



Development and implementation of an advanced mobile data collection system

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ABSTRACT

This paper describes the development and implementation of a generic data collection tool. The Mobile Information Collection and Verification System (MICAVS) provides users with a generic platform to create application specific data collection questionnaires. During the data collection phase, the system uses an Android™ application to display relevant questionnaires and interfaces. The application thus utilises modern smartphone technology to aid data collection, ensure data traceability, perform tests on said data and guide users. After collection, the collected data are exported to a range of reporting systems. Case studies of successful system implementations in numerous industries are also discussed.

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1. INTRODUCTION

1.1 Challenges within South Africa's industrial sector

Many large industries in South Africa rely on electricity as primary energy source. Historically South Africa enjoyed low electricity tariffs, which led to a high reliance on electricity. However, by 2016 the cost of electricity has risen to 527% of what it used to be in 2006 [1], [2]. This caused a sudden increase in operational expenses and has a significant impact on the profitability of large electricity consumers. Industries affected by this increase include, but are not limited to: cement manufacturing, steel producing, water utility and mining.

Companies within these industries stand to gain significant benefits by improving energy efficiency. Energy service companies (ESCOs) are therefore often contracted to assist these companies with energy related projects. Typical services offered by these ESCOs during energy interventions include energy investigations, funding arrangement, infrastructure upgrades and project management. Selected ESCOs also offer maintenance programs, in order to ensure that system performance is sustained for an extended period of time.

Meetings with ESCO clients in various industries revealed the need for a cost effective mobile data collection system. These clients described their data requirements and unique challenges they face with collecting relevant data. Details surrounding these challenges are provided in the following section.

1.2 Mining industry challenges

One of the primary industries that ESCOs focus on is the mining industry. South Africa has some of the deepest gold and platinum mines in the world, including the world's deepest gold mine, with a current depth exceeding 3800m [3]. Mining at these depths presents many unique challenges with regard to service provision and maintaining of safe working conditions. These services require advanced systems that increase energy consumption and associated expenses.

Growing operational expenses reduce the profitability of mining activities. Furthermore, the increased operational expenses coupled with declining commodity prices and ore grades, raise the need for mines to investigate cost effective methods to reduce expenditure per ton of product delivered. This creates the demand for energy efficiency improvement and ESCO services. Reduced energy consumption will result in reduced energy expenses and will produce significant drop in overall operational expenses.

Studies have shown that proper maintenance offers great efficiency improvements that offer cost savings in return. However, ESCO projects and funding initiatives require large amounts of data. Infrastructure expansion to gather data is often expensive and do not guarantee a return on investment. Therefore the developed system will provide mining companies with a cost effective data collection tool.

1.3 Water industry concerns

In addition to escalating electricity prices, large industries are placed under pressure by several resource constraints. 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. Some parts of the country are already burdened with an inadequate water supply [4].

Dr. J. Dabrowski [4] stated that over 98% of South Africa's available water resources have already been allocated across various sectors. Furthermore, estimations indicate that by 2025 the country will have a water deficit of between 2% and 13% based on expansion and economic performance. This is a major concern for the country and creates the need to implement proactive water management strategies.

Water suppliers rely on large pump sets and piped networks to transport the water. Baird [5] states that, a failure in such a piped network will have significant financial, environmental and social impacts. Brent and Haffeejee [6] further expand on this by raising the concern that not only the water supplier will be affected, but also the consumers within the service area.

In addition to water loss concerns, the large pump sets used in the industry are high electricity consumers, which relate to high electricity expenses [7]. On average 657 kWh electricity is consumed per Mega litre of water supplied [8]. Due to the heavy reliance on electrical pumps, water distribution can be considered an energy intensive industry. Some ESCOs have thus started offering their resource management strategies to large water networks.

A reduction in system losses offers the supplier many financial advantages by reducing electricity and water treatment expenses. Additionally, the environmental impact of operations is reduced and precious water resources are preserved. These advantages motivate the need for improved maintenance structures and

accurate maintenance information. Energy efficiency and maintenance projects on water systems require the collection of large amounts of data and therefore supports the demand for a mobile data collection system.

1.4 Maintenance data management

ESCO services typically include projects targeted at reducing energy consumption. These projects typically include infrastructure upgrades and improved control systems. In addition to this, ESCOs provide performance reports to the end user to ensure that the intervention operates as intended.

It was found that proper maintenance helped achieve target energy savings [9]. Furthermore, reducing wastages in pumped water schemes and on compressed air networks offer great energy saving opportunities. Complete and accurate data is however required to construct finding reports and identify system inefficiencies. Thus, the maintenance personnel responsible for these systems need tools to gather and manage maintenance data.

Maintenance staff needs effective methods to manage maintenance data. However due to economic constraints industrial users may also have difficulty funding these tools. A cost effective data collection system will therefore help industrial users to collect the data used to compile finding reports that will aid management to develop better maintenance structures.

1.5 Paper contents

The challenges described in the preceding sections indicate that clients in a range of industries share similar data requirements. Therefore, the data collection needs for a range of industry applications can be addressed by a single generic data collection system. A novel data collection system was consequently developed to satisfy the requirements described by ESCO clients. The following sections describe how this need was addressed through the investigation, development and implementation of a new data collection system. The following topics are addressed in ensuing sections of the paper:

- Evaluation of existing data collection methods;
- Design considerations for a mobile data collection system;
- Data validation structures;
- User guidance functionality;
- Case studies in the South African industrial sector;
- Concluding findings and comments.

2. EVALUATION OF DATA COLLECTION METHODS

2.1 Data collection systems

Digital data capture enables the collection of metadata, which is used to authenticate data, without placing additional responsibility on users. Computerised systems have the ability reduce data faults caused by human error. Furthermore, computerised systems offer users a range of features which ensures complete data sets, as well as validation data. Data collection systems exists, but present many shortfalls or restrictions. In this section three data collection methods are considered. These methods are: Supervisory Control and Data Acquisition (SCADA) systems, manual data recording and mobile applications.

2.2 SCADA systems

SCADA systems are the preferred method used for system control and data collection since these systems reduce the required amount of human intervention. Furthermore, these systems are utilised to achieve maximum cost saving potential offered by energy efficiency interventions by ensuring reliable system operation [10]. SCADA systems typically rely on PLCs for control and data acquisition at remote locations in order to ensure reliable operation. A Programmable Logic Controller (PLC) is a computational device and is used for industrial control and data collection in industrial applications [11].

Unfortunately the cost of implementing a PLC system is very high. In 2006 D. le Roux [12] estimated the implementation cost of a PLC system between R250 000 and R800 000. PLC installation costs are further escalated by software development and commissioning requirements [12]. The range of hardware components that form a complete PLC system includes:

- cabling for both power and communication purposes;
- junction boxes;
- a uninterrupted power supply (UPS);
- a human machine interface (HMI);
- circuit breakers.

Industrial applications, particularly mining, also require the use of high quality cables and instrumentation to withstand the extreme environmental conditions. These communication networks often span across large

areas. This creates the need for very long cables and further increases the network cost. An additional downside of a SCADA system is that the system only monitors a rigid collection of variables. System expansions are required to add new sensors and add them in the system. These expansions are costly and also serve only targeted purposes. Additionally, these expansions have integration problems due to different suppliers and systems.

2.3 Mobile applications

The development of handheld computing devices such as smartphones and personal digital assistants (PDAs) provide new data collection opportunities. Many applications have therefore been developed to collect data. Each of the listed applications presents a unique combination of features, as well as its own list of shortfalls. Therefore, none of the other applications satisfied the combined set of requirements that this study is based on. Table 1 provides a summary of the existing applications and their features.

Table 1: Data collection application comparison

		Momento database [13]	Momento [14]	Goformz [15]	Nexticy [16]	Formetize [17]	Pushforms [18]	Devicemagic [19]	Magpi [20]	Doforms [21]	Flowfinity [22]	Epicollect plus [23]	Gis_cloud [24]	Poi_mapper [25]	Prontoforms [26]	Keel [27]
Configuration	Authorised user accounts	•				•	•	•	•	•	•		•	•	•	•
	Authorised user linking				•	•		•	•	•	•			•	•	•
	Data structure versioning													•	•	
	Auto update user configuration								•		•			•	•	
	Auto update data structure configuration	•		•	•	•	•	•	•	•	•		•	•	•	
	Offline configuration management	•												•		
	Kiosk mode device limitation					•										
	Licencing and authorised access to group data					•				•	•			•	•	
Data collection	Customisable input linking	•	•			•	•	•	•	•	•	•	•	•	•	•
	Code scanning	•				•	•	•	•	•	•	•	•		•	•
	Photograph with annotations					•		•		•	•				•	
	Document scanner															
	Signature capture	•		•	•	•	•	•		•	•				•	•
	Sketch pad			•		•		•		•	•				•	•
	Sound level measurement													•	•	
Verification	Historic data access on device	•	•								•		•			
	Geo location capture	•	•	•		•	•	•	•	•	•	•	•	•	•	•
	On device calculations	•		•	•	•	•		•	•	•		•	•	•	
	Customisable data validation tests	•					•				•	•		•	•	
	Validate according to historic data										•					
	Customisable summary		•	•											•	
User assistance	User guidance on input form	•	•			•	•			•						
	Automated data set detection															•
	Workflow support via conditional sub forms	•		•	•	•			•	•	•	•	•	•	•	
	Manual task assignment	•	•	•		•	•	•	•	•	•				•	•
	Customisable map overlays												•	•		
	Review previous readings offline	•	•								•					
	Customisable validation messages					•										
Data	Customisable report integration	•	•	•		•			•		•		•	•	•	•
	Data encryption	•	•			•		•	•		•				•	•
	External system integration	•	•			•	•	•	•	•	•		•		•	•



2.4 Manual human recordings

Manual data recording is practiced in many industries. This method of data collection allows great amounts of flexibility and does not require expensive infrastructure upgrades. In some applications users are guided by forms they have to complete. However, in other cases employees do not have formal data collection structures.

Therefore, although this method is quick and easy to implement, there are significant shortfalls. The largest shortfall is inaccuracy due to human error, since during this process humans interact with data on various levels and each point of interaction creates a possible fault from human error. Possible errors can be made while: reading the meter, writing the meter reading down, reading handwritten notes, typing values into a computer and creating custom reports. It is thus clear that manual data collection has numerous human interactions and that each interaction can be considered an integrity risk.

Clients who made use of manual data collection identified additional system flaws during meetings. During manual data collection exercises employees often visit harsh environments and there are many difficulties using a pen and paper in these non-ideal conditions. These difficulties include insufficient paper support, stationary failure and harsh environmental conditions.

3. DESIGN CONSIDERATIONS FOR A MOBILE DATA COLLECTION SYSTEM

3.1 Introduction to a generic data collection system

Due to the shortfalls of the traditional data collection systems, a new system was developed. The system is designed to provide a generic data collection platform that is usable across multiple industries and applications. The primary component of the Mobile Information Collection and Verification System (MICAVS) is therefore a mobile application.

The application provides infrastructure that allows users to create custom data collection sets. These data sets can then be customised from within the application and exported to other devices without the need for further development. During configuration ingress activities are linked to items within the data set and stored in the database. During execution, the application dynamically creates user interfaces based on database entries.

When data sets are created, the set of collection variables can be personalised to address the user's specific needs. A range of data ingress activities have been created to allow the collection of various data types. During configuration, a specific data ingress activity is linked to each item in the data set. This aids users to enter appropriate data entries for each data field that they defined. Data fields can be marked as required to ensure that records are complete.

3.2 Operating system selection

The core of the MICAVS relies on an Android application which is used to create and manage log entries. Android was chosen as the best suited operating platform for the system due to the following factors. The principal factor was that Android has significant market penetration in South Africa, consequently many consumers already own Android devices [28]. These users are thus able to make use of the application without investing in new hardware.

Many ruggedized mobile devices are also commercially available. These devices are better suited for harsh operation conditions. Rugged devices can withstand risks including drops, as well as dust and water exposure factors better than standard mobile devices. Furthermore, selected rugged devices are certified for use in potentially explosive areas.

Most of these commercially available ruggedized devices employ either the Android or Windows mobile operating systems. No Apple® devices are available in ruggedized packages and are therefore not suitable for this application. Device availability and market penetration were thus considered and revealed that Android is the preferred platform for the MICAVS application.

3.3 Database

Android supports SQLite databases and therefore, the developed application utilises a SQLite database to manage data. Without root access, the database is isolated by Android so that only the associated application can access and modify the database. MICAVS uses the relational database to provide structure to the application. The database can thus be summarised in three categories namely: constants values, configurations settings and recorded data.

Constants are defined during compile time and cannot be modified on the device. These values are used to provide structured options and default values. Although these entries generate fixed outputs that offer users access to structured options, it offers developers a platform to quickly access and update crucial application options.

Configuration table values are used to manage variable interface options and predefined lists. These values can be configured on the device or using a configuration tool. During execution the application uses these tables to dynamically construct interface elements and populate lists as defined by the administrator.

Lastly data tables are used to manage recorded data. The database structure allows users to manipulate input options, by adapting the configuration tables. These changes affect the storage tables that accommodate unique configurations and thus stores data accordingly.

3.4 Interfaces

One of the key elements of the MICA VS is customisable user interfaces. Various interface elements have therefore been created. These elements include layouts for interfaces such as the main menu and sub-menus. The next and arguably most important element is the display cards. Lastly, various data ingress interfaces with fixed layouts were also created.

Interfaces are constructed dynamically from the database when the application is executed. Menu cards items including images, headings and support text are constructed from database entries. A collection of user access tables contains links between user access options and menu items. Therefore, only privileged users have access to specialised menu options such as the management interface. The MICA VS main menu with privileged user access is shown in Figure 1-A.

When creating a new log the application detects the appropriate mode and then compiles a list of data fields assigned to that particular mode. Card elements are then created based on the compiled list. Figure 1-B, shows the data input interface with a card for each data set entry. These cards contain links to the appointed data ingress interfaces. To add data the user must press on the appropriate card and use the data ingress interface to enter the relevant data. Figure 1-C, shows the numeric data ingress dialog.

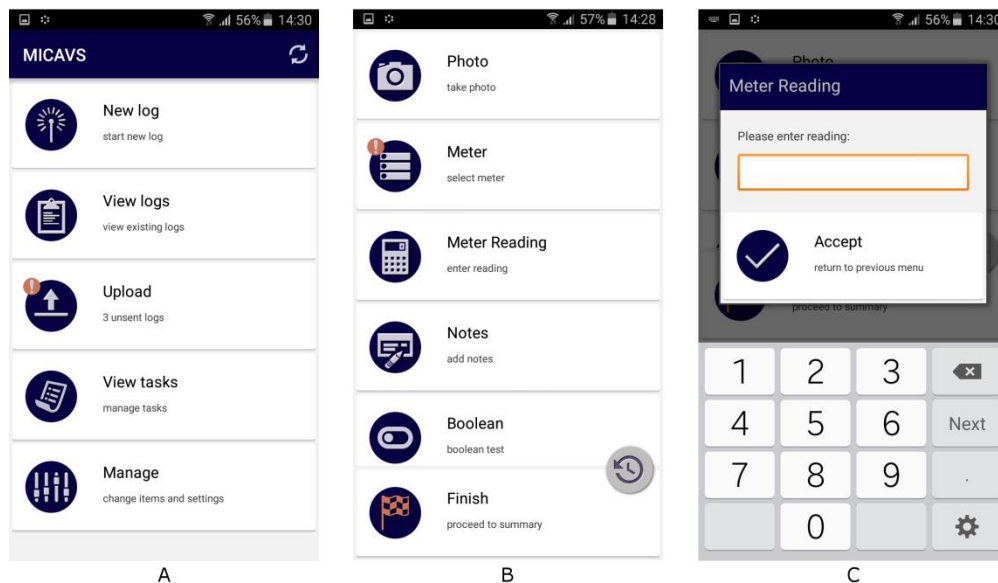


Figure 1: MICA VS customised interfaces

After all the required data fields are completed the user is allowed to finish the log. A log summary is then created by selecting *Finish* from the data input menu. This summary contains the logged data along with additional data including GPS location, timestamp and verification test results. Some data fields also have support interfaces that allow users to view the captured data. One example is the map view that shows a map with a pin where the log was created.

Test results displayed in the summary are created dynamically. If no tests are linked to the data field, a normal summary card will display only the captured data. Conversely, if tests are linked to a specific data

field a detailed summary card will be displayed. These tests are discussed in more detail in section 4. The user is also notified if the captured value exceeds the test parameters.

Figure 2 shows examples of review interfaces in the MICAVS application. Figure 2-A shows an example of a summary interface. In this case an average test was executed on *Meter Reading*. The field is emphasised by displaying a highlighted card item. In this case the test failed and an exclamation mark is displayed. A failure message can be seen by selecting the *Meter Reading* card. Figure 2-B, shows an example of the customisable failure message dialog.

Certain selected data ingress types have support interfaces. For instance, *Location* entries can be viewed on a map. Figure 2-C shows an example of the reading location as a pin on a map. The map type can also be modified to show either a satellite image, normal map, hybrid map or terrain view. Images can also be reviewed in a similar interface. These support interfaces are invoked by selecting the grey buttons on the right hand side of the interface shown in Figure 2-A.

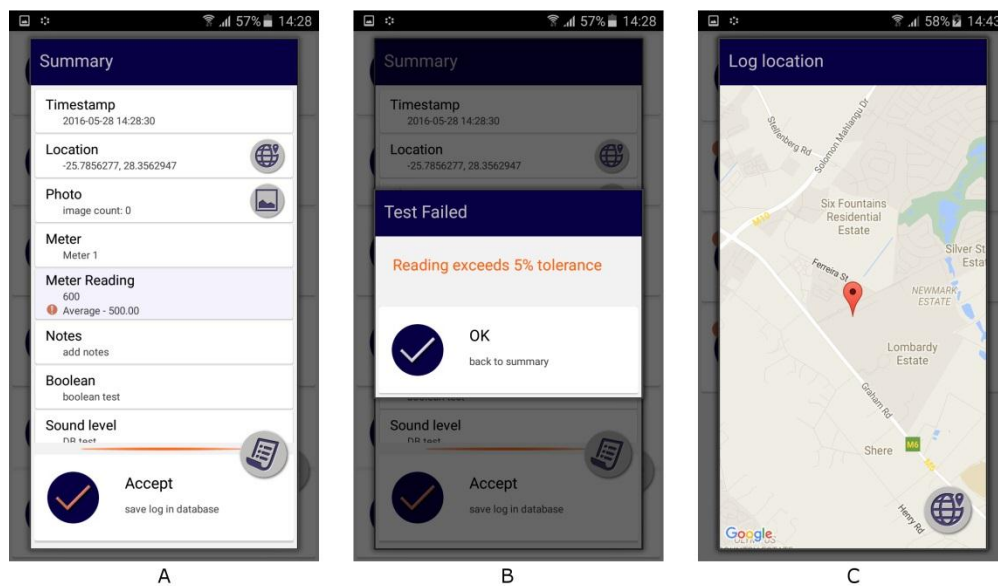


Figure 2: MICAVS review interfaces

3.5 Data transfer

The ability to transfer data is required in order to extract the full potential of the data collection system. Existing log entries can be filtered and viewed on the device. To allow customisable reports, the MICAVS exports data to remote servers in order to process the collected data. The MICAVS has been integrated with both internal and third party data processing systems to satisfy a range of user requirements.

The MICAVS was initially developed for an ESCO that provides various energy services to clients across multiple industries. To enable this, many internal systems were developed to receive, process, store and report on data collected on site. The MICAVS was therefore integrated with internal systems. The application sends structured data files to these systems via an internet connection both automatically and upon user request.

The integration enables the internal ESCO systems to receive data from the MICAVS application. The received values are then archived along with supporting data for traceability purposes. Furthermore, this integration allows the construction of custom reports and provides a platform to perform additional tests on data based on the client's needs.

A specific ESCO client also has an internal system used to track maintenance requests. The developer therefore collaborated with a team from the client in order to develop a data transfer strategy between the two systems. This strategy was conceived and implemented successfully. This allows the MICAVS application to communicate directly with the client system and enables automatic maintenance work order creations without the need for additional human intervention.

3.6 Data verification

The MICA VS provides users with a unique data verification platform. This platform provides clients with the ability to perform different data verification tests at three different stages of the data collection process. Firstly, there is a generic data validation component in the application. This component allows users to select one of multiple verification tests and apply it on a data field of their choosing. Unique test parameters can then be defined for each test. The application also has the ability to select historic data entries connected to the data field in question and compare the new entries with said historic data.

During the second verification stage, recorded data that are uploaded to the server are saved alongside metadata such as pictures that prove certain data elements. This stored data can then be used for verification for audit purposes by requesting raw data from the ESCO.

Lastly, the exported data are received by a reporting system which generates reports which can be customised according to the client's needs. This allows users to manually verify the data against previous collections or predefined values. A Microsoft® Excel template also allows users to perform advanced mathematical calculations on the dataset and use these values in automated reports.

3.7 User guidance

One of the unique functions of the MICA VS is user guidance. When the researcher joined ESCO clients during various field tests, the client made use of a note sheet that shows previous reading. New readings were compared with previous readings in order to verify that readings fell within acceptable limits.

After viewing these tests, the application was expanded to include this functionality. Users now have the ability to view previous readings while making new log entries. Users can therefore perform a manual verification that the values fall within an acceptable range.

When the user selects *Finish*, a log summary is also generated and the MICA VS performs linked tests on the data. A warning flag is displayed if any of the tests exceed the specified parameters. The user can then select the summary item to see a detailed description of the test result and verify that the entered values are correct before saving the log entry.

4. SYSTEM IMPLEMENTATION

The MICA VS system was implemented at three client sites. Client 1 is a large water supplier in South Africa and used the system to manage maintenance data. The second client is in the mining industry and used the application to manage water meter readings. Lastly, the application was used by ESCO personnel to perform an audit on a compressed air system in a goldmine.

4.1 Implementation 1: Water network maintenance

A large water board in South Africa relies on an extensive pipeline network to transport water to clients. The majority of this pipeline network is underground and totals to a combined length of 3600km [29]. These pipelines are subject to corrosion and other factors that decrease its life expectancy. According to the American Water Works Association similar pipelines have a typical lifespan of 70 years [5]. The network in question can therefore be considered mature which increases the risk of failure.

Due to the size of the network it is impractical to replace large sections of pipelines that do not present immediate risks. However, it is difficult to predict when and where pipelines will fail. According to Kahn [29], a pumped water loss between 4% and 5% was recorded for the network. This equates to 210 million litres of treated water that is lost on a daily basis. Furthermore, Kahn [29] raises the concern that the exact location of these losses are unknown, due to the fact that pipeline leaks are not accurately recorded.

These losses are a serious concern due to limited water resources in South Africa. Furthermore, these losses have significant impacts on other systems and the environment. Most of the lost water is potable water. It can therefore be deducted that 210 million litres of water received treatment without cause. The client therefore had the need for advanced data collection to record pipeline failures within their network.

Previously they relied on a manual system whereby the general public would call and report water leaks. A maintenance representative from the district was then sent out to investigate the report. If the leak was found on their network the investigator would report the fault and open a work order request.

The client had two powerful software systems, but did not utilise their potential as loads of manual labour was required to open work requests. In addition to this, according to maintenance personnel leak descriptions were not accurate. Furthermore, the collected data was inconsistent and varied according to each responder's



personal preference. Reporting structures did not support structures used to collect Global Positioning System (GPS) data or photographic evidence.

The first of the software systems was used to manage maintenance requests. After a maintenance issue was created the system generated a work order and assigned a responsible person. The responsible person then had to find the leak with limited information available and perform the required maintenance with limited prior details of what the scope of work would entail.

The second system was used to manage Geographic Information System (GIS) data. Data stored in this system has the ability to show regions where frequent maintenance is required. Unfortunately this system was not utilized, because responders did not have access to a tool that can capture GPS locations and photographs and support data. Furthermore, no automated structures were in place to process inspection findings.

When the MICAVS was provided to the client, special data import functionality was added to the MICAVS to enable communication with the client's system. Additionally, a custom data set was defined for the client. The data set formed an inspection checklist which contains user specified inputs in combination with photographic evidence, GPS locations.

After initial implementation the client distributed the MICAVS system to maintenance representatives in each operation region. The regional representatives use Android devices equipped with the MICAVS application to create detailed issue logs. These logs are then uploaded to the client servers where they are processed. The client servers receive the log data and automatically open work orders. Detailed descriptions thus provide maintenance staff with a better indication of work required.

In addition to this the GIS system could be utilised for marking locations where leaks occurred. High risk areas can therefore now be identified based on geographical similarities. This enables maintenance management to identify problem pipelines and sections and replace only limited sections of the pipe network. This improved information structure therefore enables the client to make more informed maintenance decisions and reduce expenditure.

4.2 Implementation 2: Water meter readings

In this case the client was responsible for gathering water meter reading data. To do this the client traditionally relied on manual pen and paper methods and would physically visit a predetermined list of sites and write down readings. Most of these locations were outdoors; therefore weather conditions had a serious impact on operations.

The client was supplied with the MICAVS application and a unique setup was created according to the user's needs. After the system was implemented trial tests were performed and data verification tests were developed and the system was updated with an improved configuration. Part of this improved configuration included adding additional users. Due to security concerns, selected meter readings had to be assigned to personnel who could take the readings while escorted by security personnel.

The MICAVS system is capable of detecting specific components and user modes based on predefined identification codes. These codes can be in the form of barcodes or QR codes and must be unique. The client therefore obtained barcode tags and assigned the codes to specific meters. By utilising this functionality the possibility of selecting the wrong meter was removed.

Currently meter readings are recorded on a monthly basis. The application allows the user to access previous readings during data collection inspections. A detailed summary after every log contains on device calculations that indicate possible data errors and alert the user of any discrepancies while still on site. The users record data on site and then synchronises the collected data with the ESCO's server. Next the data is backed up for traceability purposes and custom reports are generated according to user specifications.

4.3 Implementation 3: Compressed air network audit

As previously mentioned South African gold mines often operate at depths exceeding 3800m [3] which presents many unique challenges. Specialist systems have therefore been developed to allow operation in these conditions. To illustrate this, consider the compressed air network used in mines. Compressed air generation can make up between 20% and 50% of a mine's electricity consumption [30], [15]. Botha [31] continues that compressed air generation expensive and one of the most inefficient means of energy distribution in mining operations.

Part of the ESCO services includes energy audits on client premises during which ESCO personnel identify inefficiencies and system faults. These results need to be recorded accurately in order to be used to construct finding reports. Potential saving opportunities or maintenance requirements can typically be addressed if these reports are used.

In this case the ESCO used the MICAVS system to perform an audit on a mine compressed air network. Recordings were made if any leaks or misuse of compressed air systems were observed. During this investigation 18 significant air leaks were noted on a single level within the mine.

These leaks have a major impact on system performance and induce significant cost implications since the compressed air networks rely on large electrical compressor systems. If leaks are managed properly less supply from the compressors is needed and electricity costs can be reduced.

5. CONCLUSION

This paper presented a generic data collection and verification system that was developed and implemented as part of a study. The developed system relies on an Android application for data collection and integrates with various support systems. The integrated systems offer users a unique platform to create custom data gathering structures.

The data requirements for the system were therefore obtained through a combination of discussions with clients and previous ESCO experience. This prompted the development of a new data collection system. The new system allows users to create multiple custom data collection interfaces accompanied by verification and data tractability functions.

The collected data is captured using a fully customisable Android application. The application offers user guidance and data verification tools to assist users to collect accurate data. After collection the data are synchronised with support systems which are used to store the data, generate custom reports and perform additional verification tests.

The system was successfully implemented on three separate industrial sites in South African. The users reported great advantages from using the system. Custom reports have also been generated, based on the client's specific needs. These reports aid clients to make better informed decisions. Additionally, recorded data and metadata are backed up and are available for further processing and audit purposes upon request.

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