considered in the previous paragraph indicated a water loss of 720 Kl. Water lost in that single leak could therefore have satisfied the daily water needs of 2637 people. The social and environmental effects of water loss is therefore far greater than immediate financial losses.

Table 6.3: *Basic pipe burst information*

Details	Reported bursts		Unreported Bursts	
	Frequency	Leakage rate (m^3/h)	Frequency	Leakage rate (m^3/h)
Transmission mains	0.030 /km/yr	30.0	0.00 /km/yr	12.0
Distribution mains	0.150 /km/yr	12.0	0.008 /km/yr	6.0
Connections	2.5 /1 000 conn/yr	1.6	0.825 /1 000 conn/yr	1.6
Service pipes	2.5 /1 000 conn/yr	1.6	0.825 /1 000 conn/yr	1.6

Table 6.4: *Duration of reported bursts*

Details	Duration of reported bursts (days)		
	Awareness and location	Repair	Total
Transmission mains	0.5	0.5	1.0
Distribution mains	1.0	0.5	1.5
Connections	5.0	6.0	11.0
Service pipes	5.0	6.0	11.0

The developed system plays a crucial role in developing a maintenance plan that will lead to less corrective maintenance. Furthermore this will enable the utility to provide a stable water supply. To date the system has been in use for more than a year and was used to create more than 200 event-type log entries. Figures 6.14(a) and (b) provide an indication towards work and conditions where the system is used.

(a) (b)

Figure 6.14: *Water network implementation*

Entries are created and uploaded by district representatives with mobile devices. These logs are converted by the central system and sent to client systems for further processing. The converted format is an e-mail message containing the data set defined previously, along with image attachments. The client systems receive the messages and extract the data to create work orders and perform additional processing tasks.

6.4.5 Contribution discussion

The developed system plays a crucial role in developing a maintenance plan that will be used to provide stable water supply to many consumers. The system is used to gather crucial maintenance information used to perform planned maintenance. Table 6.5 provides an overview of the elements that contribute to the novel system at the hand of examples presented in this case.

Table 6.5: *Case 3 contributing elements*

Contributing element	Case example
Data verification and archiving structure	Support data including timestamps, user information and GPS coordinates are managed in the application background.
Configuration and version control structure	The generic structure of the developed system allowed users to construct a custom data set and link appropriate ingress components such as the camera or list options.
Calculation and data validation structure	Not used
Task management structure	Not used
System restriction and user support structure	Users have password restricted accounts and can therefore only access the system if they are registered. User guidance is provided by on-screen text and form completion enforcement.
Data processing and integration structure	Special processing is performed by the system to convert data to a format that can be processed by the client system. The reformatted data is sent to the client system using e-mail messages.

6.5 Case study 4: Environmental data collection

6.5.1 Background

Environmental data was neglected in past decades, but industries have recently been placed under pressure to reduce their environmental impact. The mining industry in particular is placed under pressure to conform to environmental and reporting standards. The developed application was implemented to address two environmental issues associated with the mining industry.

6.5.2 Needs

During environmental audits mining companies are required to provide proof of reported values. Multiple items that influence the environment are considered, including water, electricity, fuels and explosives. However, metering equipment is not installed in non-critical operations. In other cases such as stockpiles automated metering is simply not possible. The cost effective solution is to collect this data manually. Manual data collection subjects data to numerous interactions with personnel and is thus not suitable for auditing purposes.

Many industrial organisations rely on manual data collection to conserve record of multiple environmental elements. Human interaction with data reduces data confidence. Collected values must therefore be substantiated with support data such as GPS coordinates, user identification and photographs. Manual systems do not allow this type of data collection without human interaction with collected data. The developed system was therefore used as an alternative method to gather traceable environmental data.

6.5.3 Solution implementation

The developed system allows configuration of specific data sets without having to adapt the application and was could therefore be adapted to address a wide range of environmental data collection needs. In the first case, the system is implemented to capture and maintain a record of meter readings. Meter readings are used to calculate actual consumption figures that are used for environmental reporting.

The developed system was therefore implemented and used as a managed system to gather auditable data. Meter readings, including groundwater, potable water and electricity were recorded similar to water meter readings that were discussed in Case study 1. Meter readings are recorded monthly, using the developed system. The system allows auditors to access a single system that shows consolidated values and proof documentation.

Figure 6.15 shows how meters are barcoded for easy identification. These codes are linked to equipment or meters during the configuration process. During investigations users will utilise the mobile application to scan these codes. The system will automatically select the appropriate mode and offer the user the choice in the event where multiple options are found. Once a mode has been selected the relevant data set is loaded. The identifying data field and associated fields are pre-populated where details are available.

(a) (b)

Figure 6.15: *Meters being barcoded*

In the second case the developed system was configured to import environmental data. These values are obtained from delivery notes. Before the system was used these values were loosely documented and no formal document structure was in place to store substantiating evidence. The developed system was structured to import key values and save photographic evidence which is made available for audit purposes using the centralised platform.

Another environmental concern in the mining industry is polychlorinated biphenyl (PCB) audits. PCBs were commonly used as dielectric fluids and coolant in electrical equipment such as transformers. PCBs were later found to be toxic and legislation has been adapted to remove these substances from circulation. Transformers and other equipment must therefore be subjected to audit processes to ensure alignment with legislative standards.

Equipment audits are therefore executed by mining personnel to ensure that equipment is in good order and conforms with environmental and safety standards. The developed system was therefore used to construct questionnaires similar to forms used by inspection personnel. The developed system handles this as a status tracking operation and notifies users if audits are out of date. The captured data is suitable for audit purposes and contain relevant proof documentation, such as photographic evidence and GPS coordinates.

6.5.4 Results

Environmental data collected using the system was consolidated using the central server. Integration with the web based energy management system allowed users to access and view data. Specialised interfaces were created to display results in a useful manner. The collected data was integrated with supporting data from a large mining group in South Africa. The ESCO assisted the mining group to collect auditable data for the annual environmental audit.

Meter data was collected using the system as discussed in Case 1. This data is not only displayed as loose standing values, but form part of GRI report values. Both electricity and water meter consumption values are reported. Actual consumed values are calculated as the total billed amount excluding third party consumption. Third party totals are therefore calculated using the values collected by the system and are subtracted from the billed amounts. Figure 6.16 shows an example of the interface used to report on consumed resources.

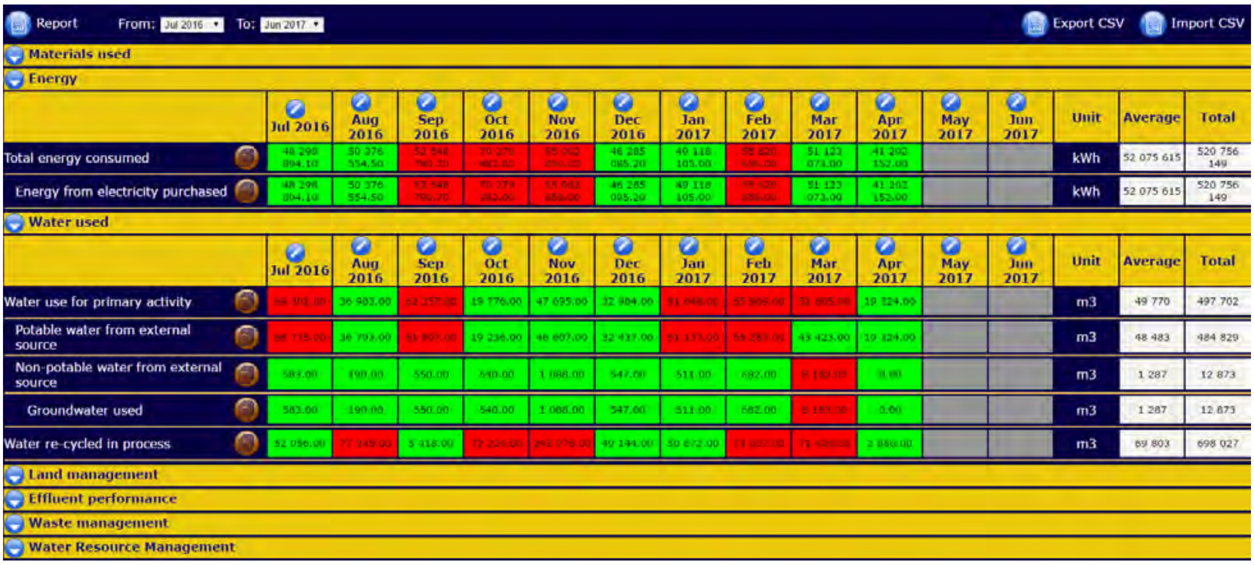


Figure 6.16: *GRI report interface*

Multiple items are considered as part of the environmental audit. Certain consumables such as explosives are difficult to track due to central stock distribution. Formal documentation structures were lacking in this area. Before the developed system was implemented, the mine representatives sent ESCO personnel photographs of delivery notes. The developed system therefore enabled mine representatives to capture data and send it to the ESCO.

The received data was processed and integrated with other client data. After integration with the internal reporting system this data was made available on the web-based interface. This provides a formal structure to collect and store a full history of data samples. Client representatives or auditors can access the collected data at any time. Figure 6.17 shows a detailed view of a specific delivery note that was imported using the developed system.

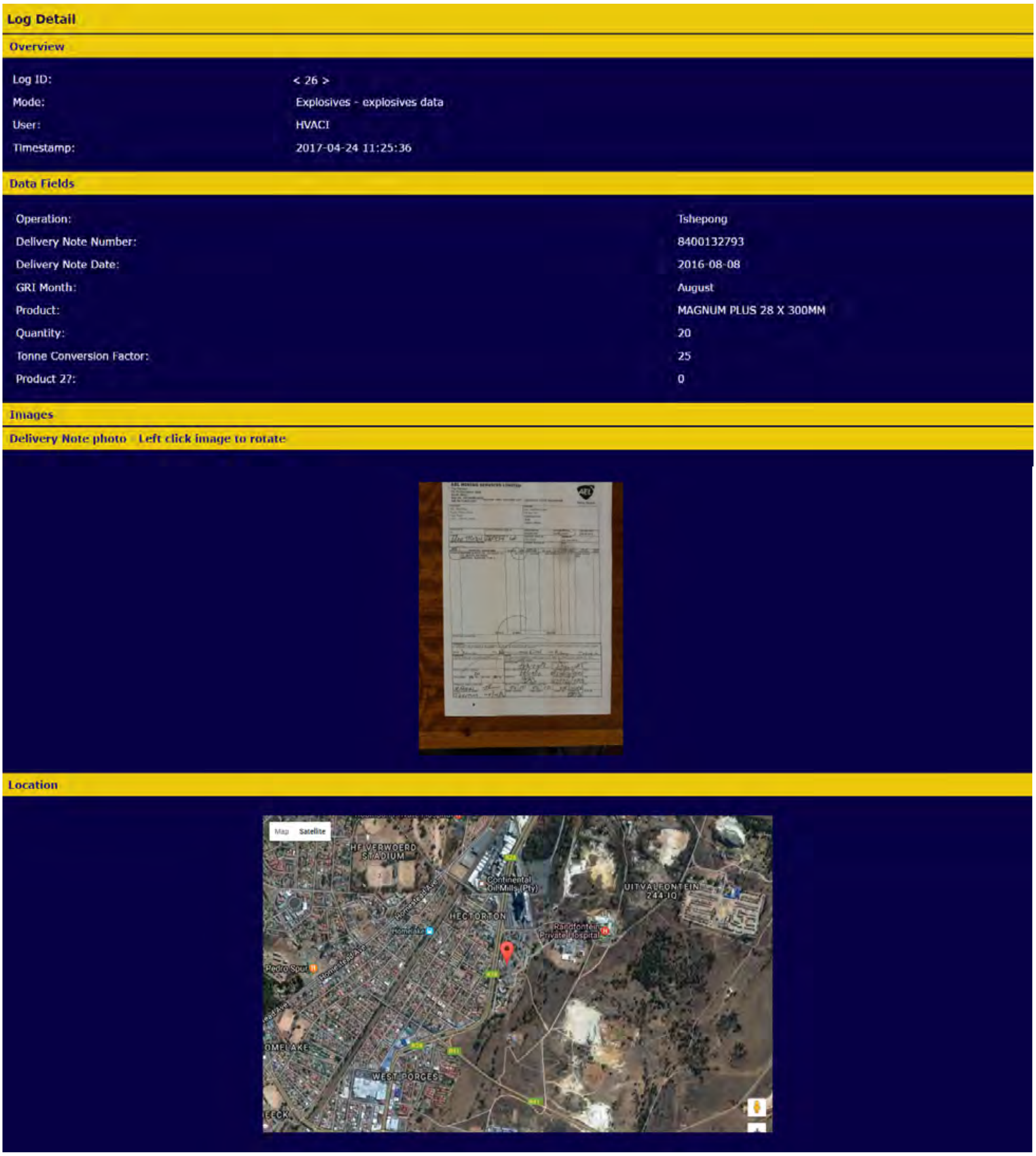
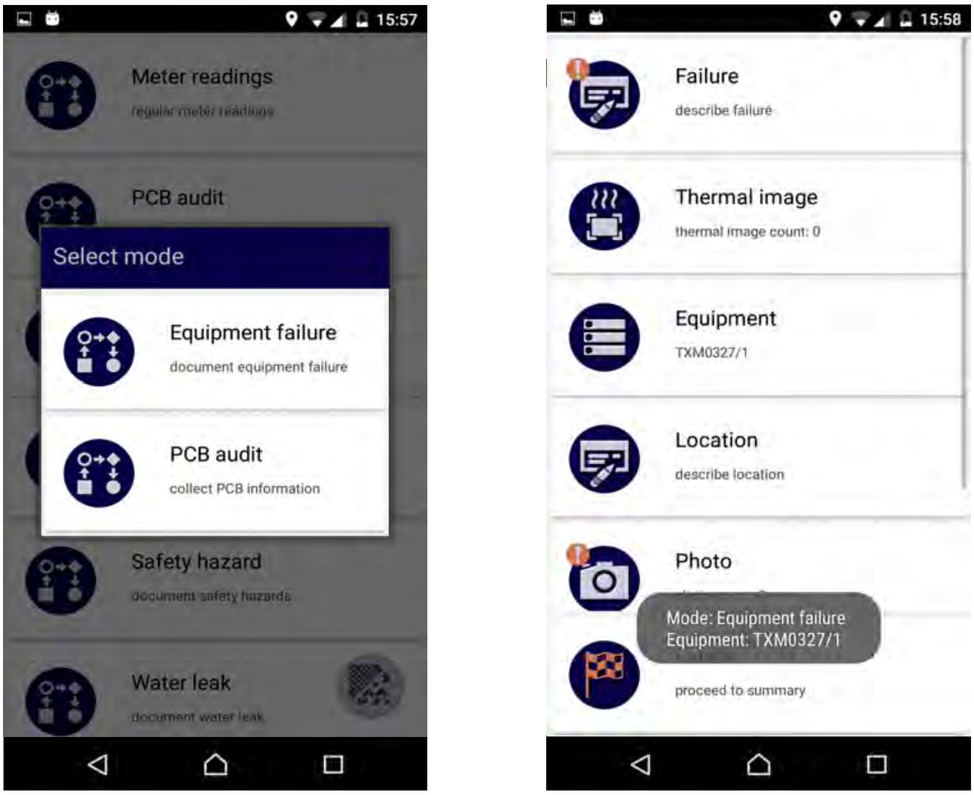


Figure 6.17: *Imported delivery note*

Various configurations were prepared to assist mining staff with internal equipment audits. The general audit concept was consistent throughout, but the specific questions were tailored according to each application. Items were registered and marked with barcode tags. During the audit process, the user scans the barcode using the mobile application.

If the code is registered, the application detects possible modes associated with the identified equipment and displays the list to the user, as shown in Figure 6.18(a). When the user selects the appropriate mode, the application loads the appropriate data set and autocompletes known values. The user is then tasked with completing the remaining item before the log can be saved. Figure 6.18(b) shows the loaded data set and an indication of the identified item, which can also be seen in the completed data field.



(a) (b)

Figure 6.18: *Mode selection and automatic form completion*

The interface shown in Figure 6.19 shows an example of equipment audits results. To achieve this, data collected using the mobile application is uploaded to the central server. The internal reporting system connects to the central server and extracts collected data. The reporting system then uses the returned data to build custom reports. The interface shown in the figure presents consolidated averages in the top table and provides status updates of registered equipment in the second table.

Figure 6.19: *Equipment audit results*

6.5.5 Contribution discussion

This case illustrated that the system can be used to address environmental data collection needs. Water readings and environmental item audits were used to show that the system can be used for such purposes. Table 6.6 provides an overview of the elements that contribute to the novel system at the hand of examples presented in this case.

Table 6.6: *Case 4 contributing elements*

Contributing element	Case example
Data verification and archiving structure	The data verification and archiving structure is used to store backup information that can be used as proof documentation for audits.
Configuration and version control structure	The configuration and version control structure is used to create and maintain a record of configurations. The configuration is saved along with the data entry to improve data traceability.
Calculation and data validation structure	Calculation and validation tests are implemented on the device to verify that the readings fall within an acceptable range. GPS tests can be used to verify that logs were taken at the right location.
Task management structure	Routine meter readings can be managed using routine task generation on the device. Alternatively administrators can assign users to investigate specific events and collect support data.
System restriction and user support structure	Only linked users and devices can access and edit group data. This improves data security and reduces false data entry.
Data processing and integration structure	Collected data is consolidated using the central management system. The consolidated data along with proof documentation is available on the support systems and can be used to access data for reporting and auditing purposes.

6.6 Case study 5: Energy awareness

6.6.1 Background

South Africa's steel-manufacturing industry is under pressure due to a global oversupply of steel products and associated low international prices (Zeelie et al., 2015). Additional pressure is caused by increasing production costs, which is largely the result of escalating electricity prices (Deloitte, 2012). The steel industry must therefore reduce operating costs to stay competitive. A reduction in energy expenses will provide the needed relief to keep the industry profitable.

In this case a large steel production works in South Africa is considered. The client group signed a service agreement with a ESCO. The goal of the agreement is to reduce capital expenditure by utilising energy more efficiently. Energy interventions are used to manage energy consumption figures. Another project is energy awareness which aims to create a culture of zero waste on the works. The system developed in this study was chosen as the mechanism to drive the energy awareness campaign.

6.6.2 Needs

The aim of the energy awareness system is to gather energy related data and distribute it among high ranking staff to accelerate optimisation action. The steel works in question consist of 9 sections, namely Bar mill, Billet mill, Blast furnace, Boilers, Coke plant, Medium mill, Rod mill, Sinter plant and Steel plant.

Energy alerts are used to log any leaks-, misuse-, or waste of resources, general alerts and safety alerts. The system had to provide generic structure that allows multiple users to create log entries. The system therefore needs to enable generic data collection across a range of applications within the industry.

User access is restricted to applicable sections. Logs can therefore be created for sections which the user has access to. When a log is synchronised with the central system two actions are required. First, the log is stored for archiving and follow-up purposes and secondly the log is reformatted and distributed among applicable users to promote awareness.

6.6.3 Solution implementation

The developed system was implemented as a measure to increase system efficiency and improve energy awareness. Two large contributing elements are managed by the system, namely leak repairs and wasteful use identification. Managing these elements will improve system efficiency by reducing wastage and promote a culture of energy awareness among employees. Application modes were created based on sections within the works and linked to applicable users.

Each mode consisted of the same questionnaire and was used to collect data on site. After data has been collected, it is uploaded to the central server. The received data is processed by the server and stored in the group database. Updated notifications are broadcasted to linked devices to notify them of the available updates. Lastly, custom processing is performed. In this case the linked custom process is an immediate rule-based e-mail notification.

Each mode is linked to selected processing options. If the e-mail notification option is selected, a list of possible e-mail alerts is loaded. The system iterates through the possible e-mail alerts and compares the received log with existing rules. If all the rules are successful, the system sends an e-mail notification to linked users. The e-mail message contains a custom-formatted CSV file and associated images as attachments as shown in Figure 6.20.

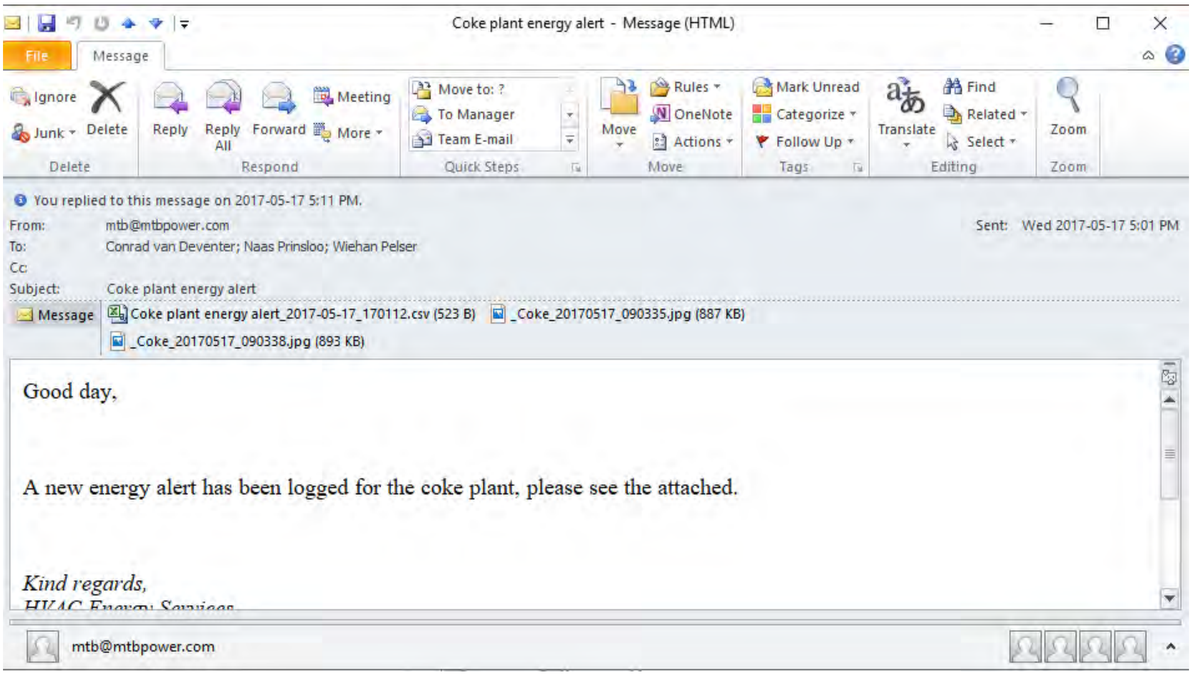


Figure 6.20: *Customisable email alert*

6.6.4 Results

A test case was implemented on the steel plant section. Users created log entries using the mobile application on test devices. The users were able to use the system without needing additional guidance from ESCO personnel. This provides proof that the system can be distributed to users with little training and that the system will provide additional guidance where needed.

Once logs were uploaded the storage and e-mail notification structures were used. The log data along with photographs were successfully stored on the central server and are available through generic interfaces. The e-mail structure excelled in practice and was used to successfully distribute customised e-mail messages to relevant recipients as soon as complete data entries ware received.

In two separate audits conducted by ESCO personnel, saving opportunities on the steel plant and coke plant were conducted. During the steel plant audit 20 saving opportunities were identified and reported using the developed system. Savings obtained by items identified in these audits will form part of larger saving initiatives. Expected yearly savings are R303 429 and R187 582, for energy efficient lighting and compressed air management respectively.

6.6.5 Contribution discussion

In this case the developed system was implemented as a tool to assist with maintenance and awareness on a steel production facility. The generic capabilities offered by the system allowed the system to conform to client needs. The test implementation was successful and the system is in the process of being extended to the remainder of the facility. Table 6.7 provides an overview of the elements that contribute to the novel system at the hand of examples presented in this case.

Table 6.7: *Case 5 contributing elements*

Contributing element	**Case example**
Data verification and archiving structure	Collected data is stored in a maintained data set and is used to track section and user performance.
Configuration and version control structure	Configuration updates are managed by the system. Historical system states are recorded and can be reinstated or updated at any time.
Calculation and data validation structure	A wide range of calculations can be used to assist with maintenance decisions. Two examples are detection of abnormally high noise levels and compressed air cost calculations.
Task management structure	Event data entries are created to mark items that require corrective action. Follow-up tasks can be used to remind users to perform additional inspections.
System restriction and user support structure	The organisation where this case is implemented has many separate divisions. The configuration enables separation of various business sections and only link applicable users to those divisions.
Data processing and integration structure	All collected data is consolidated on the central server and made available to users on demand. Special processing in the form of rule based e-mail notifications are distributed to specified personnel to create a culture of energy awareness.

6.7 Case study and system validation summary

The five case studies that were presented in this chapter show that the system was successfully implemented in the South African industrial sector. Clients used the system to perform a range of data collection and task management activities. The system provides powerful generic structures that allow it to conform to every client's needs without the need for software changes.

Components that contribute to system novelty interact in a unique manner to produce a specific outcome in each case. The components rely on the availability of one another to provide a comprehensive solution. These cases therefore serve as a validation of the developed system and prove that the developed system with all the contributing elements was needed to offer a complete solution.

Table 6.8 provides a visual evaluation of system functionality based on items discussed in each case. Items that were addressed by each case are marked with a '•'. The last column shows the that the system addresses all the required items and therefore offers a complete mobile data collection solution. The next chapter provides a detailed discussion of how the developed system addresses each element in the table.

Table 6.8: *Case study functionality evaluation*

Case studies		1) Meter readings	2) Service network maintenance	3) Water utility network maintenance	4) Environmental data colleciton	5) Energy awareness	Total
Data verification	Secure database on central platform	●	●	●	●	●	●
	Secure managed database	●	●	●	●	●	●
	Geo location capture	●	●	●	●	●	●
	Photograph with annotations		●			●	●
	Record system state with log	●	●	●	●	●	●
Configuration and version control structure	Automated configuration synchronisation	●	●	●	●	●	●
	Data structure versioning	●	●	●	●	●	●
	Auto update user configuration	●				●	●
	Licencing and group authorisation	●	●	●	●	●	●
Calculation and validation structure	Historic data access on device	●	●	●	●	●	●
	Customisable data validation tests	●	●				●
	Validate according to historic data	●					●
	Customisable summary	●	●		●	●	●
	Offline calculations	●	●				●
	Multiple variable calculations		●				●
Task management structure	Manual task assignment		●		●		●
	Intelligent offline task generation	●	●		●		●
	Task reminders		●		●		●
	Automatic task closing	●	●		●		●
	Multiple task types	●	●		●		●
System restriction and user support structure	Authorised user linking	●	●	●	●	●	●
	User access versioning	●				●	●
	Code scanning	●					●
	User guidance on input form	●	●	●	●	●	●
	Automated data set detection	●			●		●
	Review previous readings offline	●	●	●		●	●
Data processing and integration structure	Customisable report integration	●			●	●	●
	Data encryption	●	●	●	●	●	●
	External system integration			●			●
	Immediate rule based notifications			●		●	●

Chapter references

Baird, G. M. (2011). Money matters–the epidemic of corrosion: Part 1, Examining pipe life. *Journal of the American Water Works Association*, 103(12):14,16–17,19–21.

Deloitte (2012). The economic impact of electricity price increases on various sectors of the South African economy. page 108.

Department of Water Affairs (2013). DWA rolls out "no drop" assessment tool to manicipalities.

Khan, F. (2015). Capturing critical pipeline failure data for optimal maintenance management of a water supply network: a rand water proposition.

Manzi, M. (2014). 3D Seismic Imaging of the Ghost-Carbon Leader Reef of the World's Deepest Gold Mine - Mponeng Gold Mine, South Africa.

McKenzie, R. and Lambert, A. (2002). Economic model for leakage management for water suppliers in South Africa. *South African Water Research Commision.*

McKenzie, R., Siqalaba, Z. N., and Wegelin, W. A. (2013). The State of Non-Revenue Water in South Africa (2012). *The Water Wheel*, 12(1):15–18.

Park, J. (2015). Evaluating a mobile data-collection system for production information in SMEs. *Computers in Industry*, 68:53–64.

Van Tonder, A. J. M. (2011). Sustaining compressed air DSM project savings using an air leakage management system. *2011 Proceedings of the 8th Conference on the Industrial and Commercial Use of Energy*, (November):133–137.

Vecellio, E., Maley, M. W., Toouli, G., Georgiou, A., and Westbrook, J. (2015). Data quality associated with handwritten laboratory test requests: Classification and frequency of data-entry errors for outpatient serology tests. *Health Information Management Journal*, 44(3):7–12.

Zeelie, L. E., Breytenbach, W. J. J., and Marais, J. H. (2015). Investigating the possibility of a cost saving intervention on a blast furnace cold blast system. In *Proceedings of the 12th Conference on the Industrial and Commercial Use of Energy (ICUE)*, pages 30–35. Cape Peninsula University of Technology, Cape Town, South Africa.

7

Requirement alignment and novel components evaluation

This chapter serves as a verification study of the developed system. Functionality of the individual components therefore has to be verified. Further evaluations prove that the six contributing components combine to form a novel system. Lastly, the contributing components are used to verify that the developed system aligns with system objectives.

7.1 Introduction

In the preceding chapters the need for a mobile data collection system in the industrial sector was identified. The system was designed and developed in line with the set requirements. The developed system was implemented at a range of industrial sites in South Africa. These implementation cases were presented in the previous chapter and serve as a validation of the developed system.

In this chapter the system is analysed to prove alignment with requirements. The primary novel aspect of the element is that it forms a unique system by combining a range of contributing components into a single comprehensive system. The contributing components are therefore validated by assessing system functionality and its interaction with supporting components.

7.2 Requirement and system functionality evaluation

A new mobile data collection and management system was developed to address industrial data collection needs. Validation is intended to prove that the developed system aligns with requirements identified for mobile data collection and task management system (ISO (International Organization for Standardization), 2005).

System requirements were identified and presented in Table 7.1. This section considers each identified requirement. A discussion surrounding each element provides proof that the system contains elements that are used to address all the individual needs.

7.2.1 Data verification and archiving structure

Secure database on central platform

Each group has a private database on the central server. Only limited personnel have access to the server and can only access the server via cleared Internet Protocol (IP) addresses. When a new group is registered, a clean version of the database is prepared. The clean database contains blank tables, except for tables that contain fixed values, which are used to configure the device. The central system only allows linked devices with valid licences to access or change database content.

Table 7.1: *Comprehensive mobile data collection system addressed requirements*

Category	Item	Adressed
Data verification and archiving structure	Secure database on central platform	✓
	Secure managed database	✓
	Geo location capture	✓
	Photograph with annotations	✓
	Record system state with log	✓
Configuration and version control structure	Automated configuration synchronisation	✓
	Data structure versioning	✓
	Auto update user configuration	✓
	Licencing and group authorisation	✓
Calculation and validation structure	Historic data access on device	✓
	Customisable data validation tests	✓
	Validate according to historic data	✓
	Customisable summary	✓
	Offline calculations	✓
	Multiple variable calculations	✓
Task management structure	Manual task assignment	✓
	Intelligent offline task generation	✓
	Task reminders	✓
	Automatic task closing	✓
	Multiple task types	✓
System restriction and user support structure	Authorised user linking	✓
	User access versioning	✓
	Code scanning	✓
	User guidance on input form	✓
	Automated data set detection	✓
	Review previous readings offline	✓
Data processing and integration structure	Customisable report integration	✓
	Data encryption	✓
	External system integration	✓
	Immediate rule based notifications	✓

Secure managed database

System updates can be applied to the database stored on the central server. These changes affect options visible on the web interface. This allows the development team to make minor changes to the system without the need to publish software updates. These changes typically affect the fixed value tables and allow users to select additional options when configuring systems. This is particularly useful in cases where references to server operations are stored, such as processing and data transmission processes.

Geo location capture

To ensure full data traceability, each collected log contains fixed values along with the customised data set. Each log references the active user, time stamp, active mode version and GPS coordinate. The GPS coordinate serves as proof that the user is physically at the location where the task should take place. This reduces the possibility of creating false data entries without detection.

Photograph with annotations

Photographs serve as trace documentation. Photos can be used to capture a particular element or provide an overview of surroundings. Depending on the case, photos can be limited to a single photo or multiple items. Photos can be edited on the device. The edit option allows users to highlight items on the photo. Circling faulty items detected during and audit is one example. Photographs can also be used as a verification source to verify that entered values and actual values on devices, such as meters, match.

Record system state with log

Each log references the active user, time stamp, active mode version and GPS coordinate. The active system state refers to the active mode version used when the log was created. During the configuration process all changes are stored and the system state is recorded. The administrator must enter a change description when the configuration is published. This will enable administrators or auditors to track the system state and options that were available at the time the log entry was created.

7.2.2 Configuration and version control structure

Automated configuration synchronisation

The system handles synchronisation tasks without the need for user interaction. This ensures that remote systems are up-to-date and have the latest option sets available. Configuration versions are created and published from the web interface. When the administrator publishes a configuration version, a configuration update notification is broadcast to remote devices. These devices then pull the new data from the server in the background. Automatic update requests are also triggered when the application is started. This ensures that an update to the latest available version is attempted, even if the device did not receive the broadcast notification.

Data structure versioning

Two versioning structures are used, namely the configuration management structure and mode management structure. The configuration management structure stores references to updates that affect available Devices, Users, Modes and User-Mode-Links. The Mode management structure is used to define Mode details. These details include Data fields, Data field extensions, Data field relations, List options, Assigned tests and Test parameters. All changes to any of the data stored in these tables are logged according to versions. Administrators therefore have the ability to update options, review changes and revert to previous versions at any time.

Automatic user configuration updates

Changes made to configurations and mode details are performed on the web-based platform. Once these changes are published notifications are sent to linked devices. When a connection is possible the devices contact the central system and requests updates in the application background. Secondly, the mobile application checks for updates every time the application is started and downloads updates if it is available.

Licensing and group authorisation

When using the application for the first time, users must scan a licence in the form of a QR code. This QR code is generated and sent to the appropriate person using the management structure on the central control system. This licence code contains references that are used when the device registers with the server. Along with the registration request the device notifies the server what its FCM code is. This code is used to send broadcast notifications to appropriate devices.

7.2.3 Calculation and validation structure

Historical access to data on device

Devices associated with a particular configuration are permitted to download a copy of the database for off-line use. This data is used to provide users with reference values, and is used to perform actions such as task creation of calculations based on historic values. This database is arguably the most important part of the system, as it enables advanced off-line capabilities.

Customisable data validation tests

The developed system allows data validation tests to be linked, similar to the calculations discussed previously. Validation tests enable the system to check whether entered values conform to defined limits and tolerances. Validation tests are performed on the device during data collection. If a failure condition is detected, the system indicates the validation test with an exclamation mark and provides a failure description. This enables users to perform corrective action before faulty data is committed.

Validate according to historic data

Historic data can be used during calculations. Historic identifiers are defined as data field extensions and are typically unique items such as serial numbers or meter numbers. These historic identifiers are used to find previous data entries similar to the active data entry. Previous log entries can be used to perform historic calculations. Historic value calculations can be used to test conformity with historic averages, totals, incremental values and normalised incremental values.

Customisable summary

The Summary interface of the developed application can be customised to show data and calculations applicable to the user. Test feedback can be customised and has the ability to provide users with feedback on possible mistakes and corrective action, if used correctly.

Off-line calculations

Calculations are performed off-line. The historic database copy on the device enables devices to perform advanced calculations without the need to access sources stored on the internet. This enables the use of calculation options in remote locations where no data connection is available.

Multiple variable calculations

The database stores system configuration data and collected data. The System configuration tables contain references to calculation options linked to particular modes. Calculations can be performed using multiple data fields as inputs. The result can be displayed as an extension on a data field, or can be shown as an additional item. One example is the estimation of financial impact linked to an air leak with a certain set of parameters. The system allows the storage of default values. These default values can be used to define fixed values and can be replaced by values entered during data collection.

7.2.4 Task management structure

Manual task assignment

The developed system supports manual task assignment. Two of the developed three task types can be assigned to a specific user. Follow-up tasks serve as reminders for users to revisit items that were logged. Specific users can be assigned and receive notifications when the specified waiting period has passed. Managers have the option to direct assigned tasks at a specific user. The user will receive a notification and has to complete a specific entry to address the task.

intelligent off-line task generation

An intelligent task generation structure was developed to assist users with routine task management. Routine tasks such as meter readings and inspection rounds take place on fixed intervals. The system utilises the set interval parameter to establish a timeout period. When creating tasks, the system considers log entries created within the past three timeout periods. This enables the system to adapt to changes in user routines. Furthermore, the system considers data entries gathered within the last timeout period and does not create new tasks for these entries. Users can therefore generate task lists based on outstanding routine tasks.

Task reminders

Task reminders can be set for all follow-up and assigned tasks. The application will prompt the user to create a specific log if the specified time period has elapsed. If the task has already been performed, users can close the task by providing a task description. If tasks are closed prior to the reminder data, no alert will be triggered.

Automatic task closing

Tasks are linked to log entries. To close a task a user must create a log related to the specified mode. When numerous tasks exist for a specific mode, additional identifying attributes, such as serial numbers or meter numbers, are used as a reference key. Once a log with the appropriate parameters is created, the system will automatically close the log.

Multiple task types

Other systems that offer task management options were found. However, these systems provided assistance to perform a specific task. The generic capabilities provided by the developed application allow three individual data collection arrangements. These arrangements are used to perform different tasks at different intervals, and therefore multiple task types to support each mode type. Three different task types are therefore offered by the system to address all the data requirements.

7.2.5 System restriction and user support structure

Authorised user linking

The developed system utilises authorised user accounts to grant access to users and track which actions are performed by the users. User access rights are managed according to linked access levels. User access levels include full access, administrator access and general access. Each access level allows certain actions, which are managed by views.

User access is restricted to a particular group and configuration. Multiple data collection modes can be defined within configurations. Users declared within the configuration can be linked to one or many of the defined modes. During execution the system only permits access to linked modes.

User access versioning

Changes made to user configurations are stored in the versioning structure. Possible changes include the creation of new user accounts, updating account details, and linking users to particular modes. These changes are pushed to active devices when the system administrator commits changes. Furthermore, these changes are recorded in the versioning structure and can be recalled if the system needs to be restored to a prior state.

Code scanning

The system utilises the device's camera to provide code scanning functionality. The Barcode scanner interface performs image processing actions to detect possible barcode or QR codes. These codes are used to detect defined items. In addition to item detection, the code scanning interface is used to process information stored in the licence QR code.

User guidance on input form

Further user guidance is provided by on-screen visual aids. Card items are used to construct the mobile application's interface. The displayed card type provides the first hint; content cards permit further action, while view cards only display information. Moreover, card items display primary text and secondary text to display important information. Images displayed on content cards provide a visual clue to what action will be performed by selecting the card. Lastly, exclamation icons indicate card items that require action or attention.

Automated data set detection

Barcodes and QR codes can be linked to identifying elements. These elements are stored as list options linked to an identifying data field in a particular mode. A code linked to a particular item can be used to define the item in multiple modes. When the code is scanned, the system finds all items linked to that code and offers the user the option to select the applicable mode. The item will automatically be selected in the subsequent menus. Only modes linked to the user will be presented. The application will automatically select the appropriate mode if the scanned code is associated with only a single mode.

Review previous readings offline

Previous readings are stored in the device's local database. These readings can be accessed and updated at any time. Routine tasks with defined lists, such as meter numbers or serial numbers, can use these numbers to identify previous readings. The data collection interface allows users to review previous data entries during the data collection process to provide additional guidance of expected data.

7.2.6 Data processing and integration structure

Custom notification integration

Data must be processed in order to extract value from the collection process. The developed system provides various processing options. One processing option is a rule-based notification e-mail structure. The structure is used to evaluate received data. If the received data matches rules defined in the configuration, e-mail messages are distributed to a specified address list. These e-mail messages are constructed according to a personalised template.

Data encryption

The system relies on communication classes that process outgoing and incoming information. These classes inherit functionality that enables the system to encrypt and decrypt data. Due to the possible sensitivity of collected data, all data and configuration data are encrypted during transmission.

External system integration

Communication between the central server and mobile devices rely on structured requests with JSON payloads. These JSON objects are processed by the receiving system. The data is always stored in the central database. Additional actions are performed based on linked functions. Typically, received data can be reformatted and transferred to external systems using e-mail messages or API requests.

Immediate rule based notifications

The developed system offers customisable data consolidation and processing options. When data is received, the system processes the JSON object and stores the received data in the central database. Linked devices are instantly notified of new data, which will prompt the devices to pull updated data from the server and allow other users to instantly verify data accuracy. An advanced e-mail notification structure was developed and allows administrators to construct rule-based notifications that are sent to specific recipients if all the specified conditions are met.

7.3 Novel contribution verification

The primary contribution of this study is the conceptualisation and development of a comprehensive mobile data collection and management system for industrial applications. A novel system was needed to address task management, data collection and verification needs. A system capable of providing the necessary structures was subsequently developed and implemented.

A novel solution was obtained by combining six components. These components provide underlying structures that are used by other components to perform advanced actions. Selected features offered by the components are unique in their own respect. This section provides a discussion of the developed components. Integration between components provides further verification that the combined system is required to adhere to system requirements.

Data verification and archiving structure

The primary purpose of the *Data verification and archiving structure* is to collect data that can be used to substantiate reported data. This is typically required when reported data has legal or financial implications. Proof documentation must therefore be collected and safeguarded. This data can be used to validate reported figures during audits.

A range of methods are used by the system to gather supporting documentation. Firstly, the *Configuration and version control structure* stores references to any configuration changes. This ensures that the system state of any log can be traced at any time. Along with the configuration identifier, every data entry is created with user identification, time stamp and GPS coordinates. In cases where log entries are updated or edited, a second log is created with a reference to the first log to preserve the first log's integrity.

Both the *Task management structure* and *Calculation and validation structure* use data stored in this structure to obtain historic data entries. During task creation, previous log entries are referenced for follow-up tasks and routine task generation. The *Calculation and validation structure* uses the historic data entries to calculate values based on previous entries for a specific item.

When synchronising log data between the mobile devices and the central server, the *Data processing and integration structure* is used. A private database on the central server is used to consolidate all the data entries for the specific group. The database is backed up on a regular basis. Additional storage space is used to store copies of photographs that are used to verify collected data. Values stored on the central system are accessed by support systems to generate reports.

The *Data verification and archiving structure* therefore forms a critical part of the combined system and provides all the other components with structured data. This data is fully traceable and can be used to perform a wide range of actions.

Configuration and version control structure

The system was developed as a generic tool that can conform to the needs of multiple industrial clients. The *Configuration and version control structure* is used to create references to configuration values. This allows the system to store client-specific structures. These structures define group configuration data and mode configuration data respectively.

Group configuration data stores data related to registered devices, users, modes and links between users and modes. The mode configuration structure stores mode-specific data and is used to define data fields, data field extensions, data field relations, list options, assigned tests and test parameters. These structures are managed using a version control structure. All changes are recorded for traceability purposes and can be used to revert the system to a previous state.

The mobile application uses these structures to adapt system behaviour based on the active user and therefore forms part of the *System restriction and user support structure*. As stated previously, the *Data verification and archiving structure* stores a reference to a mode version with every data entry. The *Calculation and data validation structure* uses values stored in this structure to execute relevant tests with linked parameters.

Lastly, the *Data processing and integration structure* uses values stored in this structure to handle received data. Links to additional processes are stored in the group database. Certain advanced processing options, such as instant e-mail notifications, rely on rules that consist of data fields and list options which are stored in this structure. Output files are also generated, based on selected data fields.

Calculation and data validation structure

The *Calculation and validation structure* is used to perform calculations and display the results on the mobile device. These calculations are specified by values stored in the *Configuration and version control structure*. The mobile application references values stored in the *Data verification and archiving structure* to perform calculations based on historic values.

Calculation options include various numeric tests, as well as location-based tests. Numeric tests are used to compare log data with other data. If the value does not fall within a specified range, the item is flagged and a failure message is displayed. These flags and failure messages form part of the *System restriction and user support structure*, as it provides both visual and textual feedback to users.

Special calculations using multiple data fields defined in the *Configuration and version control structure* are used to calculate results and display it on the mobile interface. One example of such a calculation is the estimation of Rand values associated with air leaks. During the investigation no other system was found that could perform on device calculations using multiple entered variables.

Task management structure

The task management structure is used to guide users to perform tasks. Three mode types were defined for the application: recurring, non-recurring and status tracking. To supplement these mode types, three task types were defined: recurring, follow-up and assigned tasks.

Follow-up tasks are used to manage maintenance items. Users receive prompt notifications on specified dates that request additional logs to close. Administrators have access to assign tasks associated with non-recurring and status tracking modes to registered users. The *System restriction and user support structure* is used to restrict access to administrators only.

Routine tasks are generated on the mobile device. The system uses the *Configuration and version control structure* to find a list of applicable modes and users. In addition to this, the system considers historic data stored in the *Data verification and archiving structure* to establish which data entries are outdated and require updates. A list of tasks is then generated based on the user, mode and historic data. No similar task generation function was found during the investigation.

System restriction and user support structure

The *System restriction and user support structure* is used to manage user access rights within the application. The *Configuration and version control structure* is used to store these rights. Devices are registered and linked to specific groups in order to access group data. User account privileges are specified and linked to accounts. Administrators are granted superior access to standard users.

Mode data is also stored in the *Configuration and version control structure*. Users can be linked to multiple modes, but are only able to access data related to accessible modes. The *Configuration and version control structure* stores references that control form logic operations such as data field visibility and read-only items. This is particularly useful for status tracking modes where only certain data elements must be updated.

The barcode scanning function is used to select list items stored in the *Configuration and version control structure*. When a code is scanned, the system identifies possible modes associated to that barcode and provides the user with a short list of options. If only a single mode is detected, the mode is chosen automatically by the system. When a registered barcode is scanned, the system will automatically select the scanned item.

Accurate selections are therefore promoted by using barcodes to identify items. Further extensions are provided by the *Calculation and data validation structure*. Calculated results are displayed on the mobile application's interface during data collection, and the user is notified if any odd data readings are detected. This helps the user to record accurate data. Additional flags are displayed on menu items where action is required, and is used to display items such as unsynchronised log entries.

Data processing and integration structure

The *Data processing and integration structure* enables communication between the central server and mobile devices. Updates related to the *Configuration and version control structure* are distributed using broadcast notifications, which prompt mobile devices to request data updates from the server.

Data recorded on mobile devices are uploaded to the central server via APIs offered by the *Data processing and integration structure*. When the data is received, the system stores the data in the central database according to the *Data verification and archiving structure*. In addition to this, data is synchronised with linked group devices to ensure updated data sets are available on all group devices. Data stored on the mobile devices are used by the *Calculation and data validation structure* and the *Task management structure* respectively.

Advanced processing and reporting options are made possible by allowing integration with reporting systems through APIs. The advanced e-mail notification structure is another unique offering that allows the system to distribute structured information based on settings stored in the *Configuration and version control structure.*

A single comprehensive mobile data collection system

A novel system was created by combining the discussed elements into a single comprehensive system. The individual components offer powerful functionality, but require support from the other components to reach its full potential. Other systems do not have similar structures that offer the complete set of components offered by the developed system and are thus not capable of all the actions that the developed system offers.

7.4 Requirement and novel component correlation

Objectives of the developed system were stated in Section 1.4. These objectives stated that a comprehensive system was required and must be capable of addressing multiple data collection and task management activities in the industrial sector. The objectives can be categorised as:

- Verifiable data sources,
- Human resources,
- Data quality,
- Maintenance and awareness, and,
- Integration.

The developed system consists of six contributing components that offer a generic mobile data collection and task management solution to a wide range of industrial users. The previous sections highlighted inter-component dependencies and illustrated that these components form a novel comprehensive solution.

Table 7.2 illustrates how each of the developed components contribute to the comprehensive solution. The table also serves as an indication that all the system objectives have been met by the comprehensive system developed in this study.

Table 7.2: *Correlation between novel components and system objectives*

	Verifiable data sources	Human resources	Data quality	Maintenance and awareness	Integration
Data verification and archiving structure	●		●		●
Configuration and version control structure	●	●	●		●
Calculation and data validation structure			●	●	
Task management structure		●	●	●	●
System restriction and user support structure		●	●		
Data processing and integration structure	●	●		●	●

7.5 System evaluation summary

Three evaluations were discussed in this chapter. System functionality was evaluated based on system requirements, as presented in Chapter 3. The second evaluation focussed on the novel contribution of the study. In the last evaluation, the system objectives were compared with developed system structures to prove that the developed system aligns with system objectives.

The system functionality evaluation provided descriptions of how the system addresses each of the requirements defined in Chapter 3. This proves that the system is capable of a unique range of functions that no other system found during the investigation is capable of.

The contribution evaluation provided proof that a novel comprehensive data collection system was created. The unique collection of contributing components allow internal links that enable advanced operations, not offered by other systems. Selected contributing elements featured specialised items that are unique in their own right.

The last section was used to prove that the developed system aligns with system objectives. Five objectives were defined in Section 1.4. These objectives were stacked against the contributing components offered by the developed system and showed that the integration of these components into a single comprehensive solution enabled the system to address all the system objectives.

Chapter references

ISO (International Organization for Standardization) (2005). International Standards ISO 9000 Fundamentals and vocabulary, Quality management systems fundamentals and vocabulary. Switzerland: International Organization for Standardization ISO, Central Secretariat. (ISO 9000:2005).

8

Conclusion and recommendations

This chapter provides a conclusion of the study. A review of forgoing chapters is provided and serves as a complete work summary. The final section of the document is used to provide recommendations for further study in this field.

8.1 Study summary

Global economic pressures during the past decade have had a lasting effect on industrial organisations. Industrial organisations in South Africa are therefore affected by various international pressures such as low commodity prices and reduced demand for resources. Other domestic factors, such as escalating electricity prices and wage increases, have caused serious profitably concerns in the industrial sector.

The study considered various large industries in South Africa, including gold mining, steel production and water utilities. Various factors that contribute to profitability constraints were considered, including expenses and funding opportunities. In addition to reporting requirements associated with finances, pressures related to environmental reporting and requirements were considered.

During the course of the investigation four reporting elements proved to be recurring issues. These recurring elements were environmental data quality, equipment maintenance management, service network maintenance and human resource utilisation. These issues were taken into account and revealed the need for a comprehensive industrial data collection and management tool. System objectives of the comprehensive system were summarised as:

- Manage data and configurations in a fully traceable structure;
- Guide users with task management structures and provide automated assistance where possible;
- Perform data validation during data collection activities;
- Offer maintenance-related assistance and structure to users; and
- Provide a single platform with multiple functions and integration opportunities.

Further study revealed that no comprehensive system capable of addressing all the data requirements exists. A novel system capable of addressing the previously stated objectives was therefore conceptualised. The novelty of the system relies on the mechanism of combining multiple existing and new elements to form a single new system. The six contributing structures rely on one another to enable advanced functionality. The following structures were therefore investigated and developed:

- Data verification and archiving structure
- Configuration and version control structure
- Calculation and data validation structure
- Task management structure
- System restriction and user support structure
- Data processing and integration structure

A novel mobile data collection and management system for industrial applications was therefore conceptualised and developed. A set of system requirements was declared in line with the system objectives, and was used to guide development. Chapter 3 introduced the system design, complete with a system layout, conceptual structures and data management structures.

The fourth chapter focussed on the mobile application. The developed mobile application is considered the most important element in the developed system. Details surrounding the application architecture, user interfaces, data management, support services, synchronisation requests and task management structures are provided. When combining all these elements, the mobile application allows comprehensive data collection and task management options to users.

System integration was considered in Chapter 5. Discussions in this chapter focussed on full stack system operation. Diagrams were used to illustrate important operations performed using the system. The chapter highlighted the integration between contributing novel structures and how each element performs a specific role in supporting the comprehensive solution.

The system was implemented at various industrial sites in South Africa and was used to validate the developed system. Five case studies were discussed and show the generic abilities of the system. Advanced features offered by the system were highlighted. At the end of each case study the contributing novel components were evaluated, and reinforce the advanced capabilities offered by the integrated system. The following case studies were considered:

- Water network maintenance
- Meter readings
- Service network maintenance
- Environmental data collection
- Energy awareness

Chapter 7 presented an evaluation of the developed system. The system requirements as defined in Chapter 3, were used as reference values and were used to validate the developed system. In addition to the requirement analysis, the novel components were evaluated. The evaluation confirmed that the combination of components yields a novel solution and that it is not attainable without combining the contributing elements.

Lastly, the evaluation considered system alignment with the objectives that were defined in Section 1.4. The evaluation proved that the system addressed the objectives and indicated that the novel components contributed in addressing the individual objectives. In conclusion, the system addressed all the defined objectives by providing a single comprehensive data collection and verification system.

8.2 Recommendations for further work

This study provides a generic mobile platform that can be used to address industrial data collection and task management needs. Further improvements will always be possible as client needs expand. The system was developed with modular expansion in mind and will allow future expansions.

Mobile devices are developing at a rapid pace and offer increasing processing options. The current system relied on multiple libraries to provide extended functionality, such as barcode processing. However, poor hardware performance had a definite impact on these basic image processing tasks. Additional image processing will allow functions such as automatic meter-to-text conversions, or login options using facial recognition.

The system relied on a modular framework to enable data transmission and integration with other systems. Additional modules can be added and can be used to provide powerful bi-directional communication options with client systems.

The popularity of Android and its availability on rugged devices supported the development of a native Android application. However, many high-end users use Apple devices and therefore do not have access to the mobile system. Apple support using cross-platform tools or native solutions may provide expansion options in additional markets.

Thermal camera integration using the FLIR system proved to be a valuable tool in the industrial environment. Additional work in this area, especially anomaly detection based on image processing results, may prove to be a powerful tool in industry.