An investigation into the use of RFID for the management of cold chain logistics

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It all starts here ™

Preface

The research presented in this document is the original, intellectual work completed by the author, B.P. van Eyk. It is based on experiments conducted at the Northwest University and collaborating industry partners involved in cold chain logistics. I would herby like to thank all participants that aided in the accomplishment of the goals set forth for this master study. In particular I would like to thank the following individuals and companies.

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OPSOMMING

Navorsing het bewys dat substansieële verlies aan bedrefbare vragte plaasvind tydens vervoer. Dit kan toegeskryf word aan moontlike wan-praktyke in die koue ketting metodes wat tans toegepas word. Hierdie soort verliese is selfs meer prominent in ontwikkelende lande waar die verskaffingskettings nog nie so gevorder is soos in ontwikkelde ekonomieë nie. Die tekortkominge kan wel aangespreek word deur die gebruik van intydse moniteringstoerusting. Die toegepassing hiervan tydens die vervoer van ‘n verkoelde vrag kan die nodige data verskaf vir die verbetering van sigbaarheid van die vrag deur gebruik te maak van mobiele kommunikasie tegnologieë. Hierdie stelsels kan elke faset moniteer en onmiddelike reaksie op temperatuur fluksiasies ondersteun.

In die dokument word die toepassing van koordlose moniterings stelsels bestudeer wat moontlik geïmplementeer kan word om verbetering in die koueketting te bewerkstellig. Die tipe stelsels wat geëvalueer word sluit in RFID, GSM en stelsels.wat beide tegnologieë kombineer om sodoende koste-effektiewe oplossings vir die probleme wat tans ondervind word in die koue ketting kan verskaf. Die effektiewe gebruik van die stelsels is geëvalueer deur eerstens die werklike behoefte van die industrie te identifiseer. As resultaat van die ondersoek kon die werklike probleemareas in die koue-ketting soos huidig ervaar word identifiseer word.

Hierdie ondersoek was in essensie voltooi d.m.v. drie stappe: Eerstens is vraelyste verskaf aan individueë in die industrie om data te versamel. Tweedens is onderhoude gevoer met logistieke diensverskaffers om ‘n eerstehandse gevoel te kry oor die industrie en die werking daarvan. Laastens is meer as 80 dae van internationaal vervoerde vragte geëvalueer, deur data wat versamel is m.b.v sensore wat in die verkoelde sleepwa en sy vrag geplaas is. Verdere data is ook versamel deur die persone wat die vrag vergesel het tussen Johannesburg en Zambië.

Uit die data wat versamel is, is dit vasgestel dat die grootste tekortkomming wat tans heers die swak sigbaarheid binne die sleepwae en sy vrag is. Dit is verder ook geïdentifiseer dat ‘n meer gebruikersvriendelike oplossing benodig word wat beter integreerbaar is met die huidige praktyk bo die standaard stelsels wat tans beskikbaar is. Deur die versamelde data te gebruik as verwysings punt, kon die bruikbaarheid van die standaard RFID sisteme ter oplossing van die huidige probleme geëvalueer word. Eksperimente is uitgevoer op die stelsels in beide ‘n beheerde laboratoruim omgewing en in praktiese toepassings. Die resultaat hiervan het bewyse gelewer oor waar spesifieke tipe stelsels van die grootste nut sal wees vir die koue ketting.

Gebaseer op die inligting wat versamel is gedurende die ondersoek van die koue ketting en vermoëns van die RFID stelsels om die industrieprobleme op te los, is ‘n sagteware pakket ontwikkel wat die tekortkominge aanspreek, sowel as ‘n integrasieplatvorm vir die standaard tegnologieë. Die sagteware verskaf aan die gebruiker die vermoë om RFID hardeware te konfigureer vir spesifieke temperatuurmoniteringsvereistes van ‘n vrag wat vervoer moet word. Dit verskaf verder ook basiese evaluasietoerusting om temperature te evalueer en ‘n verslag te genereer wat die kern aspekte van die koue ketting vertoon. Die evaluasie van die sagteware het getoon dat dit verbeterde sigbaarheid aan bederfbare vrag kan verskaf wat direk tot die verbetering in die kwaliteit van goedere kan lei…

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Sleutelterme: Koue ketting bestuur,Passiewe RFID, Semi-Aktiewe RFID, Aktiewe RFID, GSM, Bederfbare goedere, Verspreidingsentrum, Verkoeldevragte, Temperatuur Monitering, RF Transmissie, Middelware, Gebruikerkoppelvlak, Data Analise, Koste aanwins analise.

ABSTRACT

Research has shown that substantial in transit losses in perishable cargo are sustained due to malpractices in cold chain logistics. Such losses are even more prevalent in developing countries where supply chain systems are not yet as advanced as those found within developed economies. This situation can be improved by using real time monitoring of refrigerated cargo, which implies the use of mobile communication technologies to sustain monitoring through the entire supply chain.

This document investigates the application of remote sensing technologies, including RFID and GSM/ GPRS communications, to provide cost-effective solutions to the needs of the refrigerated supply chain industry. The investigation into the effective use of these types of systems was done by firstly evaluating the needs of the industry and the identification of the problem areas experienced in today's cold chain.

This process was completed through three steps: Firstly through the use of questionnaires to gather information from various parties throughout the cold chain; secondly through conducting first hand interviews with parties in the industry and finally by evaluating more than 80 days of cross border cold chain operations by means of data loggers in the trailers and physically accompanying consignments to evaluate the process as performed in the field. It was determined that a lack of visibility inside the trailers was the greatest shortcoming that needed to be addressed.

It was furthermore established that this could be achieved by using a solution that is more user friendly and that achieves better integration with current industry processes than what is currently available from suppliers. Using the data collected from the field studies as reference, the suitability of several off the shelf RFID solutions were evaluated. By performing experiments both in a controlled laboratory environment and in field applications the areas where specific cold chain telemetry solutions would be the most beneficial were determined.

Based on the information gathered from the investigation of the cold chain and the capabilities of RFID solutions to solve the identified issues, a software package was developed encompassing the identified needs. The software provides a user with capabilities to configure the available RFID hardware resources for use in the delivery of cold chain consignments according to its relevant temperature parameters.

Furthermore it provides basic evaluation tools to evaluate temperature over the lifetime of the consignment and provide summary reports over this entire cycle. The evaluation of the software package indicated that it could provide enhanced visibility of perishable consignments in transit thus enabling improvements in the cold chain.

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Key terms: Cold chain management, Passive RFID, Semi-Active RFID, Active RFID, GSM, Perishable goods, Distribution Centre, Chilled Cargo, Temperature Monitoring, Middleware, User interface, Data Analyses, Cost benefit analysis.

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List of Abbreviations

RFID	Radio Frequency Identification
GSM	Global System for Mobile Communication
GPRS	General Packet Radio Service
GPS	Global Positioning System
CCM	Cold Chain Management
CCLDC	Cold Chain Logistic Distribution Centre
DC	Distribution Centre
EC	Equipment Centre
LSP	Logistic Service Provider
ROAFE	Road and Freight
REEFER	Refrigerated Trailer
WSN	Wireless Sensor Network
NPV	Net Present Value
IIR	Internal Rate of Return
ROI	Return on investment

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Chapter 1: Introduction

1.1 Chapter Overview

Research has shown that substantial in transit losses of perishable cargo are sustained due to malpractices in cold chain logistics [1]. Such losses are even more prevalent in developing countries where supply chain systems are not yet as advanced as those found within developed economies. This situation can be improved by using continuous monitoring of refrigerated cargo, which implies the use of mobile sensing and communication technologies to sustain monitoring through the entire supply chain.

This chapter provides an overview of the current problems encountered in the cold chain logistics industry in southern Africa. The use of RFID as a mobile technology that can be used to improve the quality of perishable goods that reaches the consumer will be investigated. In this chapter a brief background on the current problems, structures and technology available in the industry will be presented. Furthermore the problem statement, objectives, motivation and methodology to be applied towards conducting the necessary research in the field of cold chain management are presented.

1.2 Research Background

The effective control of freight logistics is a critical part of moving goods from the producer to the end user. Depending on the items being transported the rules applied during transit will differ vastly. For perishable goods one of the most important rules that must be adhered to is the temperature thresholds that must be maintained during all transportation processes. If the required thresholds are not maintained it could lead to reduced shelf life or the loss of the entire consignment. In fresh produce logistics alone losses of 35% globally and 40% in developing countries have been documented [1].

The temperature at a specific moment during transit is not the only concern, but of particular importance is how the consignment was handled over its entire life cycle. This implies that the entire transport cycle must therefore be monitored.

1.2.1 Key fundamentals of cold chain management (CCM)

The fundamentals applied in the cold chain are based on the standard model that is applied in other supply chains. A balance must always be maintained between the safe transportation of goods and the cost-effectiveness of the logistic process. In the supply chain there are seven fundamentals that are applied to maintain this necessary balance [2]:

1. The segmentation of customers based on services needed
2. Customisation of the logistic network to fit these needs
3. Evaluation of market demand and planning according to the results obtained
4. Dynamically deciding which product to stockpile in order to expedite the conversion of these supplies across the supply chain
5. Use resources strategically
6. Develop a supply chain-wide technology strategy
7. Adopt channel-spanning performance measures

By applying these fundamentals to the cold chain a company can maximize its efficiency whilst being competitive in its individual markets. In the application of these fundamentals the standards that must be adhered to, to ensure goods are at their optimal quality when it reaches the consumer, must not be neglected. A direct correlation between the deterioration of perishable goods and their relative temperatures can be established [1]. As temperature increases the faster natural degradation of these goods will take place. A few examples of the influence of temperature on some perishable goods are given in Table 1.

Table 1: Estimated shelf life of perishable goods under different temperatures[1] [3]

Item		**Storage potential**			
Type of Goods		**Optimal temp (OT)**	**OT +10°C**	**OT +20°C**	**OT +30°C**
Fish	Temp	0°C	10°C	20°C	30°C
	Shelf life	10days	4-5 days	1-2 days	Few hours
Mangoes	Temp	13°C	23°C	33°C	43°C
	Shelf life	2-3weeks	1 week	4 days	2 days
Green Vegetables	Temp	0°C	10°C	20°C	30°C
	Shelf life	1 month	2 weeks	1 week	<2days
Apples	Temp	-1°C	10°C	20°C	30°C
	Shelf life	3-6months	<2 months	<1 month	2 weeks

As the table indicates the influence of temperature on shelf life varies according to the item being stored. While temperatures higher than the optimal temperature substantially reduces the shelf life even greater losses are suffered for goods being stored at temperatures below the optimal temperature. This may lead to chilling damages which can render a whole consignment unfit for distribution e.g. leafy vegetables such as lettuce, spinach and cabbage are especially susceptible to frost damage.

Most first world countries have adopted cold chain control mechanisms and as a result service providers have deployed temperature sensor networks to manage cold chains to aid in ensuring the longest possible life for goods being stored and transported from producer to consumer [4]. These systems can unfortunately be very costly and thus are not being implemented in a similar fashion in developing countries.

1.2.2 Cold chain management in South Africa

In typical supply chains operated in Southern Africa cold chain integrity is maintained for certain sections during transit; full traceability of the cold chain from producer to consumer is however not yet a reality which entire industry embraces. This at least partly results from the fact that the independent entities in the value chain, including the producer, logistics service providers (LSPs), the retailer and the consumer each have different priorities when it comes to the delivery of goods.

Producers and LSP's need to maintain their profit margins and would therefore try to limit additional costs such as refrigerated transportation to the distribution centre (DC); this may lead to retailers receiving goods that will not have the shelf life promised to consumers. LSPs however increasingly realise the importance of cold chain management over the entire process to guarantee the delivery of goods of the required quality [3], and the value of real time monitoring to ensure traceability and accountability.

1.2.3 Problems encountered in current structures

The implementation of technology for the purpose of cold chain management is unfortunately not done without encountering many hurdles [5]. A great many of the solutions available today is designed for the technological excellence of the equipment and not for the effectiveness of solving the problem on ground level, to meet the specific needs of a client [6]. As suggested the solutions on offer have some disadvantages that limit their practical deployment:

- Complexity of solution beyond the skill level of the operator.
- Equipment is labour intensive to use.
- The equipment can get lost very easily in transit
- The solution is prone to malfunction and damage
- The solution is perceived to be too expensive relative to the benefit it provides.
- The solutions do not integrate with the current systems customers are already using.
- The solution does not fit into existing internal operational processes

Due to these disadvantages many potential end-users are hesitant to pursue existing solutions to manage their cold chains more effectively.

1.3 Research Proposal

1.3.1 Problem Statement

The perishable goods industry today experiences high losses in consignments being transported locally and cross border. This is due to poor management and control structures being implemented in the four different sections of the logistic chain. In the current structures little to no equipment is used that can provide continuous temperature/humidity monitoring, consignment traceability and accountability and real-time temperature alerts.

1.3.2 Research Scope

The purpose of the research is to investigate the use of RFID sensors and tags as part of a CCM tool. The investigation will evaluate RFID according to type, in order to identify the best option to be used in industry for the purpose of CCM. The best theoretical RFID solution will then be selected and further evaluated in a practical environment to determine its data retrieval capabilities and how effective it can be used to monitor the environment.

The needs of the logistic industry regarding operational simplicity, user-friendliness and interoperability with legacy systems must be investigated to allow the development of a user requirements specification. A software platform must then be designed that will satisfy these needs and the selected sensor types must be integrated into the software platform. The integrated RFID system must then be evaluated in a real world application to demonstrate that the selected RFID technology was successfully integrated into the CCM solution, to deliver results regarding the usefulness of the CCM solution, and finally to generate a realistic cost-benefit analysis for the implementation.

1.4 Research objectives

1.4.1 Primary objectives

The following primary objectives are defined:

- Identification of problem areas in the cold chain management industry.
- Identification of the technology and equipment that can address the needs of industry.
- The investigation of functionality of available RFID equipment and the extent to which it can address industry needs.
- Investigate interoperability of the different systems available on the market and the issues encountered.
- Evaluation of off the shelf RFID solutions under different environmental conditions.
- Evaluation of the temperature monitoring accuracy of RFID solutions.
- Design of a system architecture for a CCM solution, based on available technology that can solve industry needs.
- Selection of equipment according to their capabilities and the needs of industry.

- Development of a software platform to incorporate the identified needs of industry and to integrate the selected hardware.
- Evaluation of the complete CCM solution within a practical industry application.
- Cost-benefit analysis of the implementation of a solution based on RFID for the purpose of CCM.

1.4.2 Secondary objectives

The following secondary objectives are defined:

- Investigate an algorithm to extrapolate sensor values in a consignment in order to infer unknown temperatures within the cargo from known temperatures at points where sensors can be mounted.
- Determine the best placement of sensors in a consignment for optimal temperature monitoring, taking into account both the accuracy of monitoring and the cost of the solution.
- An investigation into the use of multiple communication protocols used with RFID for the operation of multi-vendor equipment.

1.5 Research Motivation

When focusing on the logistics of perishables such as fresh fruits and vegetables in Southern Africa it has been found that many participants do not adhere to the necessary cold standards to optimise the quality of goods delivered to the consumer at the end of the supply chain. This lack of adherence is partly due to the fact that some participants, e.g. truck drivers and goods receive officials, are unaware of the damaging effect of temperature on quality and shelf life of goods, with the only means of quality verification being the physical appearance of the goods at delivery. Due to this lack of knowledge and concern documented losses of up to 40% occurs in this industry [1].

In alternative cases the receiver of the goods will require specific cold chain standards that must be adhered to from the producer to the customer sites. The problem with the systems currently in place to enforce such standards is that it relies mainly on a manual process where the temperature data is only recorded at certain points in the cold chain. This process, although an improvement on the initial scenario mentioned, is clearly flawed as there is still no continuous monitoring and alerting in place. If such capabilities were available the user would be able to track the temperature fluctuation of a consignment, take action whenever exceptions occur in order to ensure the shelf life and quality of goods delivered to the consumer and have accountability data available for insurance and supply chain improvement purposes.

Many different systems are available on the market to LSP's, producers and DC's. As mentioned in section 2, the problem with most of these systems is that they are difficult to use, expensive and do not fit within the systems and processes currently implemented. Furthermore little to no data is available regarding the benefits that the implementation of specific solutions will provide towards improvement of the cold chain and the quality of goods.

It thus becomes clear that research is required in order to provide answers to the question of how RFID will influence the quality of a cold supply chain and how it will integrate with the current structures in place. The research must answer the question whether RFID systems can be used for CCM purposes and what level of contribution its integration would provide to the quality of goods and the economics of the cold chain operation. It must also provide information on the functions required to be integrated into a software platform to ensure operational simplicity, effective use of the selected RFID technology and its integration with current legacy systems.

The research will provide crucial answers towards improvements in cold chain logistics and the use of RFID in the industry with the focus on CCM.

1.6 Research Methodology

The research will be conducted using a combination of qualitative and quantitative methodologies. The basic methodology to address each objective as listed above is as follows:

- Problem Identification
- Literature study on possible solutions to the identified problems
- Design and development of a solution to the problem
- Implementation of the solution
- Testing and evaluation of solution
- Verification of results
- Dissemination of collected information

In the first stage of the research the problem needs to be defined in sufficient detail; in order to collect the necessary information two approaches must be taken. Firstly information must be gathered by directly speaking to LSP's and parties that implement any form of cold chain management. Secondly questionnaires will be drafted and sent to other parties that cannot be contacted directly due to geographical reasons; in the process more information will be collected to formulate a well-founded concept as to the problem and issues to be confronted in the cold chain industry. Information must also be collected regarding CCM standards, processes and systems currently used in the industry.

After the problem identification research has been completed, a literature study will be performed to establish what solutions to the problems there currently are in the industry. A functional analysis will be conducted along with this study to determine the benefit of each system to their relative cost. The problems and limitations of these systems must also be established in order to provide a clear direction for further research. Once the theoretical best suited systems have been clearly defined a sample of the reviewed solutions will be acquired.

The selected sample systems must then be individually evaluated by conducting a sequence of experiments. The experiments will focus on three aspects: communication range between RFID reader and tags; orientation and sensor placement and temperature monitoring capability. From these experiments the most appropriate solution in terms of functionality and cost will be selected for use in field tests.

From the data collected during stage 1 of the research a software platform must then be designed. Good operational design must be integrated into the software platform in order to provide a generic platform for effective CCM. The best evaluated system from the previous research stage will then be integrated into the platform to enable the use of RFID sensors as part of the cold chain management platform. The platform with the integration will then be tested in an operational environment to evaluate how effectively RFID can be used as a tool for cold chain management. The effectiveness of the CCM platform will be evaluated according to accuracy of environmental monitoring, data communication ability and ease of use.

After all the above mentioned stages of research have been completed, the relevant data will then be evaluated and documented.

1.7 Beneficiaries of research

The research will be of benefit to all parties implementing or using cold chain logistics processes, as it will provide them with information on areas where losses occur in the supply chain, information on the causes of these losses and information on what benefit the use of RFID sensors and mobile networks will have on the supply chain. It will also be clear what functionality is required in a software platform to enable improved management of cold chains and if interoperability with current legacy systems and new systems is possible.

1.8 Documentation Layout

The proposed dissertation layout will consist of nine chapters that will encompass all the results obtained during the investigation and will be outlined as follows:

Chapter 1: Introduction
Chapter 2: Literature study

Chapter 3: Operational analysis of CCM in industry

Chapter 4: RFID systems evaluation and characterisation

Chapter 5: CCM software architecture design

Chapter 6: Simulation of architecture implementation

Chapter 7: Software Implementation

Chapter 8: Cost-benefit analysis

Chapter 9: Conclusions and recommendations

1.9 Chapter Summary

In this chapter the problems currently encountered in the cold chain industry were presented and the necessary CCM standards were discussed shortly. Due to the extensive losses occurring in industry, the requirement for research into the improvement of cold chain systems and the proper implementation thereof is a necessity.

Furthermore, the objectives to research a solution to the problem and the methodology to achieve this solution has been discussed. The motivation for this research is that without the implementation of a system that can provide the industry with data and warning of the occurrence of problems in the cold chain, the sustainment of losses will continue.

Through the envisaged research work the causes of these losses will be clearly identified, the necessary tools to implement a possible solution to the problem will be investigated and implementation results will be obtained. This will allow industry end users to make informed decisions when improving the management of their individual cold chains to ensure better quality of delivered goods.

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Chapter 2: Literature Study

2.1 Chapter Overview

This chapter provides an overview of CCM practices currently implemented in industry as supported by literature. The information collected through this literature study will aid in the search for answers to the research questions posed in Chapter 1. Here we will investigate the different areas that involves the effective management of a cold chain. The literature review will provide information to define the exact need of the industry, to describe current solutions and to identify the gaps that exist.

2.2 RF systems and implemented network standards

The limited extent to which CCM systems have been practically deployed is partly due to the fact that most available systems are based on proprietary protocols used for communication between different system components. This expose end-users to the risk of being locked into a single source of supply. Interoperability between tags, readers and remote tracking units will help to open up the market and to allow end-users to use the same technology infrastructure for multiple purposes.

2.2.1 Interoperability of systems

Due to the use of wireless communication at different levels within the CCM system the possibility of communication interference cannot be overlooked [7] – GSM and UHF RFID for example both use communication in bands close to 900 MHz. The implementation of standards based communication as regulated within different jurisdictions will however ensure that such interference is prevented; standards based protocols will furthermore provide the required level of anti-collision to ensure that large numbers of data packages from RFID tags will be successfully collected by readers even when many devices are operated in close proximity. This will prevent a system from becoming unstable or dysfunctional when its functionality is scaled up to accommodate the needs of a large supply chain operation [8][9]. Without such standards, providing the ability to integrate different devices into a single large system, effective CCM will not be possible.

As most of the options for remote communications use existing GSM or satellite communication networks, this aspect of deployed systems tend to be standardized based on the protocols that form part of such networks [10]. The bigger challenge is to ensure interoperability between the different kinds of RFID tags and the devices that need to connect them to the outside world [11].

2.2.2 Network standards used by CCM systems to enable effective communication.

The air interface for RFID is managed by the ISO 18000 network standard [12]. The ISO 18000-1 standard defines the generic parameters for global air interfaces and the ISO 18000-2 to 18000-7 standards define the unique parameters according to the frequency range for device communication. These standards provide guidelines for the use of RFID tags in an integrated sensor network.

While most commercially available passive UHF RFID tags follow the ISO18000-6C standard [13], this is not true in the case of active RFID, where only a small fraction of available solutions are based on the ISO18000-7 standard. Table 2 indicates what network standard is used with different kinds of RFID.

Table 2: RFID networks standards used [13]

Interface Type	Frequency	Range	Example Standard
LF	125 kHz	30cm	ISO 18000-6A
HF	13.56 MHz	1m	ISO 18000-3
Active RF	433MHz	1m+	ISO 18000-7
Interface Type	**Frequency**	**Range**	**Standard**
UHF	850-950 MHz	10m +	ISO 18000-6C
Microwave	2.4 – 2.45 GHz	100m +	ISO 18000-4

These standards provide a margin of flexibility to enable the interoperability of multi-vendor devices. ISO 18000-6C for example enables the use of sensors with the network devices and requires that a read operation be completed within a defined period so enabling multiple tags to be read by the reader and operation to take place with a broad range of variability [8]. Standards based RFID is limited to communication ranges up to hundreds of meters; to add the ability to communicate over longer ranges, the use of GSM or satellite communications is required. The digital nature of GSM allows for synchronous and asynchronous transmission of data to and from ISDN terminals [14]. GSM operates on the 900MHz and 1.8GHz frequency bands, providing a 64Kbit/s signal for data transmission over long distances to the appropriate party for analysis [13]. This speed is greatly enhanced by development of the GPRS standard, with GPRS up to 115Kbit/s in the 2G network and the latest 4G standard providing up to 100 Mbits/s for mobile applications, not including the upcoming 5G standard. The speed available to CCM systems will depend on network availability and the standard supported by this network.

2.3 Technological solutions

The implementation of technology for CCM has been applied with varying degrees of success in many application areas to enhance the visibility of the environmental conditions of consignments.

The type of technology used in a container directly influences the data that can be acquired and the level of control over the monitoring operation during transit.

2.3.1 The Influence of mobile technological solutions on cold chain management

The growth in size and complexity of the logistics industry has led to a growing need to progress from traditional methods of temperature monitoring and data logging [15]. This is where RFID and GSM technologies have become a vital part of any sophisticated logistic chain. These technologies have the ability to store thousands of data samples during transit [7] and either relay this data in real-time to a web application or store the information for retrieval once an RF connection has been established.

This shift to mobile technology has proven that enhanced traceability of a consignment and the retrieval of large quantities of data from many sensors with little to no human participation is possible [12]. To truly understand what the different technologies are capable of the functionality of RFID and hybrid GSM/RFID solutions will now be discussed.

2.3.2 RFID technologies

RFID is a relatively new technology in cold chain management that can add much value in terms of detailed visibility but that is also relatively complex to deploy. In order to justify its use within a specific scenario it is essential to first determine the expected ROI (return on investment) in order to decide if the technology is worthwhile to implement [16].

RFID sensors can fall into one of three possible categories: passive, semi-passive and active. Each category has essential characteristics that make it ideal for specific applications. The different types are compared in Table 3

Table 3: Comparison of RFID tag categories [8]

Tag Type	Passive	Semi-Passive	Active
Power Source	Harvesting RF energy	Partly Battery	Battery
Communication mode	Response only	Response only	Respond and initiate
Max Range	10m	>10m	>100m
Relative Cost	Least Expensive	More Expensive	Most Expensive
Example Supply Chain Applications	Spotting items at defined points	Continuous monitoring of status of tagged items with data collection upon return	Real time monitoring of status of tagged items

The primary differences between the types of RFID tags are the ability (or not) to continuously record the current status of the tagged item, as well as the ability for real time retrieval of such data, which depends on the read range over which information can be retrieved from the tag. While passive RFID is used to only spot the presence of a tagged item passing a point where a reader has been installed, semi-passive and active RFID can record data continuously and communicate over longer ranges. RFID sensors come in many shapes and sizes and operate uniquely to the application it has been developed for. Several factors can influence the functionality that is achieved within specific applications; these include the physical environment and the physical properties of the material the sensor is placed on [13].

Wireless sensor networks (WSNs) can also contribute towards cost and energy effective cold chain monitoring, as they can provide sensors with the ability to relay data via other sensor nodes in the network. The combination of the individual sensors within a WSN allows the environmental status to be monitored with a higher degree of accuracy than what would be possible if all sensor nodes had to communicate directly with a reader node or hub [17]. The ISO18000-7 protocol for active RFID provides for the option of communication between tags in order to effectively implement a WSN. The application of interpolation techniques that use available temperature data to calculate temperature values in other sectors in the consignment where no sensors are placed can provide improved scalability and portability to sensor networks as it can reduce the unnecessary cost of additional sensors [18].

In order to extend the capabilities of WSNs to roaming networks that deliver real-time data to a data centre, the WSN must be connected to a communication device capable of roaming. The most effective way to enable roaming sensor networks to deliver real-time data is its integration with cellular technologies to enable long range communication of the WSNs [18].

2.3.3 Hybrid solutions: GSM/GPRS and RFID systems

The integration of cellular technology such as GSM and GPRS with RFID into a WSN provides an efficient method to enable real-time monitoring of a consignment in transit [19][20]. The technology is however limited to the cellular network coverage in the regions where the consignment is transported. In Africa this solution would work effectively in Nigeria, Egypt and South Africa with varying functionality in the other 51 countries[21]; in other African countries this method for remote communications can become very expensive due to roaming charges amongst different network operators.

A hybrid system consists of the combination of RFID sensor tags with a RFID reader that has cellular communication capabilities. The data is read from the tag’s internal memory and then encapsulated into a data package according to the protocol being used and send to a data server. The layers of encapsulation is then removed by the middleware and stored into the database, from where the user can access the data through a GUI designed for the system [10]. This system topology is shown in Figure 1.

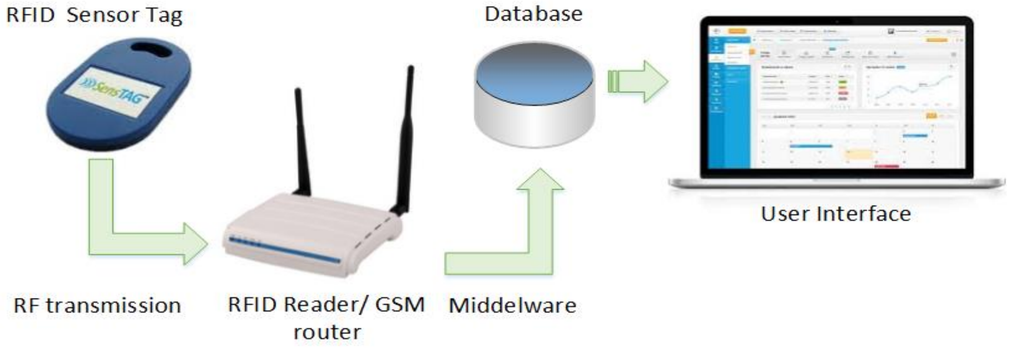

Figure 1: Hybrid system topology

The real-time monitoring benefits of such hybrid systems based on the added visibility of the cold chain are clear. The user, which includes the cargo owner and the LSP, is provided with the ability to check if the internal cargo temperature of a consignment is maintaining the cold chain requirements for the specific product. Besides the real time monitoring capabilities the system can also aid in establishing accountability for damage to goods in case of failure to maintain the cold chain standards, by recording at which point the cold chain thresholds were exceeded. This can protect a service provider from illegitimate claims for compensation if a consignment is indeed lost.

2.4 Solution integration and environmental analysis

Each supply chain has its own obstacles [22]that must be overcome to achieve effective temperature tracking. In our technology survey as described in Chapter 4 a group of different technological solutions available for CCM where evaluated to identify the limitations and abilities of each option. In this section the application of the different systems in different scenarios are investigated.

The first system consists of standalone data loggers placed on the interior of the container wall and within the consignment. These data loggers have the ability to measure the immediate ambient temperature with an accuracy of ±0.2°C; there is also the possibility for external probes added to the data logger for internal temperature measurement. The loggers can typically store between 1000 and 16000 data samples on its internal memory. The sampling rate can be defined using a custom software application. The primary limitation of this option is the lack of any remote communication and the need for manual data retrieval, which is based on a USB port or through a magnetic reader.

An alternative to the standalone data loggers are GSM sensor units [23]. The devices generally offer two options to monitor temperature: they are either equipped with an internal sensor or they can support external wired and/or RF sensors to monitor the temperature/humidity of a container. The unit is typically installed inside the container wall in a position where the airflow in the container converges and where the most accurate measurement can be taken. Real-time monitoring of air inflow temperature and optional position tracking is possible. The unit generally requires an external antenna to connect to the mobile cellular or satellite network. This may require modifications to be made to the container to place the antenna in a position with the lowest signal attenuation. The units can store between 4K and 16K of data on its internal memory. To limit the roaming cost of these devices the system must be configured to either send data at pre-determined intervals, on request by the user or when a specific set of conditions is satisfied (e.g. when a threshold is exceeded).

The next option is the use of RFID tags with internal data logging capabilities that are embedded within the cargo and read by readers installed at the depots. The tags have up to 16000 sample internal storage capability and log data on a FIFO basis. The communication range depends on the type of tag/reader combination and the amount of tags that can be read simultaneously as allowed by the network standard used. The data read by the readers are relayed to a web server where it is analysed by a software agent. The reliable retrieval of the RFID tags from a consignment is a significant practical obstacle that can lead to equipment and data losses.

A further alternative is for a reader to be installed inside the container to retrieve data in real time from tags embedded in the cargo or mounted on the container walls. The collected data is stored on the internal memory of the reader and is sent to a central server when the container is in range of the selected wide area network. This can either be a Wifi network (which will limit the retrieval of data to take place when the vehicle enters a supplier or customer depot) or it can be a cellular network that will enable real time data retrieval when required. In this setup the tags can either store data internally or relay the measured data to the reader inside the container.

When the tags are not equipped with internal memory and must communicate continuously with the container reader data may be lost in case of a temporary break in tag-reader communications due to the screening effect of the cargo itself. Tags without internal memory therefore represent a less effective solution to manage the cold chain. GSM systems further have vulnerabilities due to coverage differing along each route. In the blackout areas real time communication is not a possibility and data is only forwarded when the network coverage is re-established with sufficient signal strength.

2.5 Chapter Summary

The literature presented in this chapter was concise and discussed the technology and infrastructure available in the industry according to the reviewed documentation. The discussion detailed the functionality of different technology and theire use in general.

From this chapter it was evident that there exist different network standards that is implemented in the systems available on the market. The literature showed that these technologies function differently and the communication ranges are dependent on the operational frequency and communication protocol applied. The hybrid solution that is the combination of RFID sensor tags and a GSM base station responsible for the collection, storage and relay of data presented the best solution for CCM applicability. The purpose of this chapter is not to provide overwhelming detail but rather to aid in further discussion and as background for the technology that will be discussed in the chapters that follow.

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Chapter 3: Operational Analysis of CCM in Industry

3.1 Chapter Overview

In chapter 2, we reviewed the currently available technology in the different areas pertaining to cold chain management. In order to establish what the actual needs of the clients in the industry are, an in-depth review of the processes applied in the different areas of the industry must be completed. In this chapter we will review these process from research completed in the field by means of interviews, questionnaires and accompanied cross border trips with a LSP as included in Appendix C. This will provide the core structure in which a system designed for CCM operations must fit to provide any benefit for this industry. We will take a look at the four major links in the cold chain of perishable goods and from this evaluation define the minimum user requirements for goods being processed through the chain.

3.2 The producer

The producer forms a core part of all cold chains and the importance of strict control of temperature and handling procedures of the produced perishable goods are of the highest importance. The individual handling of items at this point will determine the shelf life and quality that will reach the consumer at the end of the chain. As soon as either fruit or vegetables are harvested, the internal natural degradation due to enzymes in the goods will start [24]; it is thus of great importance to process and cool harvested goods to the appropriate temperature as soon as possible after harvesting to slow this degradation process [3].

3.2.1 Operational Overview

The operation at each producer varies according to the type of perishable goods produced, the size of the producer and the standards set by the individual producer's clients. These three factors influences the quality of goods delivered. A generic flow for the harvesting and processing is shown in Figure 2: The post-harvest process at the producer. The process followed is strictly dependant on the three factors mentioned before. Some of the steps may not be applicable for all perishable producers though.

Before harvesting commences in the case of root and bulb perishables, they can be treated with sprouting suppressants six weeks before harvest to prevent rapid sprouting before they reach the consumer. Once the harvest has been prepared in the correct fashion according to the producer's harvesting standard the harvesting from the field can start. The produce is then harvested in one of two methods: either by means of hand or by using mechanical equipment. The harvest is then collected in bulk to be processed at the local processing centre on the farm. Once the harvested items reach the processing centre the harvest is cleaned by means of pure/treated water or air to remove all undesired particles and microbiological agents from the goods that may result in reduced quality delivered. Once cleaned to an acceptable level the goods are processed according to type and environmental needs.

Root vegetables are sorted according to their quality and dimensions, bulbous perishable such as onions and garlic are firstly dehydrated at temperatures around 30ºC, sorted and then cooled. Highly perishable goods like strawberries are cooled as soon as physically possible to reduce the degradation tempo due to respiration. When cooling perishable goods care must be taken not to cool at too high tempo to prevent cooling damage to perishable goods that negatively influence the quality and shelf life of goods.

After the goods have been cooled to the appropriate temperature it is either packed and prepared for shipment and later processing or processed and then packaged for shipment. During this process an average temperature of 4ºC is maintained for the optimal shelf life of goods [24] . After the products has been packed and placed on pallets it is continuously cooled until loaded by a LSP at the loading bay of producer site. Products are then shipped from the producer to a distribution centre, local market or directly to the vendor for distribution to the consumer.

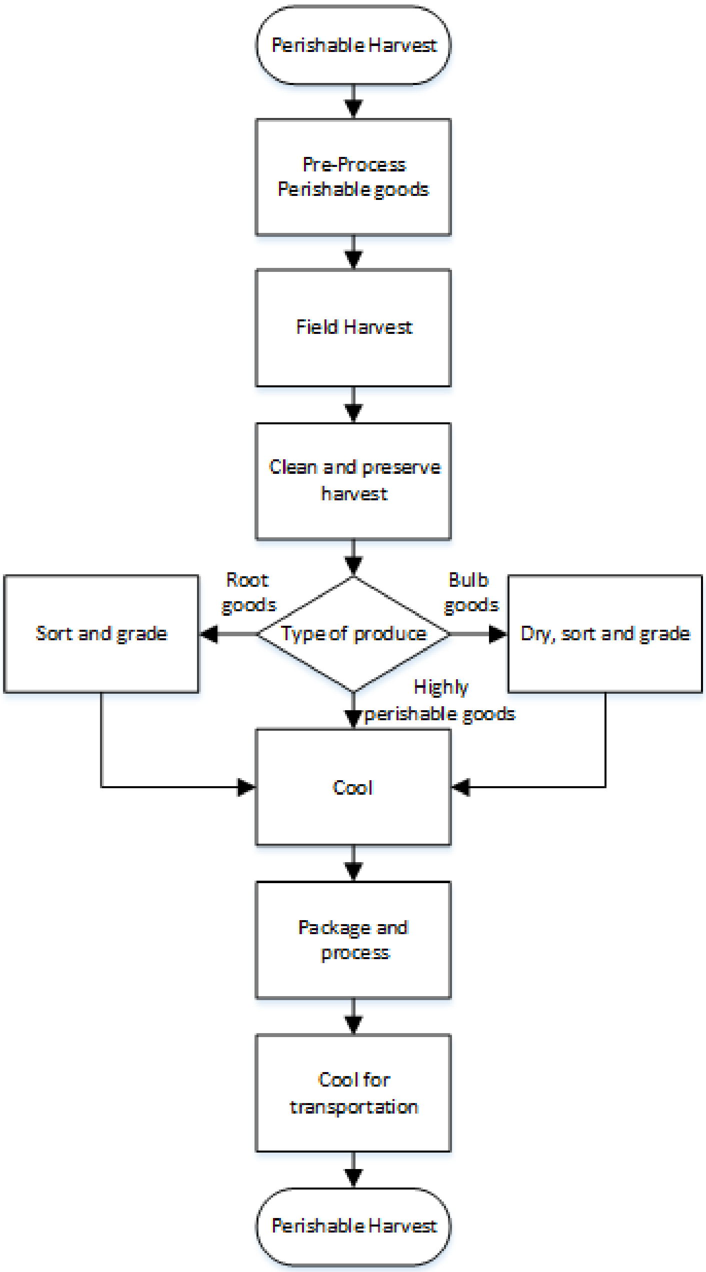

Figure 2: The post-harvest process at the producer

3.2.2 Perishable losses

During this initial phase in the value chain little to no losses is observed due to temperature. The highest degree of losses occur due to handling errors that occur during harvesting that cause external damage to the perishables. Losses of 1% to 5% has been seen from questionnaires and research conducted at farms such as York farms and Tata farms. In this stage little to no visible damage is apparent to goods because of its relative freshness. This is non the less one of the links that contributes the most towards a hastened degradation of the perishables due to slow processing procedures during the initial stages of the post-harvest.

3.3 Cold chain logistics distribution centre (CCLDC)

The CCLDC is the next import link in the cold chain that serves as an intermediary link between producers and vendors. The purpose of a CCLDC is the accumulation and consolidation of goods from different geographical areas under one roof to enable processing and rapid delivery to vendors from a single point of distribution [25]. By using such a value added service warehouse the cold chain can be better maintained: as the CCLDC is in closer proximity to vendors it can act as a logistics hub, thus reducing the risk and cost of transportation between multiple producers and multiple vendors.

3.3.1 Operational overview

Similar to that of the producer, the internal operation of each CCLDC has unique processes that are applicable to that specific CCLDC. Although the high level operation differs vastly the core operation of a CCLDC in a supply chain remains the same with the focus on maximising throughput. This is done by using a warehouse management system (WMS) to achieve a higher level of efficiency. A generic operational flow at a cold distribution centre is shown in Figure 3. This figure describes each phase that perishable goods go through when arriving at the DC until it is shipped to the vendor site.

When a LSP arrives at the DC the driver provides the operations agent with the consignment details, inventory and inspection details. The operations agent compares the information to that received from the producer prior to shipment. The temperature on delivery is then verified and if the environmental temperature is within the range specified in the documentation the quality assurance officer (QAO) will evaluate the consignment as it is being unloaded.

The purpose of the QAO is not only to determine the physical quality of perishables by means of its appearance, texture, flavour and aroma but also to verify that the internal contents of consignment reflects the information indicated on the packaging according to size and grade. Whilst unloading the QAO do spot checks on each pallet and take internal temperatures of the perishables by using a metallic probe sensor; this temperature is then compared against the temperature parameters for the specific type of item.

If the consignment meets all the criteria the consignment is moved to a pre-storage cold room. This room is normally set to generate a temperature between 3 to 6 ºC. This is a necessary action to dissipate the thermal energy the consignment may have absorbed due to solar radiation that may have impacted the perishable goods during the unloading process. If the consignment does not meet the criteria, and the perishables are either rotten or damaged beyond salvageable limits the entire consignment is discarded. When the consignment is still within safe consumption levels but does not meet the quality and specifications ordered from the producer the consignment is either returned to its point of origin or sold at the local market for a lesser value.

Dependant on the order specifications of the pallets in the consignment, they are either moved to processing, where the whole fruit and vegetables are sliced and packaged. The food processing is done at this stage by professionals under stringent health protocols and within a contained cold environment of 4ºC. In the case where the perishables are not processed they are moved to the main storage area for cargo storage and rerouting to a client.

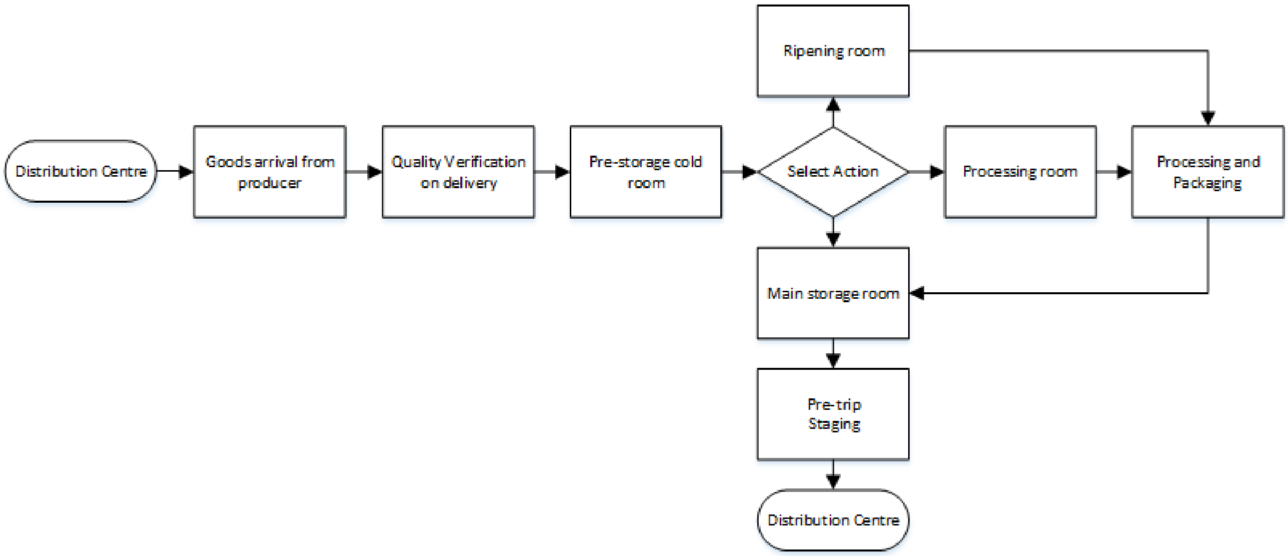

Figure 3: Operational flow for a DC from arrival to departure

If the received items are not ripe enough on delivery the perishables are moved to a ripening room. In this room the temperature is raised to 2ºC above room temperature to hasten the natural degradation of the perishables and aid the ripening process. Once the perishables have obtained the right degree of ripeness it is either moved to processing or moved to the main storage area and stored at a temperature between 0 to 3º C on well stacked pallets.

The perishables are stored in this area until an order is received from a client for delivery at their site. After the order is received the pallets are processed to meet the order requirements and then moved to a staging area. If the items have been stored in the proper cooled area no further cooling is required and the items can be directly loaded. When the load is received from the producers and must be reloaded on the same day the perishable goods are flash cooled in units to lower the internal temperature to a safe temperature to be prepared for loading.

3.3.2 Perishable losses

Losses at this point in the value chain is can be contributed to the fact that most of the smaller producers do not make use of the correct transportation methods in order to save costs. As example of this is a consignment of apples from the Western Cape being delivered to a

Johannesburg DC by an open truck with the only temperature control being a plastic sheet covering. Even if this consignment passes all QAO checks the internal degradation tempo has been highly accelerated during this period that drastically reduces the remaining shelf life of the goods. This degradation will usually only be observed at the vendor and consumer links in the cold chain.

Cooling damages can also occur in this phase if similar methods to the above mentioned process was followed and the perishable are cooled at too high tempo to rectify upstream problems. Too rapid processing of goods reduces the shelf life of perishables from weeks or months to days even if maintained in the ideal temperature conditions. Losses of up to 7% has been reported during these phases due to the different problems as mentioned.

3.4 The logistic service provider (LSP)

The LSP is the part of the link in the chain responsible for the safe transportation of goods from the producer to DC and from the DC to a client or vendor site. For each of these legs in the chain different LSPs' are responsible for the transportation of the goods that can pose an additional risk to the enforcement of temperature conditions for the perishables being transported. Similar to the previous links discussed each LSP has its own unique internal process of perishable handling and temperature control standards.

3.4.1 Operational analysis

In order to properly evaluate the process a LSP follows from loading perishables at a distribution centre to delivery at a vendor site multiple trips have been accompanied and observations recorded. The majority of these trips involved the transportation of perishables from DCs in Johannesburg to vendors in Zambia, Lusaka and then from producers in Lusaka back to DCs in Johannesburg; this route is depicted in Figure 4. For the depicted figure the upwards route travels through Botswana using the Groblersbridge and Kazungula ferry border posts to Zambia, whilst the return trip was taken through Zimbabwe using the Churundu and Beitbridge border posts to Johannesburg.

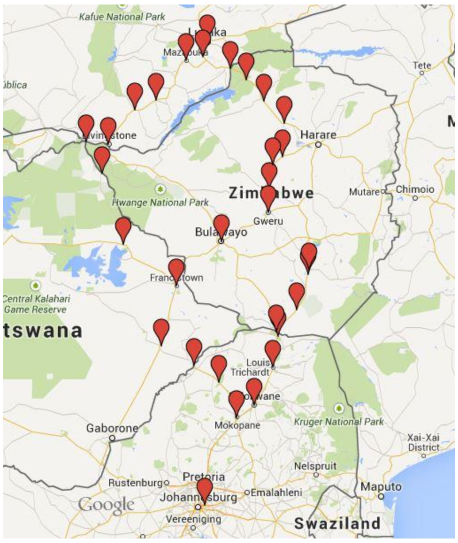

Figure 4: Route depiction of LSP delivery

In this figure only two routes are shown but in the CCM industry there are multiple routes, each with its own characteristics and turnaround times. Our research provided evidence that although each LSP has uniquely processes they all follow the same general procedures as described above. Given the risk of potentially long delays at border posts and other unforeseen events it is important for all these operators that resources are allocated to optimise the overall logistic operation, including the use of monitoring equipment to ensure the best quality of delivered goods at the client site.

To start the logistic process a LSP receives an order from a client stipulating the following information:

- The information of the hiring client
- The loading destination
- The information of the contact person at the loading DC
- The delivery destination
- The information of the contact person at the delivery destination
- Dates and times when the consignment needs to reach its destination
- A manifest of the goods that need to be transported
- The required paperwork such as paid duties for international travel etc.

The LSP then utilizes this information to plan a consignment to the client’s site; this can either be a vendor or a local DC. The planning phase is a complex process that focusses on the effective use of resources to ensure maximum financial returns. The consignment planning phase consists of the following main areas.

1. *The horse and trailer configuration allocation*

   This planning attribute is linked to the order received from the client. The truck and trailer type and size depends on the consignment inventory; the resources availability; maintenance record and fuel storage capability. Among others these four attributes form the central part in the selection of trailer for the consignment. The first defines the type, length and haul weight the trailer must be able to service. The second allows the LSP to schedule a trailer for maximum capacity utilization whilst the third provides information on the reliability of the resource and defines the usability of it for the specific route. The fuel storage capability defines for how long the trailer can provide cooling for a consignment. This not only directly influences the amount of time a vehicle can afford to wait at a border post before the consignment starts to degrade but also influences the cost of a trip to the LSP and thus to the client.

2. *The driver allocation*

   The driver is one of the most important assets in the LSP arsenal, as this person directly influences the turn-around time, fuel consumption and safe delivery of the consignment to the client. In many cases the driver is automatically linked when allocating the truck to the consignment. Thus it is important to include all pertinent information on driver history and performance when making this management decision.

3. *The fuel required for the trip*

   This attribute influence both cost to client, the maximum stand time at the border crossing and distance that can be travelled before refuelling. When planning a delivery for a consignment the LSP normally specifies authorised refuelling stations along the route where drivers must refuel. These refuelling stations are prepaid by bank transfer for a specific amount of fuel as calculated to be required at this point. The truck is refuelled at the station to the pre-purchased amount; if a larger amount of fuel is required (e.g. due to fuel theft on the route) the LSP is required to pay the balance before the vehicle is allowed to leave. When less fuel is acquired at this point the remaining amount is repaid to the LSP. As can be understood this can directly influence the turnaround time, risk to consignment and cost of the trip to the LSP.

4. The load control

   After the truck and trailer have been selected for a specific consignment the LSP is responsible to make sure that the load meets the road regulations of the entire route to be travelled for the delivery. Each country has its own specific set of rules when it comes to road transportation, thus to ensure no delays or fines are incurred the load is weighed before departure. This ensures that each axle is within the applicable regulations and that it is safe to embark on the trip. Furthermore when a consignment is loaded there is a clear maximum height beyond which no pallet may be loaded. This serves a dual purpose goal: firstly to prevent the reefer trailer to be top heavy and secondly to ensure that cold air is dispersed over all items in the consignment.

Once the LSP has successfully completed the trip plan that includes all the above mentioned attributes and the execution thereof, the vehicle can be dispatched to the loading site. An overview of the LSP's operational process is depicted in Figure 5 below.

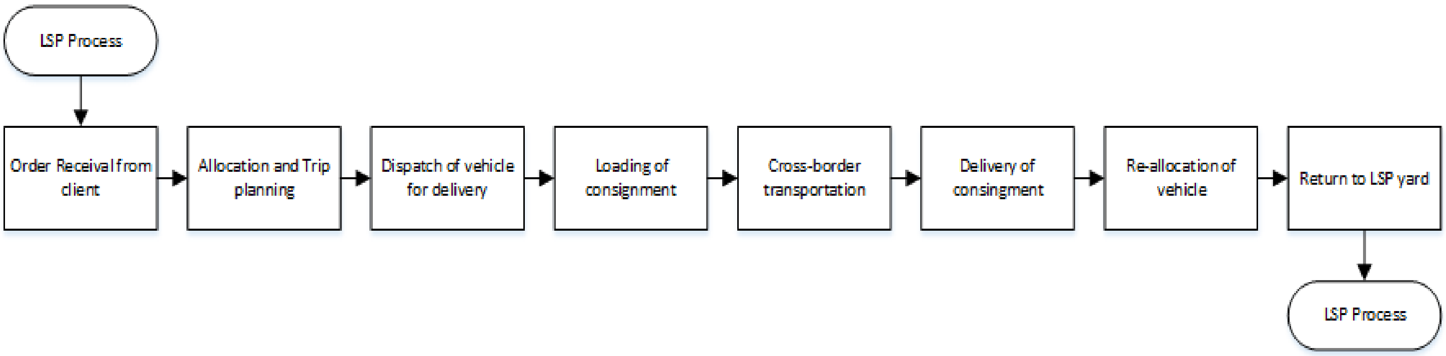

Figure 5: LSP operational overview

Before loading a reefer is precooled to the required set point for the consignment. This temperature may reflect the requirements set by the client or it may be set to the general average of 4ºC. Each pallet to be loaded may not exceed a height of 1.8m to still be under the height of the red line described earlier in chapter 2. Each pallet can consist of a mixed set of perishables; the contents of the pallet will determine the physical placement of the pallet in the trailer to match the temperature requirements with the expected temperature distribution at that point.

In Figure 6: Full-load pallet placement orientation the general configuration of a full load of 25 pallets is shown. This configuration is the general configuration for a reefer of 15.2m and is specifically orientated to distribute the mass optimally between the axes and link of the truck. The higher mass pallets, for example the potatoes, are always packed at the back of the trailer between positions 21-24 to place the greatest mass directly on the axes. During the loading process each item is counted and confirmed by the loading agent. On completion of the loading process the doors are closed in the loading bay and sealed by a security lock with specific identification code that is indicated on the document of transportation.

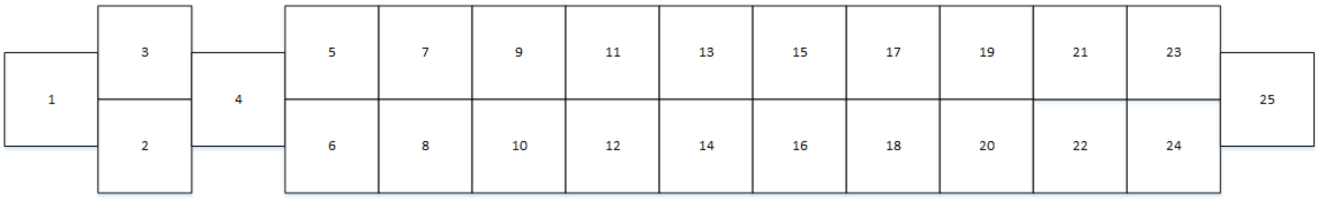

Figure 6: Full-load pallet placement orientation

On completion of the loading process the consignment is weighed at a local static scale to ensure the weight does not exceed the maximum allowed weight for the trailer and horse and also that allowed by regulation for consignment travelling on the route through various countries. The document stipulating the weight of the total consignment and that of each axle is attached to the trip documentation. On route the truck is weighed and measured by the relevant road agency by means of static or weigh in motion scales.

The time dispensed at each weighing station can last from minutes to hours depending on factors such as the route, time of year and the effectiveness of the employees at each station. If the consignments meets the stipulations for the cargo and is within the road regulations the truck is allowed to continue to its destination, otherwise the consignment is held and fined dependant on the breach. This can cause additional delays in the delivery if goods that can influence the quality of goods delivered, thus the importance of strict control in line with these regulations is clear.

When the vehicle arrives at the border post there are often queues that the trucks must fall into before it can be processed and allowed to cross into the bordering country. Special consideration is given to goods of a perishable nature being transported and it is customary for such goods to be pushed up in the queue to reduce waiting time. Many LSP's make use of running agents at the crossings to hasten the processing proses to allow the consignment to be cleared and to enter into the next country. The driver then provides the border agent with his passport and the payment of entrance duties to transport goods through a country. On completion of this phase the vehicle is allowed through the first gate and in some cases weighed and scanned inside the border crossing. This cross border process in depicted by Figure 7.

The scanned consignment is verified according to inventory list before it is cleared; this procedure is applied to ensure that non-listed goods are not smuggled into the country. Once the consignment has been cleared and the duties has been paid by the client for the importation of goods the vehicle is released to continue to its destination. Until the consignment is cleared the vehicle is held in a parking area; the clearing process can take from one hour to a couple of days. For the transportation of perishables this can be a critical problem due to the degradation of goods and the limited fuel the reefer has available. When the fuel nears depletion the LSP needs to get special permission to be escorted by border police to the nearest fuel station and back to the holding area.

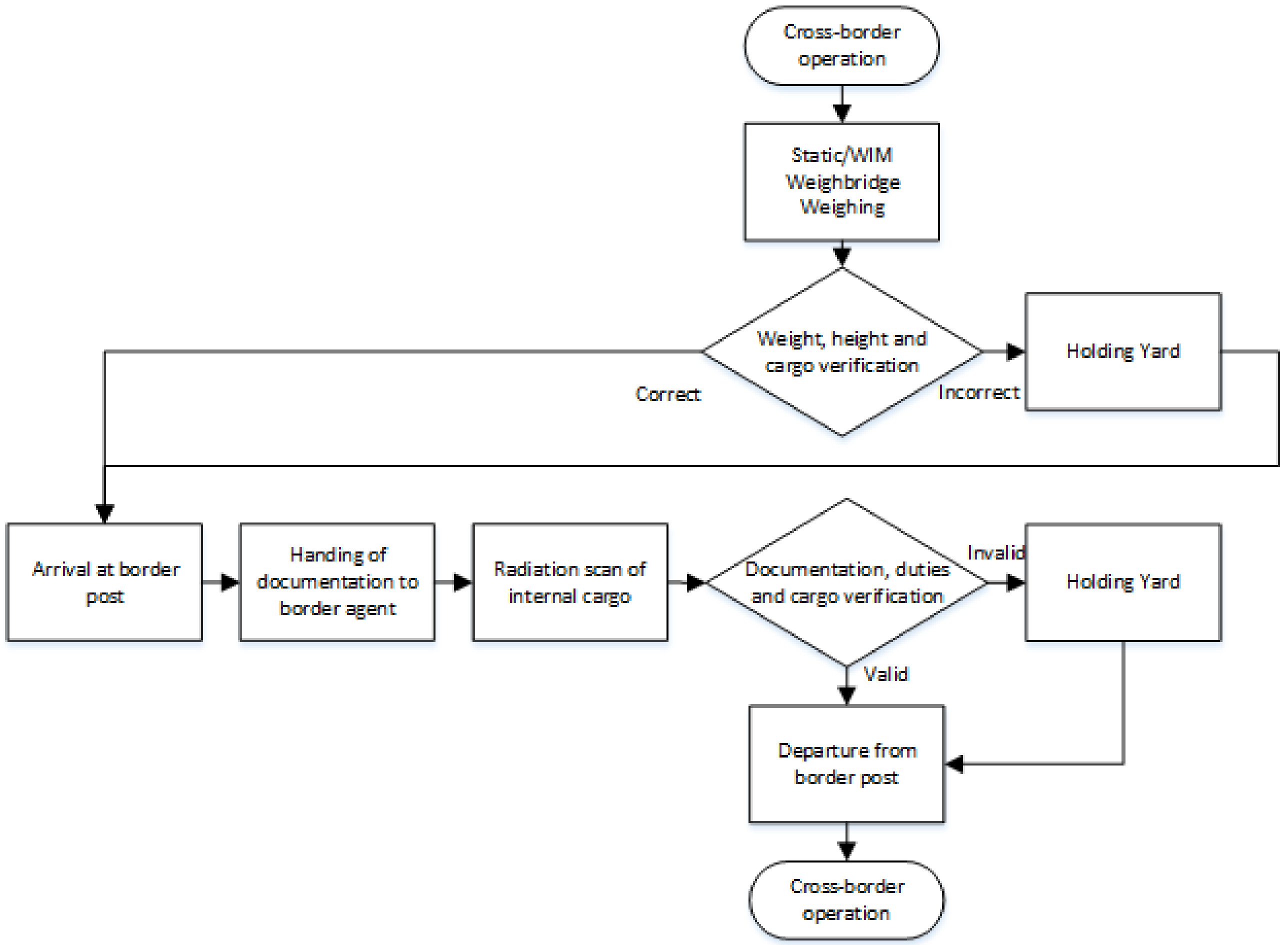

Figure 7: Cross-border operational flow

When the consignment has completed its journey to the delivery address the driver provides the receiving agent with the manifest, temperature regulation and delivery information. In the stipulated loading area the doors are opened and the items are off-loaded on a pallet by pallet basis. The pallets are then placed in appropriate areas, each with different temperatures, according to the temperature sensitivity of the perishables on each pallet. Each pallet's items are then counted and the quality verified according to the documentation provided. After verification of each pallet the goods are moved to the cooling room of the client. The unloading process takes an average time of between 20-30 minutes; during this process the reefer doors are open and the refrigerator continues running until the of loading process is completed.

3.4.2 Perishable losses

The amount of losses that are experienced by LSPs' greatly vary between the providers. This is due to the quality of equipment and reefers used by them. From various sources it is seen that the losses from the transportation of goods at this level can vary from 4% to 40%. This loss refers to the amount of cargo that makes up the consignment being transported.

In Figure 8 below the general rule of thumb for the temperature deviation in a reefer container is indicated. As seen here there is a 15% to 40% deviation in the back half of the reefer container. The biggest losses occur in the back 5m of the trailer, which further explains why less temperature sensitive goods such as potatoes are placed there.

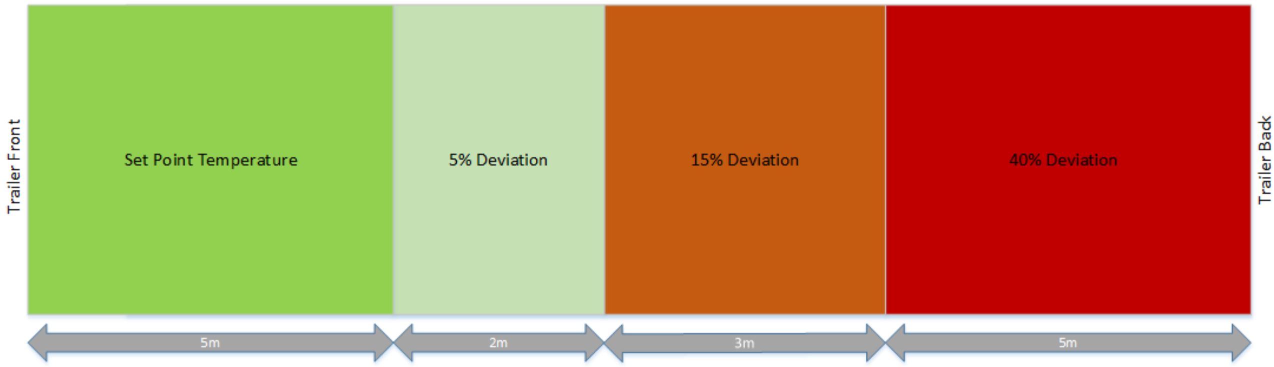

Figure 8: Rule of thumb temperature deviation in a reefer

3.5 The vendor site

The vendor site is the final step in the cold chain before perishables reach the consumers. Many of the losses occur at this point in the chain due to exposure in the transport links prior to this point. In the evaluation of vendor sites interviews with managers at SPAR, Checkers, Pick n Pay, Woolworths and Fruit and Veg city were conducted. Each vendor enforces a specific set of rules defined by their corporate and individual owners to prevent as many losses as possible and provide consumers with the highest quality of goods.

3.5.1 Operational overview

The operational parameters each vendor follows from arrival of a LSP at their site to the presentation of goods in the refrigeration units for consumer purchase is shown in Figure 9. On delivery of the consignment at the vendor the perishables are processed according to the method described in the previous subsection. The temperature on delivery is verified to gauge if the LSP has satisfied the required temperature for the perishables. The temperature specification for loading bay where goods are loaded and unloaded; the temperature of the cold room where to the goods are moved after offloading at the loading bay and the duration of this unloading processes are indicated in Table 4.

Table 4: Vendor temperature application temperatures

	Off-loading period (min)	Loading Bay Temp. (ºC)	Site Cold Room Temp. (ºC)
Vendor 1	40	10	4
Vendor 2	35	15	4
Vendor 3	25	10	5
Vendor 4	20	8	4
Vendor 5	35	15	6

The quality of the goods is then verified and if the majority is within the acceptable range set for the specific vendors, the perishables are moved to the vendor cold room that is kept at 4ºC. The local management system is then updated with the items to define the inventory of goods available to the vendor to be utilized within the store. When items are then required from the cold storage room the required amount is moved to cold storage facilities on the customer floor; during this process it may be exposed to room temperature for a period of up to 15 minutes or more depending on the efficiency of the staff.

Temperature sensitive goods such as fruit and vegetables are then stored for customer consumption in open fridges set to a temperature of 4ºC. The fridges of the larger vendors are wirelessly linked to the management system to ensure that temperature of the goods stored within is regulated to the required temperature. When errors occur in the cooling mechanism supervisors are immediately notified to allow such mistakes to be corrected.

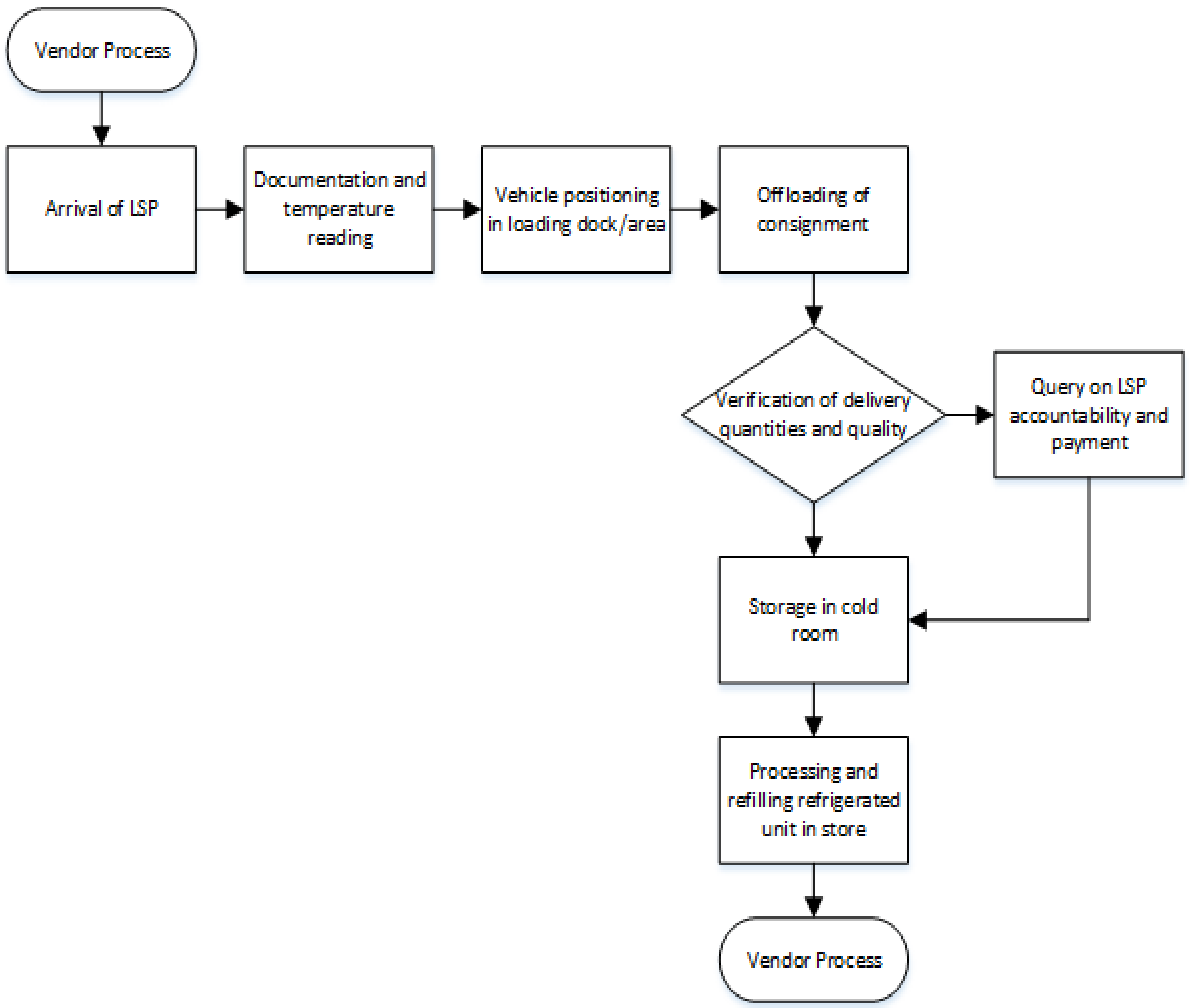

Figure 9: Vendor Process

The losses occurring at the vendor more often than not take place due to consumers removing goods from the regulated temperature environment and placing them outside the cold storage areas at room temperature; this contributes to a further uncontrollable 3% - 5% of losses in goods. The final losses are due to mismanagement and statistical imbalance in the consumption rate predicted for the perishable due to shelf life expiry. Better control of temperatures in each of the prior links will reduce the losses in this final stage due to its measurable influence on remaining shelf life by the time that is reaches the retail store.

3.6 End user requirement summary

The complexity of monitoring perishable cargo in the supply chain derives from the fact that, due to the microbiological processes within the perishables itself, temperatures cannot be expected to be uniform throughout an entire cargo consignment. Ideally the temperature of the cargo itself should be monitored, rather than only the temperatures on the periphery of the reefer in which it is transported. This implies the need to communicate wirelessly with sensors that have been embedded inside the cargo.

Some important research questions are: What is the required number of points to be monitored within each type of perishable cargo, how often measurements should be taken and how frequently this data needs to be communicated to the outside world to prevent losses.

Each of the links in the chain defines different requirements for cold chain management. To effectively control the quality of perishables the temperature fluctuation over the complete chain must be monitored and controlled [26].

Most producers display limited concern regarding the control of the cold chain and tend to apply relatively lax enforcement of temperature control, depending on the size and sophistication of the producer. The ability to measure the temperature of a perishable forming part of a bulk harvest is extremely difficult and is only controllable when the perishables are pre-processed. Once the goods have been processed sensors can be attached to the goods to initialise the monitoring process to gauge the shelf life of the goods that reach the DC, LSP and vendor. This will allow each agent along the chain to actively quantify the quality of perishables received. Unfortunately the control in this manner is only possible when the producer, DC, LSP and vendor use the same set as standards such as applied by Woolworths in their chains.

The requirements of these four phases can be specified as:

1. Temperature sensing in the warehouse area; inside trailers and on the vendor floor.
2. Wireless sensors on pallets prepared for transportation with possible real time reporting for sensitive goods such as strawberries.
3. Communication with the management system to alert abrupt temperature changes on the consignments.

On arrival of the goods from the producer the process of quality verification can be clearly sped up by means of semi-automated confirmation of historical temperature data for the goods. This can only be accomplished if the producer and the DC employ compatible processes and standardised equipment to ensure interoperability with the systems of both entities involved. The requirements of the DC in the operation discussed previously can be summarised as follows:

1. A per pallet measurement tool to notify management of the temperature and humidity of the storage environment.
2. Real time feedback to the warehouse management system of environmental conditions.
3. Identification of goods as well as environmental conditions to trace the placement and control of goods locally and link such information with the management system.

The LSP requires the ability to trace the temperatures experienced by fruits and vegetables during the transportation from the distribution centre (DC) to each vendor site where deliveries are made.

As discussed the goods may travel through several steps in the logistic chain until it reaches its delivery site. Throughout the entire process strict temperature guidelines must be adhered to in accordance with temperature logistics standards. An example of these standards are as follow:

1. Produce arriving at the DC must be kept at a temperature below 5°C
2. During processing at the DC items must maintain a temperature value between 3°C to 4°C
3. Produce leaving the DC must be kept at a temperature below 5°C during loading and transportation
4. During off-loading the produce must at no time exceed 6 °C

This general process for distribution chains used by players such as Woolworths is depicted in Figure 10; it shows the process between the supplier, DC, customer site and Equipment Centre (EC). In some cases the EC and DC may be the same site of operation to enable a greater amount of equipment to be reused in the field.

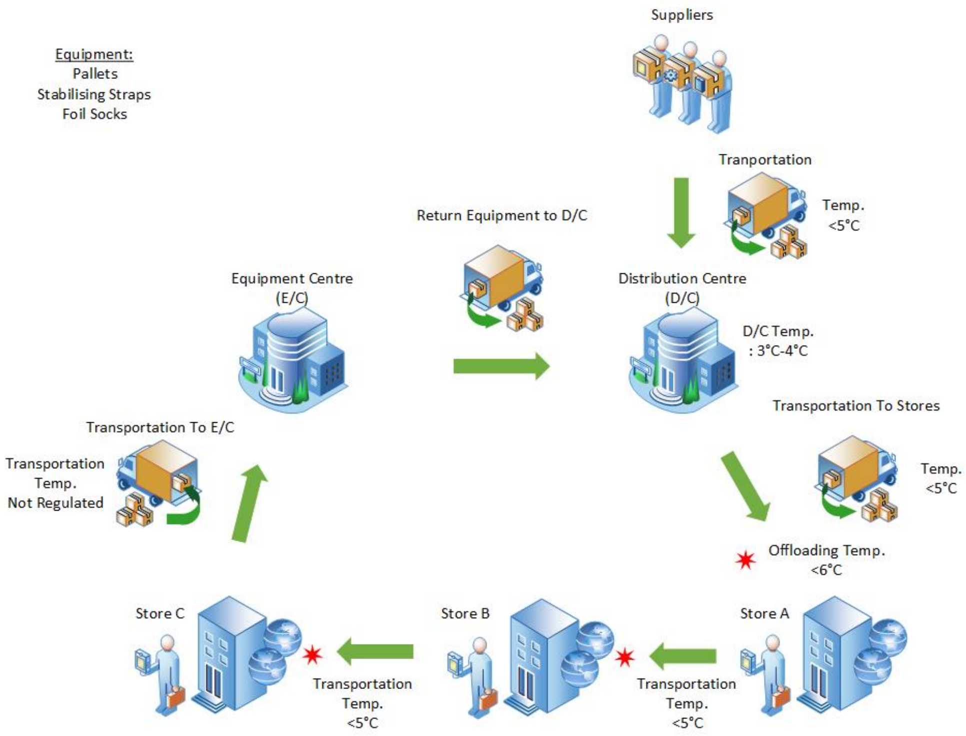

Figure 10: The Distribution Chain Overview

As discussed, the ability to monitor the temperature accurately and dependably in the logistic chain is of critical importance. Some companies aid this ability to ensure perishables is not damaged by temperature fluctuations through the use of pallet socks.

Pallet socks are made of an isolative material such as nylon that is typically lined with a foil centre to aid in the thermal protection of perishables. This simple tool although not used by all vendors greatly improve the ability to control the internal temperature of goods, if the goods had been pre cooled to the required temperature before transit.

The logistic chain between the DC and retail stores is the main area of concern as deducted from the previous analysis in this chapter. The proposed temperature monitoring process and data communication methodology for the cold chain is described in Figure 11:

- Before a consignment is dispatched the identity of each pallet going to a site is captured and a subset of pallet socks are equipped with RF temperature sensors that are linked to the consignment and its destination;
- When a delivery is dispatched from the DC the temperature monitoring will commence and all measurements are logged on the RF temperature sensors.
- The data stored can then either be transmitted continuously, on request, sent in intervals to a web server or only recovered once the pallet socks reach the equipment center.
- In the event that the cold chain standards are violated an exception must be created and either a message must be sent directly to an individual responsible for the cargo management or an exception must be created on the web server of the event that has taken place.
- The received exception data is then populated to a database for the specific item or group of items being monitored.
- From the temperature data recovered from the RF sensors upon return to the EC, profiles must be drawn to establish the reliability of the cold chain and to identify problem areas.

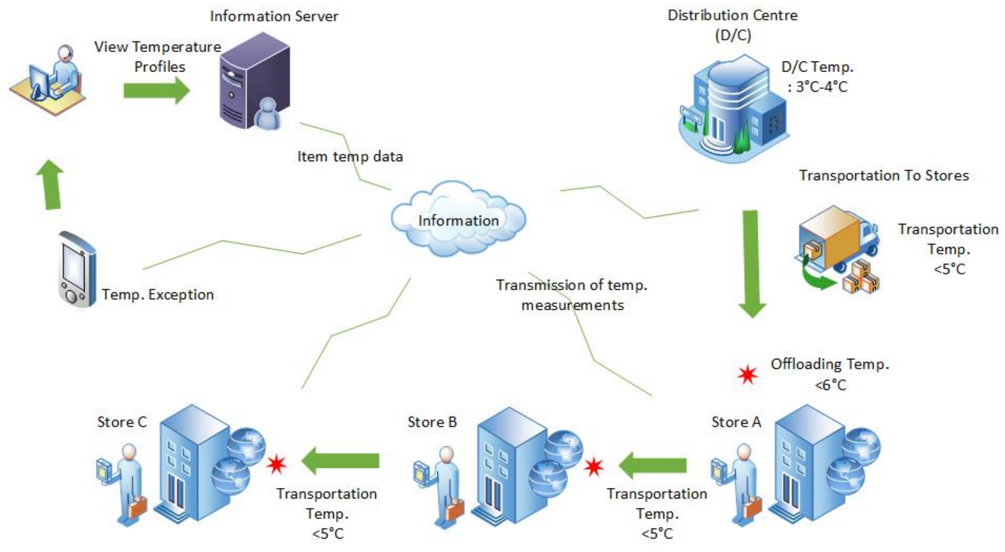

Figure 11: General operation of cold chain technology required

The LSP requirements can be summarised as follow:

1. The process to preconfigure temp loggers for a trip must either be fully automated or user-friendly requiring minimal manual effort.
2. Temperature sensors/loggers must be attachable to individual pallet socks

3. The system must not be dependent on equipment installed on a specific truck
4. Optionally: Create and send temperature exceptions while a consignment is *en-route* to a customer.
5. Allow the remote downloading of the current temperature of a specific sensor, typically when the temperature status of a consignment is disputed by a customer during the delivery process.
6. The temperature sensors/loggers must be easily retrievable after delivery
7. Automatic collection of data must take place once the temp loggers arrive back at the DC or equipment center.
8. It must be possible to view temperature profiles in an accessible and user-friendly manner
9. A report must be generated of all exceptions that occurred.

At the vendor sites the system used by the LSP is required to provide the receiving agent with the ability to verify the quality of goods on delivery. An important requirement is that the CCM system must provide accountability of goods on delivery – this will provide protection to both parties and is an essential tool to enforce proper cold chain management service level agreements (SLAs).

3.7 Chapter review

In this chapter the four individual links forming the central part of cold chain were reviewed and the operational processes of each discussed in detail. The discussions indicated that although all four links focus on the control of the cold chain, each has a unique process to be managed.

The focus of most producers is on the processing of harvested goods into a shippable product to go to the DC's. The temperature control applied by different producers depend on the temperature sensitivity of the goods and the individual knowledge of the producer. The cold chain management applied at this point, as for every subsequent point of processing, is essential as this will determine the remaining shelf life of the perishables that provided to consumers. Perishables can either be sent directly from the producer to the vendor or first to the DC. The DC is responsible for faster delivery to vendors in an area where producers are located further from consumers, fulfilling the role of a logistics hub.

The DC implements QAO to ensure maximum quality of goods that are further processed and forwarded to consumers. When the necessary processing has been completed at the DC a LSP is employed for the safe transportation of goods to the vendors. The LSP uses reefers of different sizes to move goods over various distances. The reefer containers automatically regulates the temperature according to a set point as required for the specific goods.

The environmental conditions are verified on delivery by an agent at the receiving site and if the verification does not pass a consignment can be returned or the LSP held responsible for any damages. The vendor unloads the perishables to local storage and presents the goods as needed to consumers in a temperature controlled refrigeration unit.

Each of the four links in the cold chain as discussed can be viewed as individual isolated temperature control units. A common requirements for each system, varying in size and implementation, is the remote monitoring and control of temperature fluctuations. This can be accomplished by means of a CCM system consisting of hardware and software that that will immediately notify managers with regard to temperature problems and allow agents to rectify any temperature fluctuations. Although each link in the chain is equally important regarding its influence on the quality of goods delivered, the producer, DC and vendor sites have been found to be the more stable temperature environments in the chain. From the research presented in this chapter the LSP operations can be seen as the link in the chain that is most vulnerable and susceptible to temperature instability. Further research in this document will evaluate the possibility of RFID systems to be used for cold chain management with specific focus on the LSP link in the chain.

Chapter 4: CCM technology investigation

4.1 Chapter Overview

The previous chapters discussed the crucial role of CCM in ensuring the safe transportation of perishable goods from supplier to consumer. As the transportation of perishable goods is the life blood to many economies around the world the loss of more than 35% of such goods while being transported is completely unacceptable [1]. Recent technological developments in the field of CCM will help to prevent these astronomical losses from occurring. In this chapter we will investigate some of the solutions available on the market today. Each system will be evaluated based on functionality, cost and possible benefits if used in the CCM environment.

4.2 CCM solutions for temperature monitoring

4.2.1 Data logger solutions

Temperature data loggers are devices capable of taking data samples at fixed sampling periods for the environment it is placed within [27]. The samples are stored internally to memory according to the configuration set up before use. The devices in general have only short range communication capabilities and direct contact data transferal like USB or Ethernet connections. In this section different data logger sensors will be discussed.

4.2.1.1 LogTag temperature recorder

Log tag data recorders include many different sensors each with specifications that set itself apart from its counterparts. The most cost effective range of data loggers provided by LogTag is the TRIX-8 tag (shown in Figure 13) that provides the necessary reusability for any cold chain. These sensors operate at temperatures ranging between -40ºC to 85ºC that is within the storage range of most perishable goods. The 16K byte memory allows the device to store up to 8032 temperature readings with timestamps that can be sampled at an adjustable rate of 30 seconds to a couple of hours depending on the temperature sensitivity of the goods being monitored.

The resolution of the device unfortunately differs at different temperature levels and thus directly influences the reading accuracy. The device has an accuracy of 0.5ºC between -20ºC to +40ºC ,0.7ºC between -30ºC to -20ºC and 40ºC to 60ºC and a accuracy of 0.8ºC for all other temperatures. The use of this device is thus limited by the sensitivity of goods being monitored, as some goods already start to degrade with only a 0.5ºC deviation. The battery life of 3 years dependent on usage allows the device to return the value of its investment over its lifetime. The device provides the user with on-board start and alerting functions to allow user to effectively utilise the device in the field and manage accountability of the LSP on delivery as the device will display if the set threshold has been exceeded [28].

Data is retrieved from the device using a contacted based interface cradle shown in Figure 12.

Figure 12: Log Tag Cradle interface

Figure 13: Log Tag Trix8 temperature recorder

Software platform

The free windows application known as the LogTag analyser provide users with support to download data from the cradle interface on connection. The platform provides users with the ability to configure tags before deployment, display the automatically downloaded data on selected graphs and analyse the data according to user preference. Although the software operates independently it can be integrated to larger packages by using SMTP and FTP services to a networked database, thus easily making the acquired data accessible to custom management software. No API is however available from the supplier to directly integrate the software functionality to such a custom management package.

4.2.2 Gemini Data loggers

Gemini data loggers offers the Tinytag Transit 2 temperature data logger that has been developed to monitor shipments in transit. The tag operates in a temperature range of -40°C to 70°C and samples temperature values with an accuracy of 0.4°C. The tag is able to store up to 8000 samples, taken at user defined intervals, in its non-volatile memory. The device can further be set up to store data in three modes: Stop reading when memory capacity is reached; after n readings has been taken or to continue storing data in a FIFO basis. The IP57 device operates using a Renata CR2325 battery that can operate for 12 months continuously and is user replaceable when required. The tag has a diameter of 60.2mm and a thickness of 15.3mm.

The data can be retrieved from the tag using 2 methods, either using a low cost USB cable that will require the unit to be opened and connected or by use of a USB inductive pad which easily retrieves data from the tag with a simple touch [29]. The tiny tag and inductive pad is displayed in Figure 14 and Figure 15.

Figure 14: Inductive reading pad

Figure 15: Tinytag Transit 2

Software platform

The Tinytag explorer software is a Windows based platform that allows users to easily interface with the tiny tag. It provides a simple launch page that allows users to edit the tag settings and that displays all defined settings in an orderly fashion. Data that is offloaded from the tag is initially displayed as a graph and can alternatively be displayed as a table of values. The information view summarises details of the data, including the maximum and minimum values that was reached during the monitoring period. The reports can then be exported as a Word document, Excel spreadsheet or as a .csv file for further evaluation.

4.2.3 Elpro

Elpro offers a data logging solution named the Liberto Ti1; this device is a reusable multi-Level pdf logger. The pdf logger can be set up by the user to have up to 6 alarms for temperature fluctuations and 2 temperature thresholds. The internal NTC probe can measure temperatures between -35°C to 70°C with an accuracy of 0.5°C and resolution of 0.1°C. The user can further configure the device to sample on intervals between 1 to 60 min. The general battery operation period for this device is 400 days of data logging or 14 months shelf lifespan. The device is also equipped with an on board LCD display. The display indicates general information for the sensor including: Status; Battery life remaining; Statistical data; Current temperature measurement; Profile identification and the start and end of consignment indicators. The 95mm*40mm*12mm device with 23.5mm * 23.5mm LCD screen can store up to 16000 data points which can easily be downloaded in report format through the on board USB connector [30]. The Liberto Ti1 is displayed in Figure 16.

The raw temperature data is automatically converted to a PDF document with the built in PDF generator as soon as the device is connected via the USB connector. The document displays the data collected in 5 different areas:

- Customisable report title and corresponding file name
- Area for additional information on the consignment
- Indication of alarm status for consignment
- General statistics and detailed consignment information

- Chart indicating the temperatures and thresholds maintained during transit

A typical report generated by the Libero Ti1 is displayed in Figure 17.

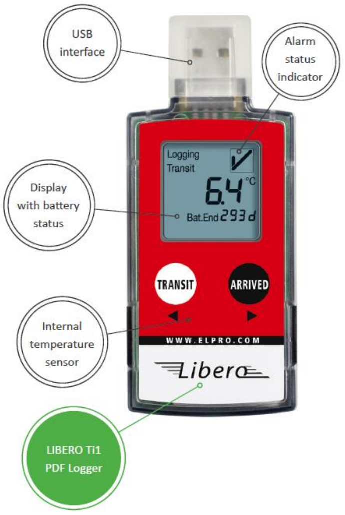

Figure 16: Libero Ti1

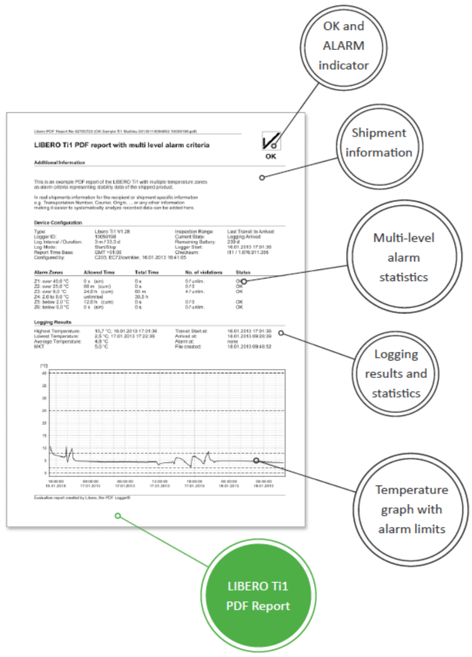

Figure 17: Libero PDF report

Software environment

The Libero Ti1 is configured using the liberoConfig software platform that enables the user to create, store and manage the settings of the specific device. This software is also used to define the fields of the report generated by the device and the thresholds/alarms the device must maintain during transit. This configuration platform is freeware and can be downloaded from the Elpro website.

4.2.4 Shockwatch

The Trekview solution from Shockwatch offers passive RFID temperature loggers that are available in various models with internal and external temperature sensors. The Trekview with internal temperature sensor can sample temperatures in the range of -30°C to 75°C with an accuracy of 0.5°C for the complete temperature spectrum. The device has the ability to store 4000 log data points. The sampling intervals can be defined by the user; when configured for the maximum sampling period the device can operate for an average period of three years. The Trekview sensor is displayed in Figure 18 below.

Figure 18: Trekview with internal sensor

The data can be read from the device using one of two methods: A desktop RFID reader (Figure 19) or a handheld data reader (Figure 20) for in transit temperature retrieval, this semi passive tags has a maximum read range of 10m. All data retrieved is filtered and displayed by means of the Trekview DMS platform. The data management system is a web hosted platform that allows users to monitor the cold chain remotely to provide improved visibility and accountability [31].

Figure 19: Trekview desktop reader

Figure 20: Trekview handheld reader

4.3 Battery Assisted Passive RFID solutions

4.3.1 GOARFID

This passive system consist of two components, the handheld UHF mobile computer (246017) and the UHF semi-passive temperature logger tag (116045). The 246017 device is a mobile hand held computer that has a built in dual functionality: it has the function of a UHF RFID reader and a 1D/2D barcode scanner with mobile communication ability by means of GSM/GPRS. It also incorporates Bluetooth v2.0, integrated A-GPS and WLAN connectivity. The device operates with the MS windows CE4.0 operating system using a Marvell PXA-320 806Mhz CPU for information processing. The unit has a ROM of 512MB and a RAM of 256MB, with both its 3.5" touch screen display and 32 key numeric interface provides easy access to the device and stored data. The reader can operate in an environment between -10°C and 60°C. It has two independent batteries for operation: 4000mAh for the systems operation and a 2600mAh for the reader; recharging takes an average of 5h.

The RFID reader operates on a frequency band of between 865 MHz to 928 MHz enabling reading to take place at a maximum distance of 5m.

The 116045 semi-passive sensor tag is designed to be compliant with the EPC Class 1 and Class 2 standards thus enabling most UHF RFID readers that comply with this standards to read these tags. The tags operate on a frequency band of 860MHz to 928MHz and can be read at a range of 10m in free space. The tag can be programmed to sample temperatures at specific interval with specified thresholds. The tag can store up to 8192 samples on its 16KB memory. The tag can operates and sample environmental temperature between -20°C to 70°C. The 16bit temperature sensor is able to measure temperatures accurately to 0.1°C [32]. The devices are displayed in Figure 21 and Figure 22.

Figure 21: UHF semi passive temperature logger (116045)

Figure 22: Mobile handheld reader (246017)

Software Platform

Each system from GAORFID comes with a demo software package that provides the essential functionalities to evaluate the systems. This software only provide the basic options regarding the control and evaluation of data received. They also offer a SDK package that can be used to develop custom software to meet the specific requirements of a system in which it is used.

4.3.2 CAENRFID

4.3.2.1 A927Z UHF semi passive RFID tag

The A927Z is the UHF semi passive RFID solution from CAENRFID. The tag is designed to be used a variety of applications such as perishable goods and pharmaceutics. The device can be used with any standard UHF reader that communicates in the frequency band of 860MHz to 928MHz and interfaces using the ISO 18000-6C communication protocol. The sensors are capable of communicating over a maximum range of 10m in free space and 2.5m when in the proximity of metal, when read with 2W effective radiated power (ERP). The sensor is powered by a 3V Li/MnO2 Renate CR 2450N battery to allow the sensor to function for a period of up to 3 years.

The battery life is dependent on the operational frequency and sampling rate defined by the user for the sensor; these intervals are defined in Figure 23. The battery is non replaceable in order to maintain the protection rating of IP67. The sensor is capable of storing up to 8000 samples on its internal 17484 byte memory; data is written at speed 100µsec. The device is able of operating in the temperature range of -30°C to 70°C and can be set up to create alarms for user defined high and low temperature values for the specific consignment. The 13cm *2.3cm*1.3cm sensor has the ability to log data with an accuracy of approximately 0.1°C [33]. The A927Z is shown in Figure 24 below.

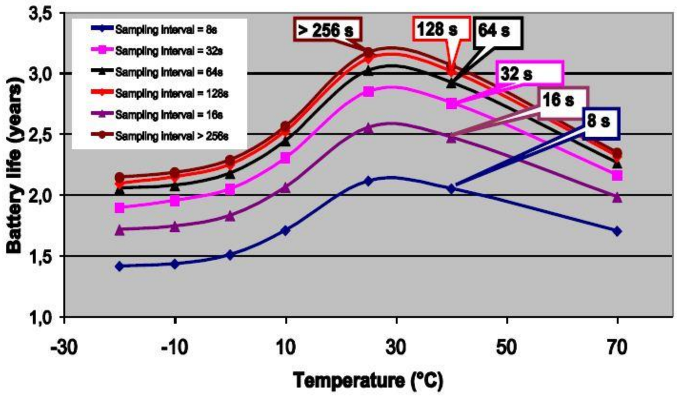

Figure 23: Battery life for A927Z for various sampling intervals

Figure 24: The A927Z UHF Semi-Active temperature sensor

4.3.2.2 RT005 semi passive RFID Tag

The RT005 is a semi passive UHF EPC C1G2 tag that uses the ISO18000-6C standard to communicate data between the sensor and the interrogator on a frequency between 860 to 928 MHz. The tag can be configured to store up to 3958 samples at intervals between 1 second to 18 hours. The tag uses temperature bins to define areas of different temperature conditions with up to 16 temperature ranges. The RT005 tag can be engaged and temperature exceptions viewed by press of a button. The tag is capable to internally calculate the shelf life and mean kinetic temperature. This multi shipment tag has a battery life of 2 year of continuous monitoring on a 15min interval. The tag has two sensing modes: one with internal sensor for environmental temperature measurement and the other with a temperature probe for measurement of internal temperatures of perishables [34]. The sensor is shown in Figure 25. Both the types of sensors only provide temperature monitoring capability and no humidity sensing is possible.

Figure 25: RT005 Temperature tags

The data can be acquired from the above mentioned tags using any standard UHF reader. Caen RFID offers the Ion R4300P long range reader UHF reader using the easy2read proprietary protocol to query data from the tags. The embedded reader with 4 antennas run a standard Linux operating system, this allows for on-board computing of data without reader connection. Data collected from sources can be forwarded to a local system by means of an Ethernet connection or by means of a GPRS modem. This interrogator can operate in a temperature range between -20ºC and 55ºC to communicate with sensors up to 15 m away [35]. This reader is shown in Figure 26.The slate desktop reader is the short range UHF reader from Caen designed to read sensors up to 1m. The USB powered device can operate in an environment between -10 ºC to 55 ºC at a max power of 400mA. The dual antenna A4 reader make it possible to easily read sensors in remote areas [36]. The reader can read up to 15 sensors efficiently in their field. The reader is shown in Figure 27.

Figure 26: Caen RFID Ion UHF reader

Figure 27: CAEN RFID Slate UHF reader

4.3.2.3 Software Platform

The sensors from CAENRFID comes with a demo software package that enables the user to read and evaluate the data sampled by the RF tags. The software provide the user with basic analytical tools to manage collected data and configure the tag to operate in the required manner. The demo software for the RT0005 also has the additional functionality to define alarms for the different functions of the tag.

There is also a SDK available for the development of custom software to suit the specific needs of an application. The package allows software to be developed using Visual C++, Java and Microsoft.Net. The package is structured in libraries to help with the development of object oriented software and the implementation of the appropriate communication protocol to interface with the corresponding RFID tags.

4.4 Active RFID solutions

4.4.1 SensMaster

Sensmaster provides a RFID temperature and humidity logging tag the ISON TM802-B201that uses the 2.4GHz- 2.5 GHz ISM band to communicate.

The tag applies the GFSK technique for data modulation and frequency hopping to increase the throughput of data. This allows the device to be read and send information at a range of 80m to a TM700 series RFIDs reader. The device can only be configured at a range of 10m and communicates at a maximum power of 1mW. The 8cm*4cm*20cm sensors can operate in a temperature range of -18°C to 80°C and make measurement with an accuracy of approximately 0.5°C.

The device can store up to 10 000 samples on its internal memory and also provide the user with 36 bytes of memory to store user configurations. The sensor can be configured to sample at intervals between 1s to 1000s, to have out of range temperature alarms and other level oriented alarms. The sensor comes with one of two protection ratings according to the battery it is powered with. The IP 57 version is powered by two AAA batteries and are user replaceable and last for up to a year whilst the IP67 version comes with an internal battery and last for 2 years but is not user replaceable. The battery life will depend on the sampling tempo and frequency of use of the sensor. The sensor is shown if Figure 28.

The Celebes S reader allows the user to read the ISON sensor tag. The reader also operates on the 2.4GHz frequency and enables communication up to 80m with the 2.5dBi antennas connected to the reader. The reader is powered using PoE or via a 12-30VDC power supply and has three interface possibilities to the evaluation platform. The device can interface using RS232, Ethernet LAN or a Bluetooth interface. The 15cm * 4.5cm * 100 cm device with IP54 rating can read up to 200 tags per second [37]. The corresponding reader is shown in Figure 29.

Figure 28: Ison temperature and humidity sensor

Figure 29: Celebes S RFID reader

Software Platform

Sensmaster has an evaluation platform that enables the user to interface with the ISON tags and enables configuration of the tag for a specific consignment. The application further enables retrieved data to be exported to an Excel format for evaluation. The application offered is a desktop based solution.

4.4.2 Microdaq

The solution from Microdaq includes a GSM mobile base station and data collector that serves as a central hub to collect data from the independent RTR-501 temperature logger. The base station connects to the internet by means of a GSM connection which it uses to transmit collected data to the web server. The data is transmitted in pre-determined intervals to the server. The station enables the sending of real time messages with notification when the temperature values goes out of the specified temperature range.

The mobile station is powered by 4 general purpose alkaline AA batteries that is user replaceable. The device can operate continuously for 10 days, transmitting data on 10 minute intervals. The system is accompanied by utility software that enables the user to apply simple setup the operation parameters in a timely and simplistic manner.

The system operates in a temperature range of 10°C to 55°C with battery power. The device has a physical dimension of 9.6cm * 6.6 cm * 3.9 cm with an antenna length of 10.9 cm. The independent RTR-501 temperature loggers utilises an internal sensor probe for the temperature measurement. The device can operate and measure a temperature range of -40°C to 80°C with an accuracy of 0.5°C at a resolution of 0.1°C. The temperature sensor can be set to be taken on 15 different predefined intervals and up to 16000 measurements can be stored.

It can also be set up to function in two recording modes: the first is to continuously measure and store data on a FIFO basis and the second is to record data only until the maximum capacity of the device is reached. The IP67 device communicates with the base station on a frequency band of 902 to 928 MHz to enable a line of sight communication of 150m, this communication is accomplished by means of proprietary protocol to ensure collisions are limited in the GSM band. Powered by an AAA battery the device can operate for a period of 10 months dependant of the selected operation interval. The device has a physical dimension of 66mm*47mm*19mm with an antenna length of 24mm [38]. The two devices discussed is shown in Figure 30 and Figure 31.

Figure 30 : RTR-501 Temperature Logger and data collector

Figure 31: GSM Mobile base station

4.5 GSM/GPRS sensor solutions

The GSM/GPRS sensor is a remote device that possesses an on board temperature sensor or thermocouple sensor probe. The devices are individual units capable of relaying data in real time to a server application where the temperature information can be processed. The devices can possess the ability to process data in real time and send temperature alerts to individuals by means of email or SMS.

4.5.1 Aptifirst

The AGT01 GSM Temperature Monitor for Aptifirst is a mobile temperature device that communicates using the GSM/GPRS connection. The device can be divided into 2 segments: the communication unit and an external temperature probe. The device can operate in a temperature range of -30°C to 70°C and measures data with a resolution of 0.5°C. The device can be set up using the mobile network or a desktop application that can run on a Windows OS. The device is capable of sending remote alert messages using 3 different modes.

It can send an email message to a specific account; send a SMS text message to a maximum of 10 mobile cell numbers or miss call the same number of numbers to indicate an error in the temperature measure compared to the defined operation range. Furthermore the user can configure the temperature to be read in incremental 10 min intervals up to 60 min. The captured data is send as a .CSV file to an email address every hour; the user also has the ability to request the latest data log by means of SMS if so desired. The device requires a power supply between 5 – 60 VDC and be capable of delivering 7ah [39]. Figure 32 shows the physical GSM unit.

Figure 32: AGT GSM Temperature logger with external temperature sensor

4.5.2 HW Group

The HWg-Ares 12 GSM/GPRS thermometer is the remote monitoring device from the HW group. The device is capable of interfacing with third-party central solutions, thus simplifying integration with current platforms. The device communicates using its quad band GSM unit, it can be set up to communicate with up to 5 different mobile cell numbers and email addresses. The device alarm functionality send to these numbers is defined as three possibilities: email, SMS or HWg-push.

During operation the user can request the status of sensors by means of texting or calling the device.

Storage of up to 1700 records is possible on the devices 2 Mb memory that can thus take measurements for up to 200 days at 5 min intervals if all three possible external sensors are connected. The device has an internal Li-Ion battery as backup and can operate from an external power source between 9 to 30 VDC that is capable of delivering 5A maximum current. The device has a physical dimension of 76mm*93mm*28mm and can operate in a temperature range from 5°C to 50°C.

Data collected from the temperature sensors can be forwarded to the free HWg-PDMS platform that runs on a webserver. This software is available if the devices is not interfaced with a current software environment of the user [40]. The device is shown in Figure 33 which follow.

Figure 33: HWg-Ares 12 GSM/GPRS thermometer

4.6 GSM/GPRS and RFID Hybrid systems

The systems evaluated in this section provide the operational ability to gather data from multiple RF sensors in transit and relay the data in real-time to the person of interest via a GSM/GPRS module. These systems thus provide the ability to analyse data in real time and alert the user about fluctuations in temperature, thus enabling the user to act and avoid uncontrolled damage of perishable goods.

4.6.1 Wireless Links- Piccolo Plus

The Piccolo plus from Wireless Links is based on a roaming reader/communication unit that communicates with up to 50 RF tags and that can communicate with a base station via the GSM network.

It can be expanded to incorporate a GPS for asset tracking, RF reader to read active tags over a range of 70m in free space and many other features such as vibration sensing, 3D accelerometer and Wi-Fi communication [41]. The unit effectively acts as a hub that can read temperature values from up to 50 tags. The tags do not have on board storage capability and all samples must be relayed to base station within the sampling period or it will be lost at the next sampling procedure.

The unit processes the values it receives from the individual tags and sends the data by means of GSM/GPRS to a server where the temperature values are displayed. When the unit is not within a GSM coverage area it can store up to 5000 readings; when connectivity to the cellular network is restored these values are transferred to the server.

The unit can be configured by means of USB to transmit data according to the required intervals. Furthermore additional trigger events can be added to send an alert when an action occurs that does not meet the standard operating protocol, for example a temperature value that goes beyond its operating specification. The operation of the Piccolo unit with the temperature sensing active RFID tags is shown in Figure 34.

Figure 34: Piccolo RFID sensor network [42]

The RFTag connects to the Piccolo unit by means of 2.4 GHz IEEE802.15.4 transceiver. The tag sends out a ping to the unit every 10s which transfers the data to the Piccolo unit for processing. The RFTag operates on a 600mAh lithium battery that can power the tag for up to 5 years under normal operation. Beyond the functionality of cold chain monitoring the unit also provide the ability to track the geographical position of the container in transit. This data can be useful when looking at the possibility to provide a client with status information on the consignment and also allows a LSP the ability to better use their available resources.

In order to allow real –time communication with the temperature sensors and GPS data on an *ad hoc* basis (e.g. when a temperature is queried by a customer at a delivery sites) a unit will need to be installed on each reefer trailer.

Fleet.Net Software

This proprietary software is a web based solution using google maps to aid with fleet management, presents an excellent solution for fleet and cold chain management. The enterprise version of the software operates using SQL server for the storage of information. The software is completely web based and no software needs to be installed on any individual computer and can operate with various operating systems. It also provides the option to generate SMS alerts to specified users if a set parameter is not met as configured by the user. This is ideal for temperature alerts for items not within the set cold chain standards.

4.6.2 Digicore: Ctrack and iKaya temperature monitoring system

The Ctrack iS200 GPS and GSM unit provides tracking feedback of the vehicle it is connected to, the unit offers 6 Digital inputs and 1 Analog input to which a wireless base station can be connected. Operating from an 8 to 32 Vdc power supply the unit is ideal to operate on any vehicle with a 12Vdc battery. The device has two external antennas to retrieve proper data during tracking.

The iKaya IAS base station is a routing device that can operate individually relaying temperature and GPS coordinates or as part of an external system such as the iS200 unit form Ctrack. The base station retrieve data using an external antenna operating on 433MHz or from wired sensors connected to the device [43]. The wireless sensor probe from iKaya communicates to the remote base station through 433MHz channel. The probe can operate in a temperature range of between -55ºC to 125ºC monitoring the temperature environment with an accuracy of +- 0.5ºC and resolution of 0.0625ºC. This sensor operates using an internal DC power source 2.7Ah 3.6V Lithium-Thionyl Chloride battery. The device has two additional analogue inputs on the PC for additional probes to be connected. The data from this devices is then also forwarded to the base station over the channel [44].

The Ikaya company offers a utility software package that runs on windows to manage the data on the sensors and receive feedback via the base station from the associated sensors. The Base station runs a proprietary protocol from Ikaya that allows up to 8 wired and wireless sensors to be connected to the station at one time. The sensors are directly associated using the command prompt and stays associated to the base station until the unit is disconnected in this manner or by connection on the wireless sensor [45]. The sensors needs to be polled on continuously to retrieve the sampled data from the sensors because the tags has no internal data storage.

4.6.3 Yrless International: Base Station GPRS/RFID sensor system

This system is comprised of two essential components: the BS1000GSM base station and the WW5000-TS temperature sensing tag. The BS1000GSM base station is equipped with GSM/GPRS technology. The base station can transmit data every 20 minutes to a server where the information is stored and can be reviewed. Each base stations is fitted with GPS, tilt sensor and internal temperature sensor for individual operation. The power for unit operation is supplied from an independent power source.

The unit is capable of reading up to 500 WW5000-TS tags at a maximum read range of 5km. The data collected from these tags is stored on the base station’s internal 8Mb memory or transmitted every 20 minutes if the cellular network is available. The base station can be further configured to send notifications through the GSM network as alerts for temperatures that are outside the temperature range.

The tags function on a heartbeat transmission of data, transmitting every 20 minutes to the base station if possible. Each tag sensor also has an internal 32K memory for the on-board storage of information. When the maximum data storage is reached the older data is overwritten to maintain current read data. In this configuration the tag can last for a period of 2 years. The tags are not rechargeable but are manufactured as a sealed unit with built-in battery; once the battery has run out the tag must be discarded.

This version of the Yrless system has the same limitation as the Piccolo system above, in the sense that a base station unit must either be installed on the vehicle or at each customer site in order to enable the real time recovery of temperature information [46].

4.6.4 Yrless GSM temperature sensor

The GSM temperature sensor (GSM 1200-TS) is a standalone unit that is designed to measure the ambient temperature and transmit stored data directly to the server via the GSM network. The device is constructed with an internal non rechargeable battery that can take temperature measurements every 5 minutes and transmit in 12 hour intervals. In this configuration the unit has the ability to operate for a 2 year period. The unit does not have the ability to be queried for data on unscheduled time periods by the user. The system does have the ability to view SMS queries made to the system waiting on the server and perform these requests when it uploads data to the server. If a SMS query is sent to the base station during a none sampling period, the user will be required to wait for the data until the following online data upload [46]. The different configurations that can be made to transmission periods and the energy requirements is shown in Table 5.

Table 5: Upload time vs. Battery life

Temperature Reading Interval (Min)	Number of uploads per day	Battery life (Years)
5	2	2
5	4	1.3
5	6	1
5	8	0.75

Because the schedule for each consignment will differ, it will be required to setup a transmission schedule for the specific consignment before it is dispatched form the DC. This scheduling of each device can be done through use of the web server. This will allow a consignment to be monitored according to the users' exact specifications.

Web server software

The Yrless software offers the same basic functionality as the Wireless Links Fleet.Net software. On the server there are colour codes indicating that a specific temperature sensor or a group of sensors has not been transmitting data for a certain time. The progression of time and alerts are indicated with a specific colour to indicate the priority of notification. If the system is GPS enabled the physical position of the tags are also indicated on a map for relative locating. The Fleet.net has more analytical functionality, providing better methods of generating reports, tracking the cold chain of a consignment and view data. The core functionality is similar and provides the essential capabilities to monitor and evaluate the cold chain of a system.

4.6.5 GAORFID-Active RFID solution

This active RFID solution consists of a 2.4GHz gain adjustable active RFID reader (217001) and the active RFID temperature sensors (127003L). The 217001 uses an omni-directional antenna that allows the reader to retrieve information from RF-tags in a 100m radius. The reader operates on a frequency range of 2.4 GHz to 2.5GHz (UHF) for communication purposes. This enables data to be transferred at rate of 1Mbps to read up to 100 tags/sec. The device can be set up to transmit data by means of two methodologies: the first is to upload data to the host system in real-time as soon as data is read from the tags or secondly as a buffer device that stores information on the device until the host system is queried. The reader itself can operate in an environment where temperature can vary from -40°C to 80°C.

The 120073L is an active RFID tag with an external fixed temperature probe that has the ability to measure temperature values in a range between -20°C to 60°C with a precision of 2°C. The device can store up to a 1000 temperature readings that is time stamped in a first in first out (FIFO) queue. It also operates on the 2.45GHz frequency band and can be setup to be read at a range between 2m to 50m by the reader. The device can operate for a period of a year after which the internal battery can be replaced and the sensor re-used [32]. The readers and tags are displayed in Figure 35 and Figure 36.

Figure 35: Ethernet RFID reader (120073L)

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Figure 36: Active RFID sensors tag (217001)

4.7 Cargo Management Software Packages

4.7.1 GPS Gate

This third party GPS tracking platform is designed to improve the operational business process through rebranding existing systems through operational APIs. This thus makes it possible to integrate many systems under one platform infrastructure. The systems currently supported only includes products from international tracking companies that unfortunately limits local market investment and leads to possible higher cost devices for the African market due to . By preforming this integration with off the shelf products tracking partners can offer GPS services under a different brand than that of the manufacturer of the hardware systems.

The GPS Gate platform provides access to multiple maps for the most accurate tracking environment along the specified route in the region. Although this package provides the ability to integrate systems that has temperature monitoring abilities the analyses of this collected information is limited to display of the captured values in table format. This web interface focuses on the accurate tracking of assets in the field and is not designed for cold chain management purposes in general [47].

The platform makes ease of operation simple through the use of pre-configured templates that the user can select to configure the system using GPS Gate server. The platform further provides functions for driver statistics, fuel consumption monitoring and real time notifications of route anomalies. Overall this platform provides the functionality to effectively monitor a company's assets on route providing additional visibility and management tools to enable LSPs to improve the utilisation of their assets in the field by means of improved turnaround time and control.

4.7.2 Fleetboard

This is a logistic management platform used for the management of Mercedes fleets and logistic workflows to aid in improving the management process by means of assisting tracking hardware such as the TiiRec GPS and GSM on-board recorder. The tiered product uses logistic hardware with truck navigation for effective route utilisation. It furthermore offers a messaging service to the driver to communicate information on the route, the fuel usage and statistics of assets. It uses standard logistic workflows to improve the logistic operation in general and individual workflows for flexible integration with specific companies and their unique procedures. It includes an overall management platform that provides real time data back to a server to manage orders, drivers and easy to view maps. This enables fleet managers to optimally use their fleet in the field to complete orders in the shortest turnaround times [48].

The Fleetboard temperature management platform for temperature sensitive cargo provides continuous information on the temperature of the cargo. The temperatures are measured by wired sensors placed over the length of the trailer. The data is transferred automatically to a server where the information is available to the user when required. Problems can be identified before damage is caused and an email, sms or fax is automatically sent to a user to indicate threshold triggers before the cargo can be damaged. This also provides an essential service to provide evidence on accountability and the temperature assurance. The temperature is measured by a maximum of 8 sensors in 10 minute sampling rates. Additional information includes door open and close procedures and the processes of the refrigeration unit. Data is transferred in 10 minute intervals nationally and in 30 minute interval internationally to ensure data costs is limited for each route [49].

4.7.3 Pulstrack Fleet Management Platform

The Fleet Supreme web-based software package from Pulstrack electronics is a comprehensive fleet management solution. This package along with GPS/GPRS or satellite systems provide LSPs with the ability to monitor their local or cross border operations. The platform provides a dashboard operation interface housing the application specific functionality required by users to effectively manage their operational environment. The benchmark fleet management system provides the following functions [50]:

- Logistic operational management
- Asset tracking
    - Position
    - Fuel Consumption
    - Temperature Fluctuations
- Financial and maintenance management
- Manifest information and accountability
- Customer and Supplier management
- Simple reporting and evaluation

The overview of the system functionality offered by Pulstrack is shown Figure 37 below.

Figure 37: Pulstrack operational overview

Management of the cold chain is done by using two wired probes. The probes are independently placed at the cooling unit of the trailer and at the door of the trailer, the latter is also used to gage open and close orientation of the doors on route. The sensors relay data collected on the temperature environment to the tracking unit installed on the trailer that forwards the data to the software platform for analysis and anomaly notifications when necessary. This package is a comprehensive fleet management system that provide all the essential tools to effectively manage the LSP operational as a whole with the added ability to manage temperature requirements of temperature sensitive consignments.

4.8 Functional Comparison

In this section the essential functionality of each system will be compared and a price for the base system given. All prices given in the section are as quoted 01/04/2015 and might change according to exchange rate fluctuations. All prices excludes VAT. In Table 6 the systems are compared according to five functional areas and product costs. In Table 7 the remote sensors of the systems capable of RF communications are compared according to their critical functionality and cost. The data presented in this table is as provided in the datasheets for each system from the different companies.

Table 6: RF system and their communication capabilities

Company	Product	GSM /GPRS	GPS	On-board Temperature sensing	Power Supply	Rf-Enabled	RF-Sensor	Estimated Cost p/unit I
Hybrid GSM/RFID systems								
Wirelesslinks	Piccolo Plus	Yes	Yes	Yes	6-30Vdc	Yes	RFTag	6320
YRless International	BS1000-GSM	Yes	Yes	Yes	12Vdc	Yes	WW5000-TS	10600
Ctrack	S200 and Ikaya basestation	Yes	Yes	Yes	12Vdc	Yes	Ikaya Temp Tag	10200
MicroDAQ	RTR-500GSM	Yes	No	No	8-34Vdc	Yes	RTR-501	6809
BAP and Active RFID tags								
GOARFID	Ethernet Reader (217001)	No	No	No	9Vdc	Yes	Active Sensor (127003)	6490
GOARFID	Handheld UHF MC (246017)	Yes	Yes	No	9Vdc	Yes	UHF Semi P - 116045	20350
CAENRFID	Slate reader	No	No	No	5Vdc	Yes	A927Z/ RT005	9360
CAENRFID	R4300P Reader	Yes	No	No	9Vdc-30Vdc	Yes	A927Z/ RT005	28800
SensMaster	Celebes S	No	No	No	9-12Vdc	Yes	LISON	5625,2
GSM Based Systems								
YRless International	GSM1200-TS	Yes	No	Yes	12Vdc	No	N/A	3198
Aptifirst	AGT01	Yes	No	Yes	12Vdc	No	N/A	7110
HW group	HWg-Ares 12	Yes	No	Yes	9-30Vdc	No	N/A	10820
Data Loggers								
Gemini data loggers	ACS 3030 Inductive Pad	No	No	No	5Vdc	Yes	Tinytag Transit 2	1150
Elpro	No Reader Req.	No	No	Yes	5Vdc	No	Liberto Ti1	0
Shockwatch	No Reader Req.	No	No	Yes	5Vdc	No	Trekview	0
Logtag data loggers	Cradle interface	No	No	No	3,7Vdc	No	Trix8	600

Table 7: Remote Temperature Sensors

Company	Reader	Sensor	Com. Range (m)	Number of sensor readable	Total Samples Storable	Operation period (Years)	Estimated Cost p/sensl(R)
Hybrid GSM/RFID systems							
Wirelesslinks	Piccolo Plus	RFTag	70	50	0	2	765
YRless International	BS1000-GSM	WW5000-TS	100	50	8000	2	590
Ctrack				8	0	1,5	1700
MicroDAQ	RTR-500GSM	RTR-501	150	10	16000	0.83	2189
BAP and Active RFID tags							
GOARFID	Ethernet Reader (217001))	Active Sensor (127003)	50	25	1000	1	638
GOARFID	Handheld UHF MC (246017)	UHF Semi Pas -116045	10	25	8000	3	935
CAENRFID	Qid Bluetooth reader	UHF Semi Pas (A927Z)	10	25	8000	3	495
CAENRFID	Slate reader	UHF Semi Pas (RT005)	10	25	4000	3	495
SensMaster	Celebes S	ISON temp Sensor	80	50	10000	1	454.90
GSM Based Systems							
YRless International	No Reader Required	GSM1200-TS	N/A	N/A	8000	0,5	3198
Aptifirst	No Reader Required	AGT01	N/A	N/A	6	No Internal source	7110
HW group	No Reader Required	HWg-Ares 12	N/A	N/A	1700	No Internal source	10820

Data Loggers							
Gemini data loggers	ACS 3030 Inductive Pad	Tinytag Transit 2	0.1	1	8000	1 year	925
Elpro	N/A	Libero Ti1	USB	1	16000	1 year	1850
Shockwatch	Desktop reader	Trekview	0.1	1	4000	3 years	604
LogTag	Cradle Interface	LogTag	Conduc tive	1	8000	2 years	350

In Table 8 the software platform option of each company is compared. This table indicates if the software is cloud based and the calculated cost per unit and amount of sensors managed.

Table 8: Middleware for unit operation

Company	Product	Software	Web Viewable	Cost Per Unil/m (R)	Cost Per Selr p/m (R)
Wirelesslinks	Piccolo Plus	Fleet Manager	Yes	495	11
YRless International	bS1000-GSM	YRless International Server	Yes	500	N/A
YRless International	gSM1200-TS	YRless International Server	Yes	500	N/A
GOARFID	Ethernet Reader (217001)	Demo software	No	N/A	N/A
CAENRFID	Slate Reader	Demo Software	No	N/A	N/A
Gemini data loggers	ACS 3030 Inductive Pad	Tinytag Explorer	No	907 (Once-off)	N/A
GPS Gate	Piccolo Plus	GPSGATE sever	Yes	621,88	+125 > 5 sensors
Fleetboard	TiiRec GPS/GSM	Fleetboard	Yes	500	N/A
Pulsit Electronics	N/A	Pulstrack	Yes	350 p/u	N/A

4.9 Cost-Analysis

In the cost analysis presented in this section, each of the discussed products have been compared according to their theoretical performance as given by their individual specifications. The cost analysis was done to evaluate what the relative cost will be to implement a certain product to monitor the temperature of a company with 40 trucks transporting goods to a client and returning to a single DC and EC. Sixteen options are compared in this section, in the comparison two scenarios are compared. The first scenario is that 25 pallets are tagged by a sensor in each trailer for 40 trailers, to provide visibility of 1000 pallets in operation.

The second scenario is that only 10 pallets are tagged or 10 sensors are placed on the inside periphery of the trailer to monitor a total of 400 pallets in operation. In both scenarios the criteria is used that a single reading unit is placed at the DC and EC, for those systems that require additional reading equipment.

The equipment required for each scenario is shown in Table 9 and the corresponding cost comparison in Table 9 and Table 10. The costs for the individual sections are summed to indicate the total cost of the corresponding scenario. Furthermore in each scenario the software cost is calculated for use over a period of a year using the package provided by each company and includes the additional cost per sensor for use over this period.

Table 9: Cost Comparison

Sc n.	Company	Product	Number of Units	Sensor	Number of Sensors (Periphery Monitoring)	Number of sensors (Pallet Monitoring)	Software
Hybrid GDM/R–ID systems - real time monitoring							
1	WirelessLinks	Piccolo Plus	40	RFTag	400	1000	Fleet
2	YRless International	BS1000-GSM	40	WW5000-Ts	400	1000	YRless International
3	Ctrack	IKaya basestation and Ctrack reader	40	IKaya Sensors	400	1000	MaxSystem
4	MicroDAQ	RTR-501	40	RTR-503	400	1000	.CSV Forwarding
BAP and Active RFID systems –passive monitoring							
5	GOARFID	Ethernet Reader	2	Active RFID Tag	400	1000	Basic Freeware
6	GOARFID	Handheld Reader	2	Semi Passive Tag	400	1000	Basic Freeware
7	CAENRFID	Ethernet Reader	2	Semi Passive Tag	400	1000	Demo Software
8	CAENRFID	Desktop Reader	2	Semi Passive Tag	400	1000	Demo Software
9	Sensmaster	Celebes Reader	2	Ison Tag	400	1000	Evaluation Software

GSM Systems- real time monitoring							
10	YRless International	GSM1200-TS	0	N/A	400	1000	Yrless International Server
11	Aptifirts	AGT01	0	N/A	400	1000	.CSV Forwarding
12	HW group	Ares 12	0	N/A	400	1000	.CSV Forwarding
Data Loggers –passive monitoring							
13	Gemini Data loggers	Inductive USB Pad	2	Tinytag Transit 2	400	1000	TinyTag explorer
14	Elpro	N/A	0	Libero Ti1	400	1000	Libero Config Freeware
15	Shockwatch	Desktop Reader	2	Trekview	400	1000	Trekview DMS
16	LogTag	Cradle Interface	2	Trix8	400	1000	LogTag Analiser

The information listed in Table 10 define the values for the systems according to the scenario where 400 pallets are monitored.

Table 10: 400 sensors cost comparison for each system scenario

Scenario	Manufacturer	Ider Cost (	ISensor Cost (R)	Ital System It(R)	Soflre Cost(R)	Total Cost(R)
	Hybrid GSM/RFID systems					
1	Wirelesslinks	252,800	306,000	558,800	3,080	561,880
2	Yrless Int	424,000	236,000	660,000	1,000	661,000
3	Ctrack	408,000	1,120,000	1,528,000	2,000	1,530,000
4	MicroDAQ	272,360	181,960	454,320	0	454,320
	BAP and Active RFID tags					
5	GOARFID	12,980	255,200	268,180	0	268,180
6	GOARFID	81,400	374,000	455,400	0	455,400
7	CAENRFID	18,720	198,000	216,720	0	216,720
8	CAENRFID	57,600	198,000	255,600	0	255,600
9	Sensmaster	11,250.4	181,960	193,210.4	0	193,210.4
	GSM Sensors					
10	Yrless Int.	0	1,120,000	1,120,000	5,200	1,125,200
11	Aptifirst	0	2,844,000	2,844,000	0	2,844,000
12	HW group	0	4,328,000	4,328,000	0	4,328,000

	Data Loggers					
13	Gemini Data Loggers	0	370,000	370,000	0	370,000
14	Elpro	2,300	744,000	746,300	907	747,207
15	Shockwatch	0	241,600	241,600	0	241,600
16	LogTag	1,200	140,000	141,200	0	141,200

The information listed in Table 11 define the values for the systems according to the scenario where 400 pallets are monitored.

Table 11: 1000 sensors cost comparison for each system scenario

Scenario	**Ianufactrer**	**Ioduct Cost (R)**	**Isor Cost (R**	**Iotal Sysl Cost(R)**	**Software Cost(R)**	**Total Cost(R)**
			Hybrid GSM/RFID systems			
1	Wirelesslinks	252,800	765,000	1,017,800	0	1,017,800
2	Yrless Int	424,000	590,000	1,014,000	0	1,014,000
3	Ctrack	408,000	2,800,000	3,208,000	0	3,208,000
4	MicroDAQ	272,360	454,900	461,709	0	461,709
			BAP and Active RFID tags			
5	GOARFID	12,980	638,000	650,980	0	650,980
6	GOARFID	81,400	935,000	1,016,400	0	1,016,400
7	CAENRFID	18,720	495,000	513,720	0	513,720
8	CAENRFID	57,600	495000	552600	0	552600
9	Sensmaster	11,250.4	454,900	466,150.4	0	466,150.4
			GSM Sensors			
10	Yrless Int.	0	2,800,000	2,800,000	5,200	2,805,200
11	Aptifirst	0	7,110,000	7,110,000	0	7,110,000
12	HW group	0	10,820,000	10,820,000	0	10,820,000
			Data Loggers			
13	Gemini Data Loggers	0	925,000	925,000	0	925,000
14	Elpro	2300	1,860,000	1,862,300	907	1,863,207
15	Shockwatch	0	604,000	604,000	0	604,000
16	LogTag	1200	350,000	351,200	0	351,200

The total cost of each system to be applied for an operational period of 1 Year on 400 pallets and 1000 pallets independently, as applied to the before mentioned scenarios are compared in Figure 39 and Figure 40. This figure provides a visual representation of the price comparison of the corresponding systems.

Legend	
Hybrid systems	
RFID Systems	
GSM systems	
Data loggers	

Figure 38: Chart Legend

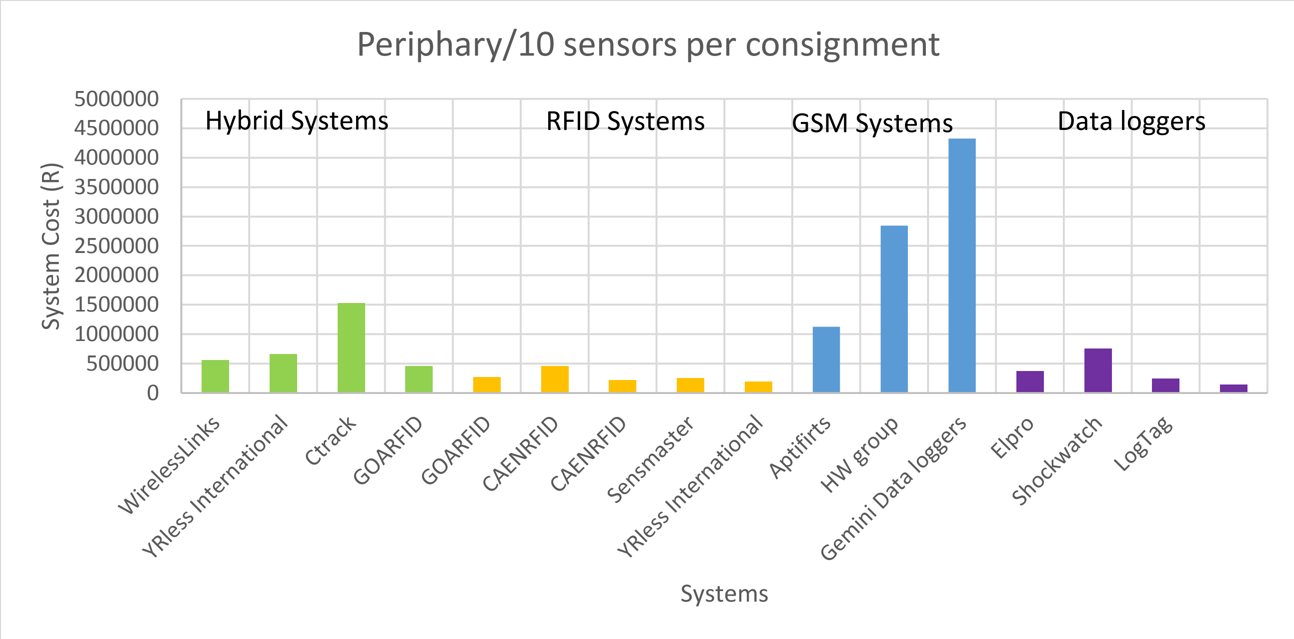

Figure 39: System Cost Comparison Graph for 400 pallets

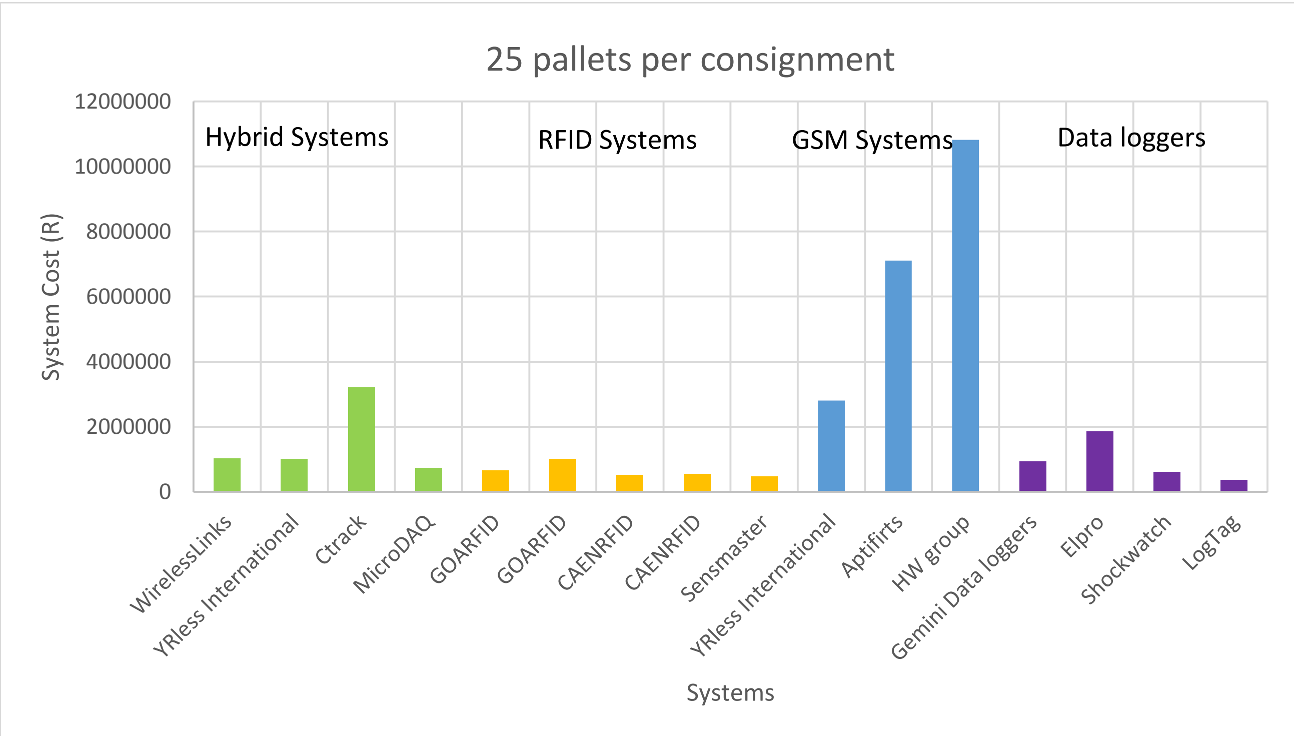

Figure 40: System Cost Comparison Graph for 1000 pallets

4.10 Recommendations

In this chapter sixteen different systems have been reviewed offering various solutions to the user requirements discussed in the previous chapter. Four of the solutions use RF temperature tags that are combined with a GSM unit to link the individual sensors into a measurement network. Three of the solutions provide a purely GSM based temperature sensor device for real-time temperature monitoring. Another pair of solutions provide a data logger solution that can only deliver its data when physically linked to a reader at the end of the cold chain. The final solutions is a combination of active RFID tags on the majority of pallets with a minority of pallets using a compact GSM sensor unit that operates independently and stores and relays information to the server.

In order to determine what system would provide the best suitable solution for CCM, the functionality the core benefit of each system will now be compared against each other according to the above mentioned sections. Firstly the Piccolo Plus unit presents a cost effective active RFID solution to capture data inside the trailer and also the pallets. The downside of this system, similar to the Ctrack system, is that the individual RF tags cannot store the captured data when not in communication with the Piccolo reader unit. This is due to the fact the RF sensors do not have internal memory for the storage of data and depend on the reader for storage and routing of data to the server. This would require a reader to be installed on each truck of a company as calculated in the comparison above.

The base station and remote sensors network from Yrless international provides an effective alternative to the Piccolo Plus and Ctrack units, costing the same as that offered by Wirelesslinks and sufficiently less than the Ctrack. The benefit of this system above the Piccolo Plus and Ctrack is that each remote sensor can store data locally if the base station is not available. This allows for base stations to be placed at essential parts in the logistic chain to read data or in the individual trucks for real time temperature monitoring.

The alternative solution from Yrless is a GSM temperature sensors that measure temperature locally and send data to the appropriate server. This unit eliminates the risk of data loss or communication blackouts between active RFID tags and the base system. Although the system is compact and easy to use in different applications in the cold chain, its cost is 276% more than the Yrless system in scenario 2, for implementation of real-time monitoring on the same amount of pallets. This units is furthermore still dependant on the GSM network to relay data to an online server for data analysis.

The hybrid solution from Ctrack using the Ikaya system cost indicatively more than either scenario 1 or 2. This is due to the fact that the individual sensors used is 3 times more expensive than that of the two systems included in scenario 1 and 2. This raised system cost is further exacerbated by the combination of the Ctrack and Ikaya systems for temperature and position tracking. The benefit of this system is the theoretical improved reading capability of the 433MHz system with the unfortunate downside of no internal sample storage on the sensors.

When evaluating the Ethernet system with active RFID from GOARFID as analysed in scenario 4 it has been found that it is 35,92% less expensive than the equivalent Yrless base station solution. The system only has basic software that accompany it and can perform basic functionality. If an expansion of the software functionality is required the SDK must be purchased additionally for ASP.net development. Furthermore the active sensors can only store 1000 samples whereas the WS5000-TS can store up to 8000 samples and operate twice as long on its internal 3,2V battery.

The alternative option from GOARFID as explained for scenario 5 is a costly system and requires a large capital investment for the handheld readers, which may have a theft risk in the African environment. The system provide added mobility through the entire cold chain which enables the users and clients to monitor the cold chain in near real-time.

An equivalent solution to the semi passive solution from GOARFID, the CAENRFID sensor from scenario 6 offers the same versatility with 50% reduction in cost per sensor. The sensor allows reading data by any UHF reader which communicates using the ISO 18000-6C standard. Custom software can be developed for the application using a free SDK from the CAENRFID.

In scenario 7 the Ison tag from Sensmaster provides both temperature and humidity sensing capability, with a 1.3% less cost than the system of scenario 6 of similar setup. The system can operate using an evaluation software package or using the software services developed by other companies for device operation.

In scenario 8 the mobile solution from MicroDAQ is reviewed, the solution provides the necessary functionality to provide a solution for the user requirements. The cost for the mobile base station is on average the same than other reviewed systems. The drawback of this system is the cost of the individual temperature sensor loggers: due to the addition of unnecessary functionality that is not required for the application the device cost twice as much as similar systems. Thus for large implementations the system is not ideal due to the influential cost aspect.

The systems evaluated in scenario 9 and 10 are GSM temperature sensors that can provide real-time monitoring of the cold chain and provide similar functionality than the GSM1200-TS from YRless with the added benefit of real-time data querying. The added benefit of these systems does not justify the additional cost of 200% and 300% more respectively for each system to only monitor 10% of the total amount of pallets.

The option evaluated in scenario 11 is a standalone data logger option that is RF capable and cannot provide real time data feedback. Data can only be retrieved at the end of the consignment when returned to the EC where data is read by an inductive pad at close range; this implies that data must be retrieved from tags one by one. This system provides the user with the means to provide accountability to the cold chain and review the efficacy of consignment delivery. The device however cost up to 30 % more than systems that can provide near real-time and real-time monitoring of the cold chain.

Similarly to the scenario 11 the solution from Elpro in scenario 12 provide excellent functionality and is a well-designed product that operates effectively and can provide the necessary temperature information of a trip. It provides complete, well formatted reports on its data, but the data can only be retrieved at the end of the cold chain. The data must furthermore be individually extracted from the loggers by means of USB that may be time consuming and ineffective which again does not justify its even higher cost in comparison with similar remote temperature sensor systems.

The final systems included in this evaluation are the four data logger solutions that provides wired data retrieval solutions. When compared with the passive RFID solutions the cost closely is comparable, but with the loss of long range sensor readability. Between the four solutions evaluated the LogTag solution is the least expensive and ideal for passive temperature monitoring.

The devices evaluated in this section each provide unique benefits for the operational improvement of the cold chain and for possible further investigation of the RFID feasibility in the cold chain operation. In order to align this with the objectives of the study whilst using the results of this chapter's evaluation and the comparison in this section the following units is recommended to proceed with.

- The 2.4 GHz active RFID Piccolo Plus solution from Wirless links.
- The 400MHz active RFID Ctrack solution from Digicore
- The semi passive 900MHz CAENRFID
- The LogTag data loggers, for verification of captured samples.

These units according the comparison can theoretically provide an effective solution to manage cold chain logistics and provide a record of temperature fluctuations. These systems will be used in the further chapters to investigate to what degree these type of RFID systems will be effective in the implementation in a cold chain environment.

4.11 Chapter Review

In this chapter a variety of different solutions to the user requirements set forth in chapter 3 were evaluated. The systems evaluated in this chapter represents the best subset of the solutions evaluated and that could be best suited for implementation for CCM according to their technical specifications. The options selected range from relatively simple solutions such as USB data loggers to more complex systems utilizing both GSM and RFID technology. The best possible solutions from the evaluated options aimed at functionality and cost was included and reviewed in this document and the recommendations were made with the information available.

It was established that there are four types of temperature monitoring solutions not including the standard wired sensors. The first devices are the general purpose data loggers suitable for capturing data for historical temperature analysis. These devices are limited in their communication abilities and are more often than not reliant on direct contact data retrieval, which implies long time delays if data must be retrieved on a regular basis from a large number of tags. The second is the battery assisted passive RFID solutions that is similar in monitoring capability to the data loggers but have the ability for data to be retrieved at a distance of up to 15m, which allows a more hands-free method to retrieve data in a short time period.

This also provides the additional ability to provide real time feedback of temperature fluctuations of the internal environment or the periphery of the pallets to immediately determine the viability of good on delivery. The third type of device is the active RFID system functioning at different frequencies and thus different communication reliabilities within a water based consignment. The devices in general has a readability of further than 15m and sends data to a interrogator that forwards data by means of GSM/GPRS to a webserver to be stored and analysed, providing the user with real time data on the consignment and other variables such as position and fuel consumption. The final type of device is the GSM/GPRS sensor unit that is a completely independent device with on-board temperature sensor.

As discussed in this chapter there are many more viable RF and RFID solutions that can be used to solve the problem of effective cold chain management. The 16 systems evaluated in this chapter was selected with regards to their technical ability to best solve the requirements of the industry. The three solutions that are the Piccolo Plus, Ctrack and CAEN RFID systems was found to be the recommended systems for clients in the industry that have the requirements as specified. Further investigation is now required to determine which of the type of RFID solution represented by these selected solution would be the best practical solution in the industry. In the following chapter we will focus on the design and implementation of a software platform for the purpose of effective cold chain management using these three different RFID solutions.

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Chapter 5: The Design of a CCM software platform for interoperable use of RFID solutions

5.1 Chapter Overview

The previous chapters provide us with a clear description of what the purpose of the research is, what currently is done according to literature in the industry, what the user requirements at each of the four critical links in the cold chain are and some of the systems that is on the market to aid in cold chain improvement. In this chapter, the design for a cold chain management platform will be discussed that incorporate the CAEN RFID systems, Wireless link system and the Digicore system reviewed in the previous chapter. In the sections to follow we discuss the necessary building blocks to implement the requirements specified in Chapter 3 in a manner that provides the functionality to manage the entire logistic process whilst providing interoperability between these proprietary systems under one roof.

5.2 Conceptual Software design

The research has shown that the most vulnerable link in the cold chain is that of the LSP at the various levels from producer to consumer. In this section the conceptual design for a software package that can provide the user, which is either an LSP or client of the LSP, with critical statistical information on the route and the contents being transported.

5.2.1 Fleet Management software overview

When analysing the process, combined with the input of an industry expert Jitesh Naidoo, it is clear that there exist three critical areas in the management process that needs to be adhered to in order to meet the basic needs of supply chain management. The first is that ’f vehicle and asset tracking to allow LSP's to manage the use of the resource in the field effectively allowing the estimation of delivery times, avoidance of route deviations and the maximisation of turnaround times. The second important aspect is the control of fuel consumption to verify the average fuel consumption to the customer site, to indicate theft on a route and the characterisation of the driver profiles. The third is the control and management of the cold environment to set standards to ensure that a perishable consignment is transported safely from pickup to delivery.

The overview of the essential supply chain management platform is shown in Figure 41 that follows. The ROAFE (Road and Freight) management platform must provide general administration functionality to control the above mentioned three areas in the supply chain. Falling under this functions of admin in the three sections are:

Queuing system:	The vehicles must be able to be queued according to the availability of the assets thus maximising the turnaround time and the profit that can be made from their utilization.
Beacon Monitoring:	Beacons and POI must be defined along the route of the delivery. These beacons must then be used to monitor the progress of the vehicle along the route and the use of the valid stop and go points of interest.
Performance Dashboards:	The vehicle information on the route position, speed, fuel consumption and temperature of the consignment must be displayed on the active reporting data that is continuously refreshed within real-time.
Trip Monitoring:	The trip monitoring includes the monitoring of violations in the geofences configured for the trips. The fuel usage according to benchmark information and the temperature of the items in the cargo.
Incident Logging:	The log information of accidents and theft on the route for specific driver and cargos of clients. This includes statistics on the route, position and cargos lost during the incidents.
Road Waybill:	A digital version of the road waybill as measur'd before departure after loading a client's consignment. Beyond this information, an inventory list of the consignment can also be electronically added to verify the load as correct on delivery. The data can then further be used for statistical calculations of fuel consumption relative to weight and temperature distribution relative to position.
Predictive Movement Query:	This function will a'low the automatic prediction from a truck's position to calculate an accurate delivery and return time. Predictions of the temperature fluctuations and damage over an x amount of time to perishables in the consignment.

The information presented above must then be viewed in a statistical information reports that provide clear information on the trip's clients, fuel and consignments. This information must be discernible by a person with novice computer skills and knowledge.

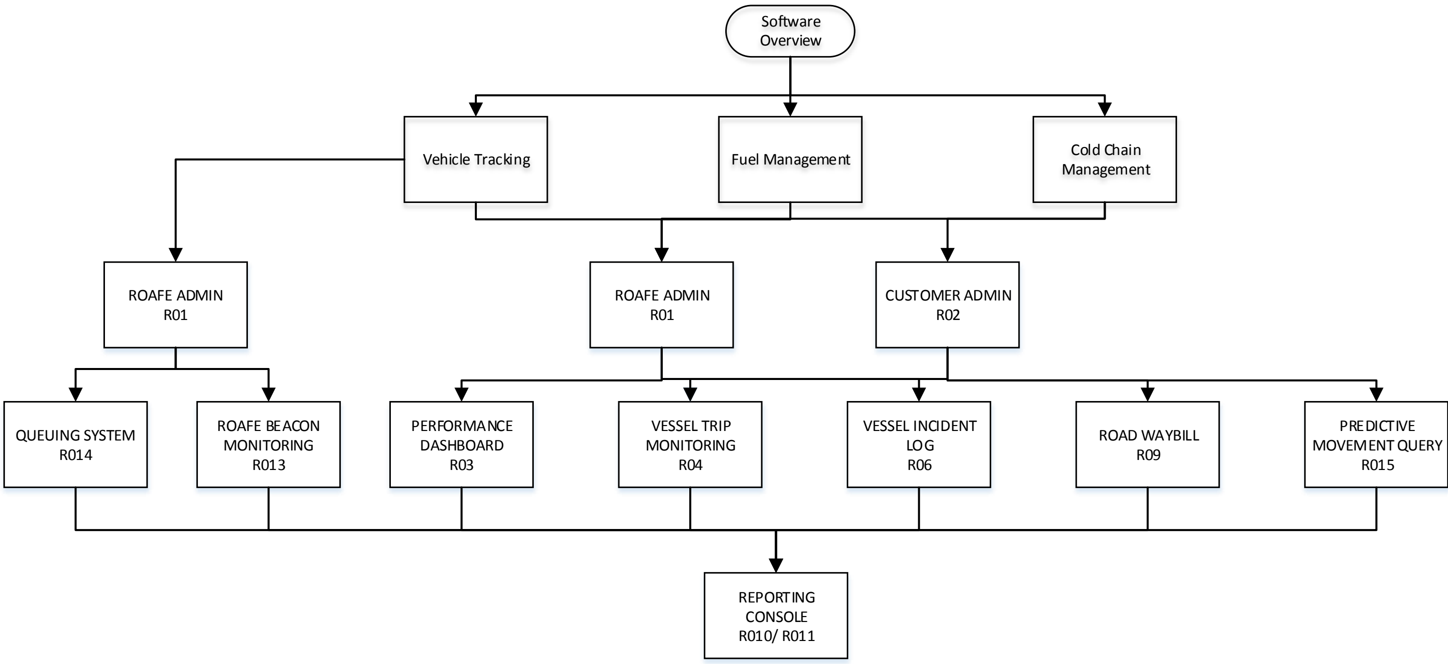


Figure 41: Software Overview

5.2.2 Cold Chain conceptual software breakdown

The overview shown in Figure 41 above depicts the basic requirements for supply chain management. The functions shown here is not all required to perform effective CCM. In this section, the breakdown from the above figure is shown for the purpose of CCM. The administration requirements for CCM is shown in Figure 42 and defines the requirement for the preparation of a consignment to be transported for a client.

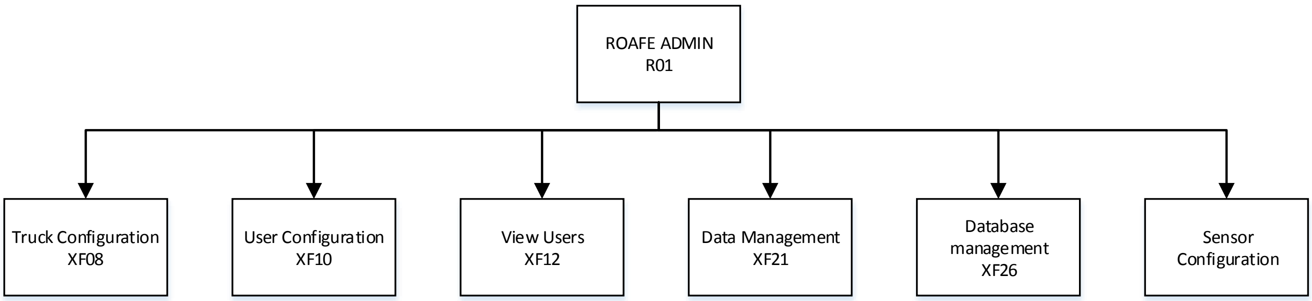


Figure 42: ROAFE ADMIN software Level 2

The customer administration for clients that requires the delivery of a consignment is shown in Figure 43 below. This indicates the functions that provide information to the clients on route to define the fluctuations of the transported consignment.

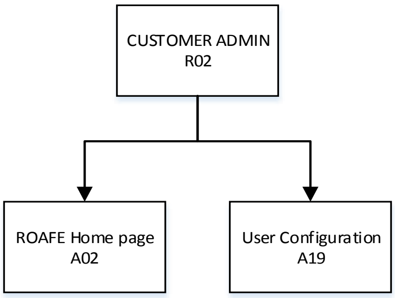


Figure 43: Customer Admin Level 2

The third level of detail is shown in the figures to follow. This describes the essential functions required in any software solution for CCM. The functions allow for more than the tracking of environmental temperature, but the entire process from an order is received to the delivery of the customer site and all the steps in-between. Figure 44 defines the three elements required to transport goods from A to B. This include the horse, trailer and driver that satisfies the requirements of the consignment.

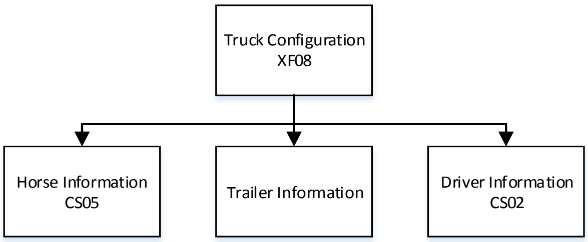


Figure 44: Truck Configuration Level 3

To allow the safe operation of software and the use of the functions in an accountable manner, the functions of Figure 45 is required to define user, customer and driver profiles.

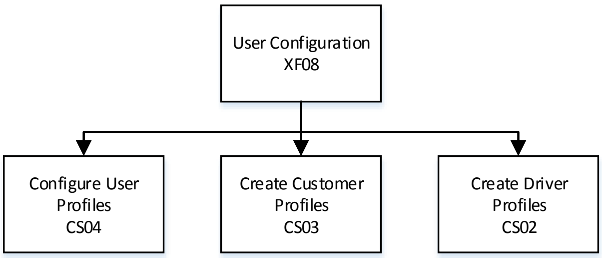


Figure 45: User Configuration Level 3

After the information has been created easy management of the data is crucial to reuse, store and dispose of when required. The user information must be used to allow access to the software platform and link user to operations conducted on the platform. Driver information must be recalled to establish the history of operation to gauge how effective the driver is in accomplishing the duties of delivering a consignment safely on time at the client.

The truck information builds on this premise of effective control by knowing the details of the each mobile asset in the yard and the maintenance requirements. Customer details are the next fundamental part in the design to establish the order and payment history. This will allow the user the ability to gauge the trustworthiness of the customer and cost of operation to service the client. This function is indicated in Figure 46.

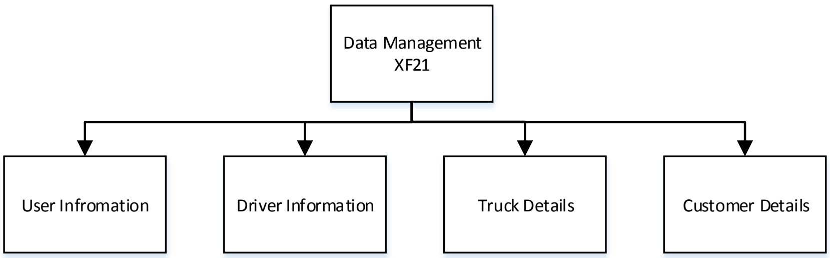


Figure 46: Data Management Level 3

The recall of the information fed to the system must be done by means of SQL queries of a database. The information stored her is defined in the flow diagram shown in Figure 47.

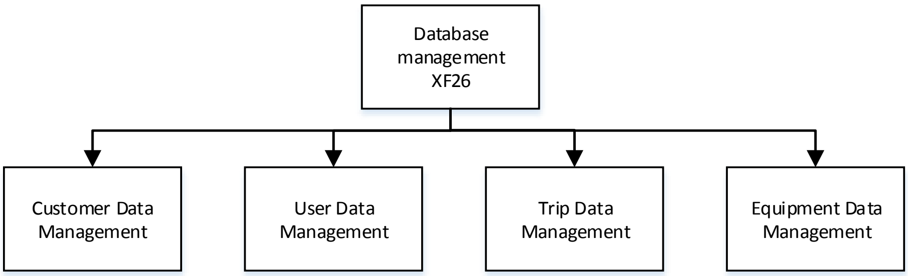


Figure 47: Database Management Level 3

As mentioned the software must provide security of information and the ROAFE home page provides this. The user, LSP or customer, can login to the software and gain access to the information in the database and the functions defined in Figure 44 to 47. Once the user has access to the software he can navigate between the functions by means of navigation tabs.

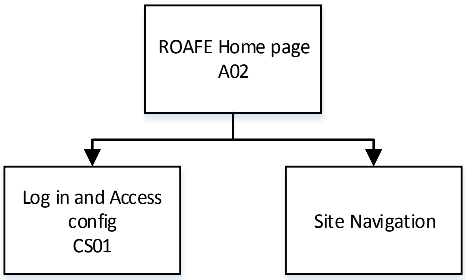


Figure 48: ROAFE Home Page Level 3

The acquired information from the vehicle configuration, user configuration and equipment configuration functions can now be used to configure a trip per customer order. The trip configuration includes the following:

- Creation of a new consignment
- Destination of pickup and delivery
- Agents responsible at each point
- Vehicle allocation
- Inventory allocation

After the configuration of the trip plan it is necessary to configure sensors for the purpose of temperature management. The user must have the ability to select between different RFID systems to monitor the temperature. The data for the sensor must be automatically configured according to the selections made in the trip planning phase. The data retrieval methodology must also be configured once-off to establish how the data is retrieved from the sensors in either real time or passive method. This is shown in figure 49 below.

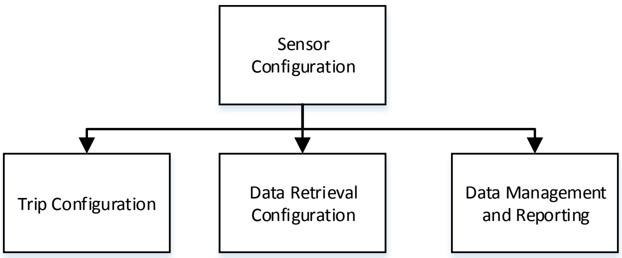


Figure 49: Sensor Configuration level 3

The data retrieved from the configured sensors, dependant on the functionality of the unit allocated to vehicle configuration reports on the route and temperature of consignment in real-time or passive retrieval. The reporting must provide information of route, temperature fluctuation and predictive statistical information of the consignment. The information provided in the reports must be clear and to the point ensuring the communication of essential information as per the user requirements defined in Chapter 3. The reporting lines is depicted in Figure 50 below.

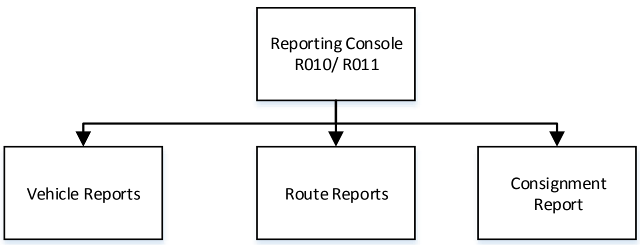


Figure 50: Reporting Console Level 3

5.3 Software operational analysis

The above described conceptual design for the CCM platform indicated the flow of information in the management and planning of a perishable consignment. This flow is depicted in Figure 51 below. The figure shows steps 1 to 8 of the management process reflecting industrial flow for CCM.

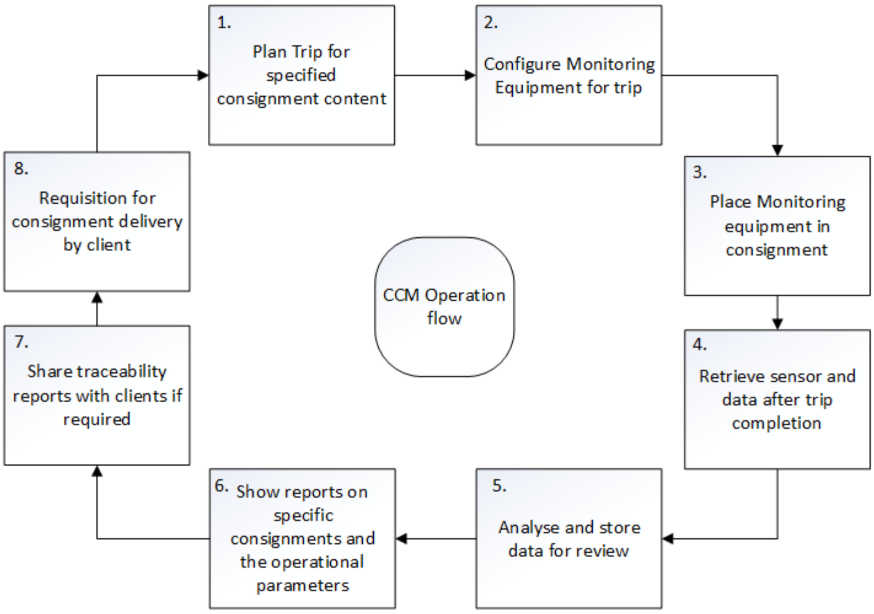


Figure 51: Operational Flow of CCM software

The software design provides the user with the ability to manage the cold chain process in a guided step methodology. The aim is to gather the required information from the user with regards to the specific consignment to be transported. Standard information on the assets available to the client is provided to the system and stored in the connected database. The information is gathered via input forms that guided the user to provide valid and complete information to the system. The data can later be altered by means of recall. By incorporating this data storage capability to the system, information can be reused multiple times thus saving time to redefine data during the trip planning phase.

In the trip planning phase allow the user to consolidate information for a specific type of consignment. The information provided during this phase define elements such as temperature control, turnaround time and the agents responsible at each phase. Once the relevant data has been collected from the trip and the plan has been configured, a user can then configure equipment to meet their cold chain needs. The selections made during the trip planning phase is then loaded from the database to set the parameters for the sensor to be configured to. On completion of the configuration of the temperature tags, the units are connected to a consignment or pallet in the trailer. The units can either have real time or passive monitoring capabilities. Dependent on the configuration of the specific units the data is relayed to the web server by means of data polling or direct data retrieval. The data is then processed on the server side. The processed information is stored to the database and used on the reporting page for temperature verification and validation for the client. This system workflow is depicted in Figure 52.

Figure 52: Software overview

5.4 Preliminary CCM design

The ability to easily extract data from temperature sensors in the cold chain is essential to improve efficiency during the process. Although the functionality of the hardware plays a crucial role in cold chain management, the software accompanied by it is equally important. The correct software must enable a user with little computer skills to operate the system with ease and view data from a trip in a manner that is relevant and meaningful to the company.

In the logistic chain, there are 3 essential parts where the software platform comes into play. The first part is at the DC before a consignment is sent to the customer site. The functionality required at this point is shown in Figure 53 below.

The general concept is that the user must have the ability to register a sensor on the system to enable its future identification. Once registered the sensor's acceptable temperature range for a specific consignment must be set up and linked to the relevant consignment.

The relationship between sensor and consignment must then either be manually documentable or automatically stored on a web server database as a reference for data received in transit or at the EC (Equipment centre).

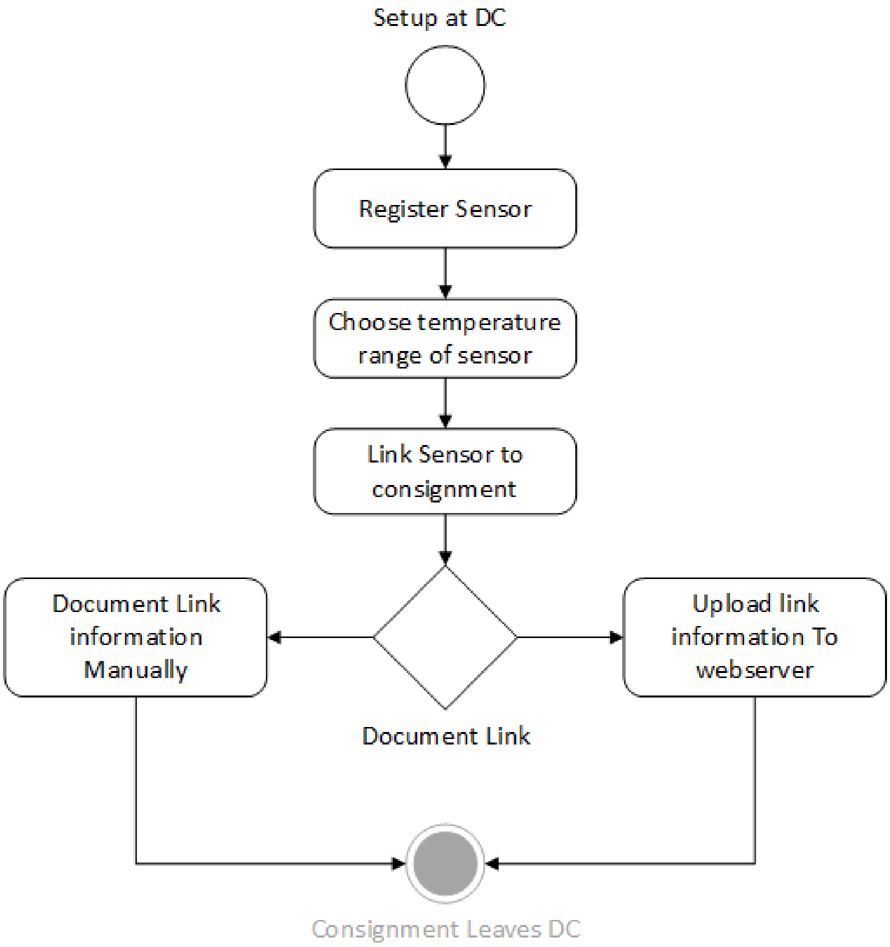


Figure 53: Software functionality at DC

The second requirement is that the software must have the ability to receive, process and display temperature data by using the wireless (GSM/GPRS/RF) communication capabilities of the temp loggers. The functionality required for data processing in transit is shown in Figure 54. The received data must be evaluated according to the consignment it is monitoring, as linked during DC setup.

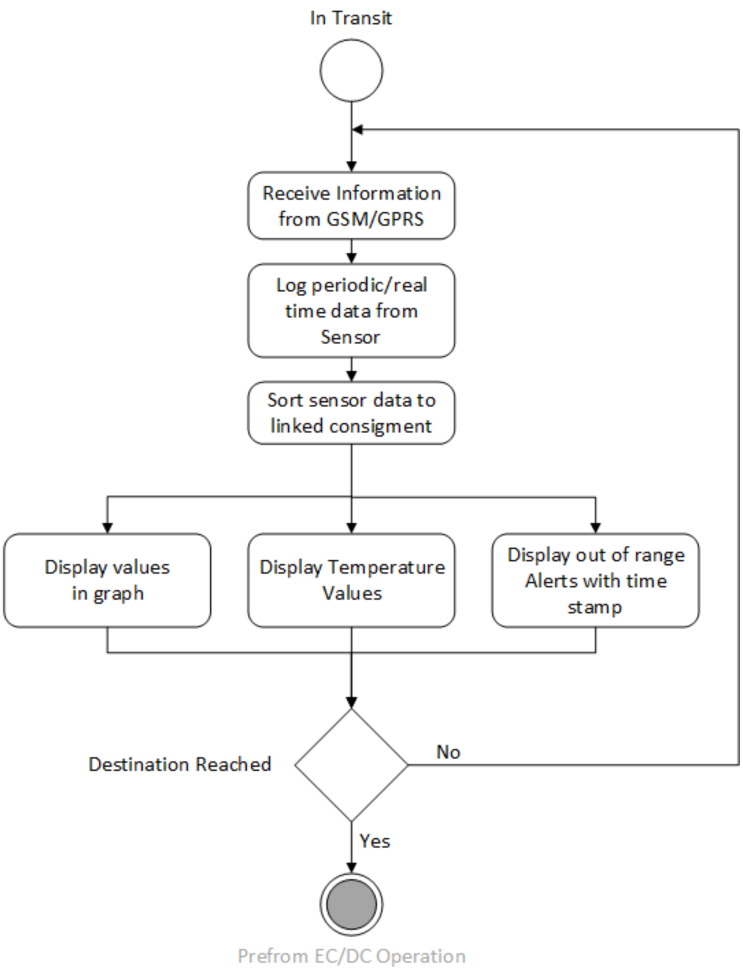


Figure 54: Software functionality for consignment in transit

The software must, at least, be able to generate three kinds of data outputs from the consignment information:

- Visual graphs of the temperature vs. time.
- Tables of values received
- Temperature alerts triggered during transit if thresholds are exceeded and stored on the sensors memory.

This process will continue until the consignment reaches its intended destination.

The third and final part is the functional requirement when arriving at the EC; this process will be different for hardware that does not have remote real-time communication capabilities. Even for GSM/GPRS based systems, it is also possible that not all data of a consignment has been transferred while the goods were in transit, as the system may be configured to only communicate alerts in order to save both battery power and communication costs. The overview of this requirement is shown in Figure 55.

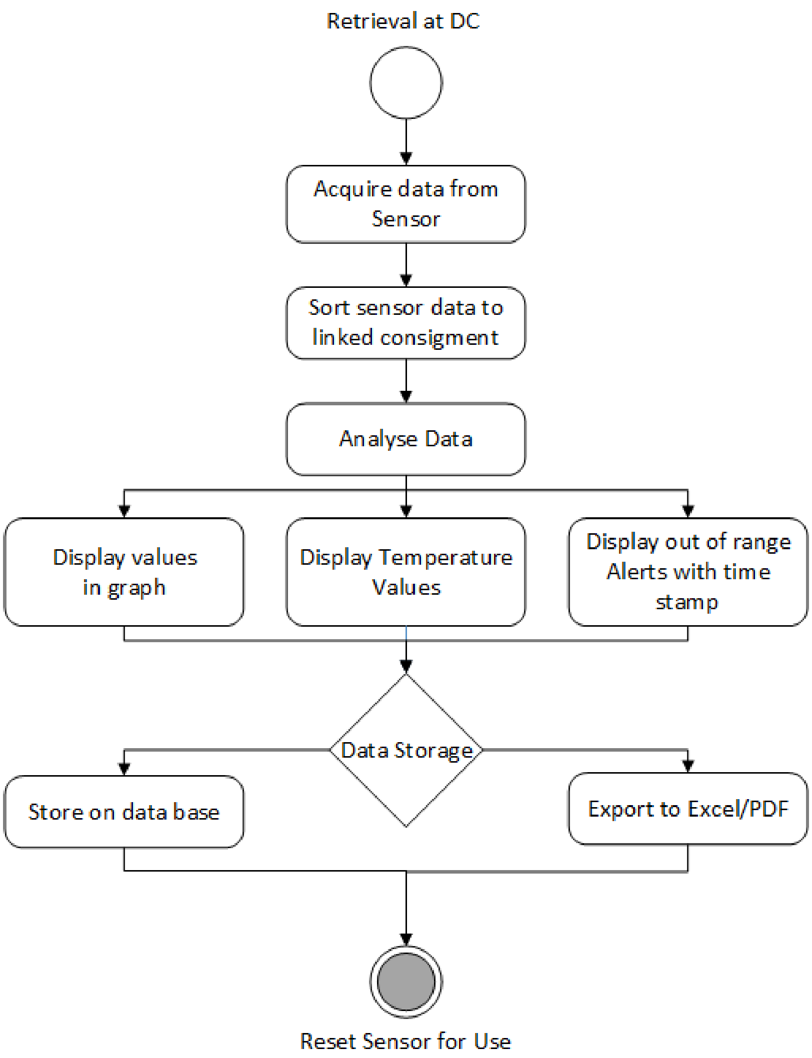


Figure 55: Software requirement at the EC/DC

At the EC once the data is acquired from the sensors by means of RFID or USB the information must be analysed by the software and the data linked to the appropriate consignment as referenced at the DC. The software must again, at least, be able to output the acquired information as a graph, temperature values and alert periods. The information must then either be stored on a database for reference at a later time or be exportable as either an Excel or PDF document containing the information of that specific consignment.

It must be possible to reconfigure the software to associate the sensors with the next consignment dispatched from the DC. The entire software platform must be of such design to accomplish the majority of operations with little human interaction required and delivering all information in an easily understandable and meaningful manner.

5.5 CCM detail design

5.5.1 The development environment

The development environment must firstly be defined, this will provide the necessary information on the capacity and functionality to meet the requirements being defined for. The simplest package to use is and integrate with team software is that of Microsoft Visual Studio 2013 using the VB.Net language. This will enable the development of web application software to meet the requirement of mobility. The application will be developed using webpages along with an object oriented approach. The software needs to be connected to an external database for the storage of information. The database will be developed using the SQL Server 2012 to provide the application with a simple relational data integration.

5.5.2 Graphical user interface (GUI) design

5.5.2.1 Login Page

The login page is the standard page a user is routed to when logging into the web application and is routed back to on expiry of the allocated session key. The interface requires the UI listed in Table 12 that follows.

Table 12: Login Page

Identification:	Widget:	Function:
Username	Textbox	The username defined during the creation using the user information page.
Password	Textbox	The unique eight letter password created by the user.
Login	Button	The match provided information with that stored in the database under the user information table.
Cancel	Button	Clear the user information provided.

5.5.2.2 Management Page

I. Management of information

The management page provides the user with the functionality to create new information for assets available to the company. The user can then further use the page to view and manage information stored to the database. The data provided on this page will be used in the functions on the other pages of the software platform. The required UI for this page is listed in Table 13 that follows.

Table 13: Retrieve stored information and create new data

Identification:	Widget:	Function:
Data Selection	Dropdown list	Select the data from a list according to the required category.
Retrieve Data	Button	Read data from the database according to the selection of the user in the drop-down list.
New User	Button	Navigate the user to the user information page.
New Driver	Button	Navigate the user to the driver information page.
New Horse	Button	Navigate the user to the horse information page.
New Trailer	Button	Navigate the user to the trailer information page.
New Equipment	Button	Navigate the user to the equipment information page.

II. Create New Information

- User Information Page

The information identifying a user in the company to be of the company and provide access to the web application to manage the cold chain. The required UI for this page is listed in Table 14 that follows.

Table 14: User Information Page

Identification:	Widget:	Function:
Username	Textbox	Username is a unique identifier of the name and a random 4 digit string.
Name	Textbox	The name of an employee at the company.
Surname	Textbox	The surname of the employee.
Password	Textbox	A unique 8 digit password to be used to gain a level of access
Address	Multiline Textbox	The home address of the employee.
Email	Textbox	The email addresses of the employee.
Cellular number	Textbox	The cellular contact number for the employee.
Access level	Dropdown list	The level of access a user is granted to the software. The levels for a user is an administrator, manager, employee and client.
Submit	Button	Verify the information provided in each widget is correct and pop up a notification on any validation errors in the user input. If all validators are satisfied the data is stored to the database.
Cancel	Button	Clear all user information from input widgets.

- Driver Information Page

The information for the driver on the current location of residence, the individuals driving history and performance as well as the information on the passports and licenses. The required UI for this page is listed in Table 15 that follows.

Table 15: Driver Information Page

Identification:	Widget:	Function:
Name	Textbox	The name of the driver.
Surname	Textbox	The surname of the driver.
Sex	Radio Group	The sexual orientation of the driver.
Date of birth	Textbox	The age of the driver.
Nationality	Textbox	The country of origin of the driver.
ID Number	Textbox	The ID number if a local driver.
Passport Number	Textbox	The Passport Number if hired for cross-border transportation.
Passport Ex. Date	Textbox	The date when the passport while become invalid.
Passport Issue Location	Textbox	Where the passport was issued to the driver.
Driver Licence Number	Textbox	The driving licence number.
Licence Ex. Date	Textbox	The date of expiry of the licence.
Licence Issue Location	Textbox	The location where the licence was issued to the driver.
Vehicle Class	Textbox	The class of vehicle the driver is licensed to drive.
Years Driving	Textbox	A number of years the driver has been a driver for.
Total Accidents	Textbox	A number of accidents the driver had during this period
Address	Textbox	The residential address of the driver.
Home Number	Textbox	The residential telephone number.
Cell Number	Textbox	The mobile number to contact the driver when on the road.
Email Address	Textbox	The email address to contact the driver alternatively.
Submit	Button	The submission of the validated data to database for the driver of the company.
Cancel	Button	Clear the information of the user input form.

- Horse Information Page

The information provided on the horse for the capacity, fuel usage, maintenance schedule and load capacity. This is used to define the capability of the vehicle and the trailer it can haul for the delivery of a consignment. The required UI for this page is listed in Table 16 that follows.

Table 16: Horse information page widgets

Identification:	Widget:	Function:
Make	Textbox	The manufacturer of the horse.
Model	Textbox	The year of manufacture.
VIN	Textbox	The vehicle identification number of the horse.
Chassis Number	Textbox	The chassis number uniquely identifying the vehicle.
Registration	Textbox	The registration as per motor vehicle road requirements.
Fleet Number	Textbox	The number that identifies the horse in the local fleet.
Engine Capacity	Textbox	The size of the engine reflecting the power of the horse.
Max Haulage Weight	Textbox	The weight the horse is allowed to safely haul.
Fuel Capacity	Textbox	The amount of fuel available to the horse, this includes all fuel storage tanks. The standard thank and if available long haul tank.
Axle Configuration	Textbox	The configuration of the axis to carry weight.
RFID EPC Number	Textbox	The trucks linked with an RFID tag can be defined here.
Submit	Button	The data is verified to be of the correct length and data type. If it meets with the validation rules the information is stored to the database table.
Cancel	Button	The user input is cleared.

- Trailer Information Page

The information provided on the trailer define the registration, capacity of the trailer, type and haulage capacity of the trailer. The length and type of the trailer define the capacity of the trailer and is crucial for the calculation of temperature deviation in the cargo as will be discussed later in the chapters to follow. The required UI for this page is listed in Table 17 that follows.

Table 17: Trailer information page widgets

Identification:	Widget:	Function:
Make	Textbox	The manufacturer of the horse.
Model	Textbox	The year of manufacture.
Chassis Number	Textbox	The chassis number uniquely identifying the vehicle.
Registration	Textbox	The registration as per motor vehicle road requirements.
Fleet Number	Textbox	The number that identifies the trailer in the local fleet.
Engine Capacity	Textbox	The size of the engine reflecting the power of the horse.
Max Haulage Weight	Textbox	The weight the trailer is allowed to safely haul.
Fuel Capacity	Textbox	The amount of fuel available to the horse, this includes all fuel storage tanks. The standard thank and if available long haul tank.
Trailer Length	Textbox	The length of the trailer is required to aid the user in knowing the uses for vehicle and the eventual analysis of the temperature values received.
Axle Configuration	Textbox	The configuration of the axis to carry weight.
RFID EPC Number	Textbox	The trucks linked with an RFID tag can be defined here.
Submit	Button	The data is verified to be of the correct length and data type. If it meets with the validation rules the information is stored to the database table.
Cancel	Button	The user input is cleared.

- Equipment Information Page

The equipment page will allow the user to add monitoring equipment for the purpose of cold chain management and vehicle tracking. The required UI for this page is listed in Table 18 that follows.

Table 18: Equipment information page widgets

Identification:	**Widget:**	**Function:**
Name	Textbox	The name of the units.
Manufacturer	Textbox	The manufacturer of the devices.
Type	Dropdown List	A list of types of sensors the user can select to define the ability of the units.
Quantity	Textbox	The amount of sensors available to the company.
Min. Op. Temp.	Textbox	The minimum temperature the unit can accurately operate at.
Max. Op. Temp.	Textbox	The maximum temperature the unit can accurately operate at.
Total Sample	Textbox	The samples that is able to be stored on the internal memory of the device.
Submit	Button	Submit the information to a database for the company.
Cancel	Button	Clear all the user information provided.

5.5.2.3 Trip Planning Page

1. Create Trip Plan

The trip planning page provides the user with the ability to use the information stored to the database in the management page. The user can create a new trip plan for a consignment from scratch or recall the information of an unfinished trip plan. The trip planning page provides the user to define the specification of the consignment ordered by the customer. The user will be able to link loading and delivery destinations, dates and agents. The then further will have the ability to link a specific inventory to the trip or use a default inventory definition. The final information the user will be able to provide on this page is the allocation of the vehicle configuration for the trip. The required UI for this page is listed in Table 19 that follows.

Table 19: Trip Planning Page Widgets

Identification:	Widget:	Function:
Consignment ID	Textbox/ Dropdown List	The unique name for the trip being planned.
Client	Dropdown List	The client/customer which placed the order for delivery.
Loading Location	Dropdown List	The location selected from a list where the perishable consignment must be loaded.
Loading Date	Textbox	The date/time when the cargo must be loaded.
Dispatch Agent	Dropdown List	The agent responsible for the loading process.
Delivery Location	Dropdown List	The location where the consignment must be delivered.
Delivery Date	Textbox	The date/time when the consignment must be delivered.
Receiving Agent	Dropdown List	The agent responsible for the delivery process.
Inventory	Dropdown List	A list of predefined inventories to be transported. This represents the items and temperature parameters for the consignments to be transported.
Allocate Vehicle	Dropdown List	The button directs the user to the vehicle allocation page.
Submit	Button	Submit the information if valid to the database.
Cancel	Button	Clear the information provided by the user in the form.
Report	Multiline Textbox	A report defining the information of the trip and the parameters thereof.
Configure Equipment	Button	Transfer the user to the equipment configuration page.
New Agent	Button	Transfer the user to the new agent page to create an agent on the route.
New Location	Button	Transfer the user to the new location page to create a new location for loading/delivery.
Manage Inventory	Button	Transfer the user to the inventory page where the user can create and manage inventories for the trip.

2. Create Agent for delivery/loading

The agent creation page defines new agents of companies that will either be used as the contact person at the loading site before transportation or at the delivery destination. The required UI for this page is listed in Table 20 that follows.

Table 20: Agent Creation Page widgets

Identification:	Widget:	Function:
Name	Textbox	The name of the agent responsible for loading and offloading.
Surname	Textbox	The surname of the agent.
Cell Number	Textbox	The cell phone number for the agent to allow the driver or LSP manager to contact them and make arrangements for delivery if necessary.
Email	Textbox	Further alternative contact method.
Submit	Button	Store the data to the database once passed the validation.
Cancel	Button	Clear the information from the input form and return to the trip planning form.

3. Create Location of interest

The location creation page defines the loading and delivery destination of the consignment to allow route definition and tracking of a consignment and aid the driver in his the operational duties. The required UI for this page is listed in Table 21 that follows.

Table 21: Location creation page widgets

Identification:	Widget:	Function:
Address	Textbox	The physical address where a delivery/ pickup can be made.
GPS Co.	Textbox	The GPS co-ordinates for the location to allow mapping.
Submit	Button	Store the location to the database for reuse.
Cancel	Button	Clear the information from the input form and return to the trip planning form.

4. Create Inventory for consignment

The inventory will provide the user with the ability to select and add items to an inventory list. The list will then be used to automatically calculate the parameter for the consignment and that needs to be used for the monitoring and management of the cold chain. The required UI for this page is listed in Table 22 that follows.

Table 22: Inventory Creation Page Widgets

Identification:	Widget:	Function:
Name	Textbox	The name of the inventory list being created.
Perishable Item	Textbox	A list of perishable items the user can select from, this is defined in the temperature standard page.
Add Item	Button	The perishable items are added to inventory list loading the data from the stored information of the defined standards.
Inventory	Data Table	The select items' parameter is loaded and displayed in the table.
Analysed Inv.	Data Table	The most sensitive limits for the consignment is calculated and displayed in the table.
Submit	Button	The inventory list and calculated parameters are stores to the database.
Cancel	Button	Clear the information from the input form and return to the trip planning form.

5. Create Temperature standard for consignment

The general definition of the parameters for perishables is provided to the system and stored to the database to be used for the calculation of temperature deviations. The required UI for this page is listed in Table 23 that follows.

Table 23: Temperature Standard Creation Page Widgets

Identification:	Widget:	Function:
Perishable Name	Textbox	The name for the item being defined for example apples
Min. temperature	Textbox	The minimum temperature the item can be stored at before damage occurs.
Max. temperature	Textbox	The maximum temperature the item can be stored at before the degradation is extremely accelerated and damage occurs.
Shelflife	Textbox	The ideal shelf life of the item when properly handled.
Shelflife +10ºC	Textbox	The shelf life when the items are placed at a temperature of 10ºC above the ideal.
Relative Humidity	Textbox	The humidity that enables the longest shelf life.
Activation Energy	Textbox	The energy that defines the degradation tempo of the item.
Submit	Button	Store the item to the database if the data is valid.
Cancel	Button	Clear the user input.

6. Allocate Vehicle for consignment

The vehicle allocation page provides the user with the ability to select a horse, trailer or driver configuration for a specific trip to meet the needs of the clients order needs. The required UI for this page is listed in Table 24 that follows.

Table 24: Vehicle Allocation Page Widgets

Identification:	Widget:	Function:
Horse Information	Dropdown List	A list of the horses available to the company and not transporting an active trip.
Trailer Information	Dropdown List	A list of the trailers available to the company and not transporting an active trip.
Driver Information	Dropdown List	A list of the drivers available to the company and not transporting an active trip.
Allocate Vehicle	Button	Allocate the vehicle to the trip plan.
Cancel	Button	Clear the user input in the form.

7. Consignment Sensor Placement

The page will allow the user to link configured sensors to the consignment. This will allow the calculation of statistical information for the purpose of temperature evaluation on the capture of the data to the server. The required UI for this page is listed in Table 25 that follows.

Table 25: Sensor Placement Page Widgets

Identification:	Widget:	Function:
Consignment ID	Dropdown List	A list of the consignment planned is currently in the field.
Placement Type	Dropdown List	A selection to place sensors either on the periphery or on pallets.
EPC Sensors	Dropdown List	A list of the sensors configured for the trip.
Visual Trailer	Image Buttons	Connect sensor to a position in the container visually.

5.5.2.4 Equipment Configuration Page

This page will allow the user to select the equipment available to the company. Then use the system selected to configure sensors to the appropriate temperature values for the consignment being transported. The required UI for this page is listed in Table 26 that follows.

Table 26: System configuration page widgets

Identification:	Widget:	Function:
Manufacturer	Dropdown List	A list of systems available to the user for the purpose of monitoring the consignment.
Select Manufac.	Button	Load the relevant equipment configuration input form for the manufacturer if the selected devices.
Equipment Table	Data table	The monitoring equipment available to the company from the manufacturer selected.
Connection Type	Dropdown List	For multiple devices the user can select between them and make a choice of connection.
Connection Address	Textbox	The communication address for the device selected to connect to it.
Consignment ID	Dropdown List	A list of consignments specified during the trip planning phase.
Detected Sensors	Dropdown List	A list of sensors detected from the connection established to the selected unit.
Select All Sensors	Checkbox	Select all the sensors from the list.
Sample Rate	Textbox	The tempo at which data must be collected by the sensors configured.
Min. Temp.	Textbox	The lowest allowed threshold for temperature.
Max. Temp.	Textbox	The highest allowed threshold for temperature.
Start Time	Textbox	The time when the unit needs to begin monitoring.
Sensor Table	Data table	A table of the sensors detected by the connected device.
Sensor Detection	Button	Read sensor through the connected device.
Configure	Button	Configure the sensor with the parameters set by the user.
Cancel	Button	Remove user input.

5.5.2.5 Data Retrieval Page

This page enables the user to connect to relevant units to retrieve the data from sensor returning from the field. This page is mainly focused on the retrieval of passive data from the sensor when they are not capable of real-time data streaming. The required UI for this page is listed in Table 27 that follows.

Table 27: Direct Data Retrieval Widgets

Identification:	Widget:	Function:
Consignment ID	Dropdown List	A list of the consignments planned for a company and is currently in the field.
View Page	Button	View the appropriate page to retrieve data from the devices.
Connection Type	Dropdown List	For multiple devices the user can select between them and make a choice of connection.
Connection Address	Textbox	The communication address for the device selected to connect to it.
Connect	Button	Connect to the device selected.
Detect Sensors	Button	Read sensors in the field of the device.
List of Sensors	Dropdown List	List the sensors detected by the device.
Retrieve All	Checkbox	Select all sensors to read data.
Retrieve Data	Button	Read data samples from the selected sensors.
Average Temp	Dropdown List	A list of average values for the data read from the sensors.
Temp/Time Graph	Spline Graph	A graph to display the samples read in ºC vs time.
Sensor Placement	Data Table	A table with the sensors configured for the consignment and their positions where they were placed in the consignment.
Read Sensors	Data Table	The average values for the sensors and limits triggered in the field.

5.5.2.6 Reporting Page

The reporting page provides the user with the ability to retrieve information stored to the database. This information includes the trip plan, temperature samples and their analysis to characterise the trip from pickup to the delivery of the cargo. The required UI for this page is listed in Table 28 that follows.

Table 28: Reporting Page Widgets

Identification:	Widget:	Function:
Consignment ID	Textbox	Select the consignment from a list stored in the database to view the corresponding information.
Report	Multiline Textbox	Retrieve and display the relevant information from the table.
Temperature Graph	Graph	Display the temperature stored for the trip and other relevant information.
Save	Button	Save the report in PDF format to a required place externally.
Print	Button	Print the using the locally connected printer.

5.5.3 Functional software design

The interfacing of the different sections of the complete software package is key, to confirm the software to a functional unit that use relevant data that is not unique to a specific individual area. Thus to avoid duplication and the storage of redundant information, the overlapping areas must be clearly defined and shared among the different sections, Appendix A defines the variables and functions in further detail.

The CCM software will have the following overlapping section in common:

- Login information
- User Information
- Company Information
- Truck Information

In this section, the definition of the functionality behind the pages defined in 5.5.4 will be discussed. The complete process as designed for optimal usability by a user of general computer skills and to aid them in operating the system with the utmost ease is discussed here. As will be seen the design has been done to allow the system to perform a great amount of function and processing in the background to simplify the operational process of cold chain management.

Equipment file creation

The management page provides many different input forms as previously defined. The process of these forms is the general process of adding information to the database for use. There is no complex functional process involved in these function, except for the equipment creation option. The equipment creation process shown in Figure 56 defines the process to add new equipment to the database of a company. The users can add generic equipment to the database that is used in the operation process of their individual logistic operation or select to add information defining the capabilities of temperature and other environmental sensors for CCM. On submission, the data provided is evaluated by the system to be of correct format, length and validity. The data is then stored to the Equipment table from where it is recalled when used by the user later in the operation cold chain logistics process.

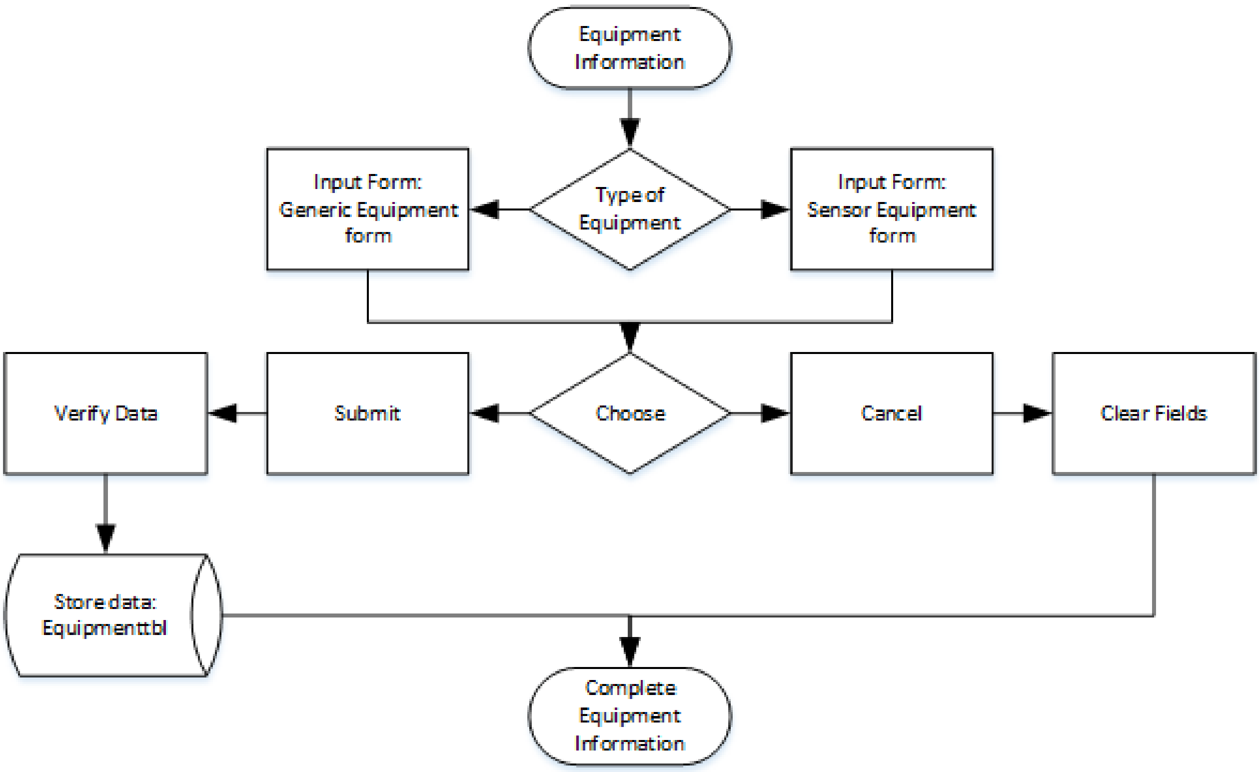


Figure 56: Add new CCM equipment

Trip Planning

The functionality behind the trip planning page is the crux of the CCM software platform. This enables the user to utilise the data and define the needs of a client in a manner that provide critical information to the system to perform intelligent processes to improve the process of logistic operation. The trip planning page offers the user with three menu selections as indicated in Figure 57.

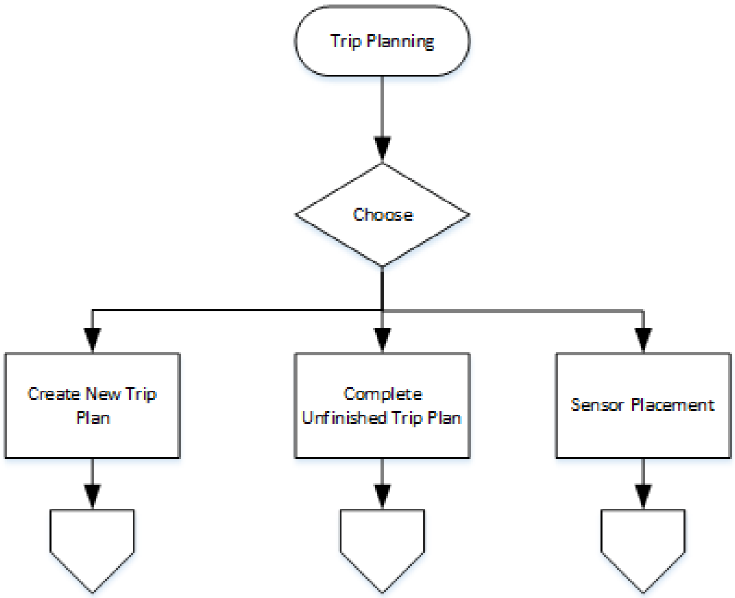


Figure 57: Trip planning overview

The first is that of creating a new trip plan from scratch, the second is loading an unfinished trip plan from the database or after a configuration is completed the placement of sensors connected to the trip plan. For the first selection, the user is directed automatically to the creation page. The process indicated in Figure 58 is then followed. When the page is loading, the software recalls all the data available from the database for the clients, agents and locations the company has already used. The data is then loaded to the relevant drop-down list for the user to select from. The user is required to provide all the other information required to successfully analyse and manage the trip.

The stored information does not always reflect all information required for the definition of a trip such is in the case of a new client to the company. The user can then add the information in a structured and guided manner by selecting the corresponding button for the information. If the user does not have all the information at this point of the planning process, the user can elect to submit the data as is and supply the outstanding information at a later stage before configuring equipment for the consignment.

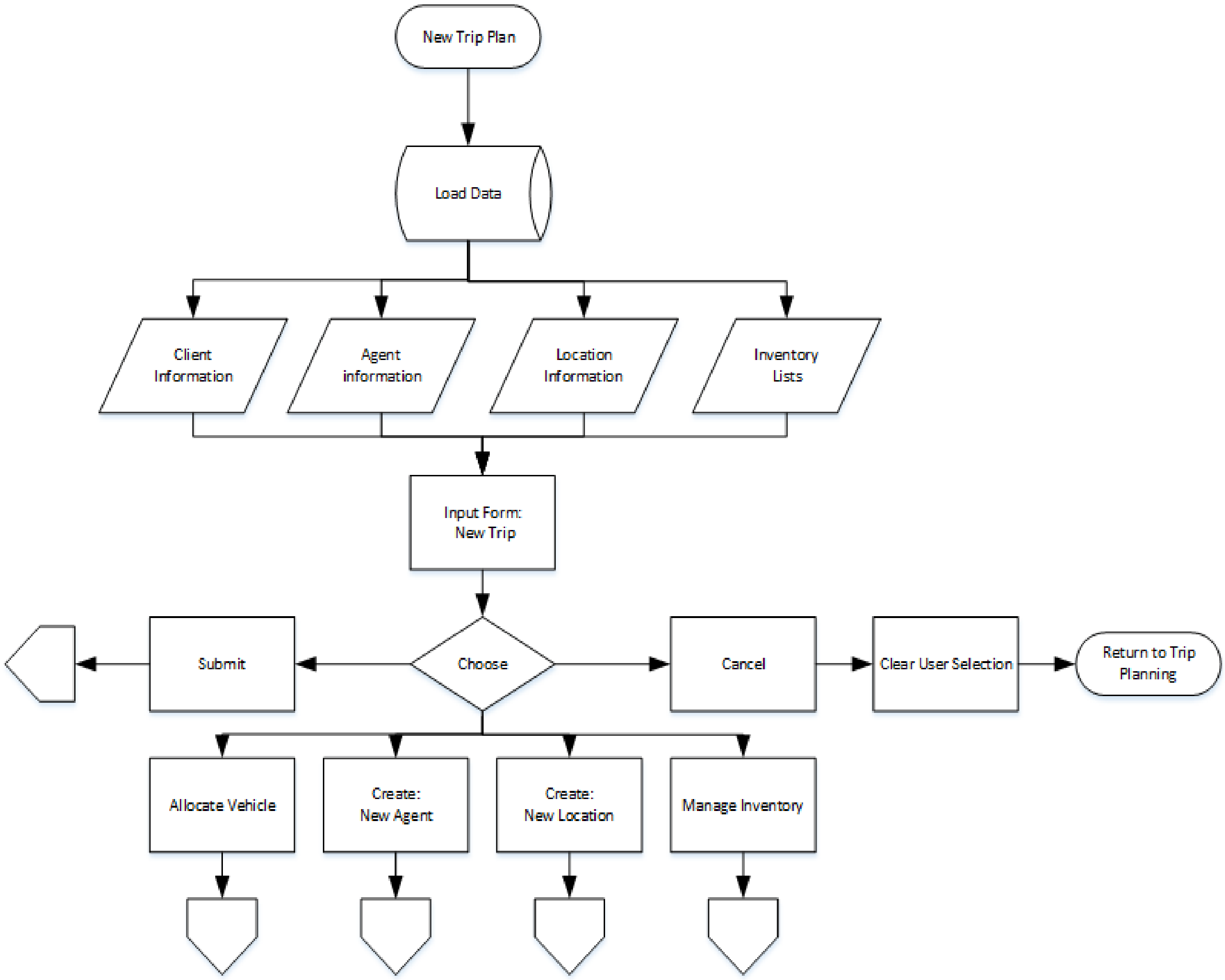


Figure 58: New trip creation flow

In the scenario where the user returns at a later stage to complete the trip plan the user follows a similar process to that discussed above. On selection of the consignment identifier all data previously provided for the consignment is loaded from the trip planning table in the database. On submission completion of the trip plan, a report is generated to its defined parameters and the configuration button is enabled. This enabling provides the user with the ability to configure sensors and other monitoring devices for the trip using the defined parameters.

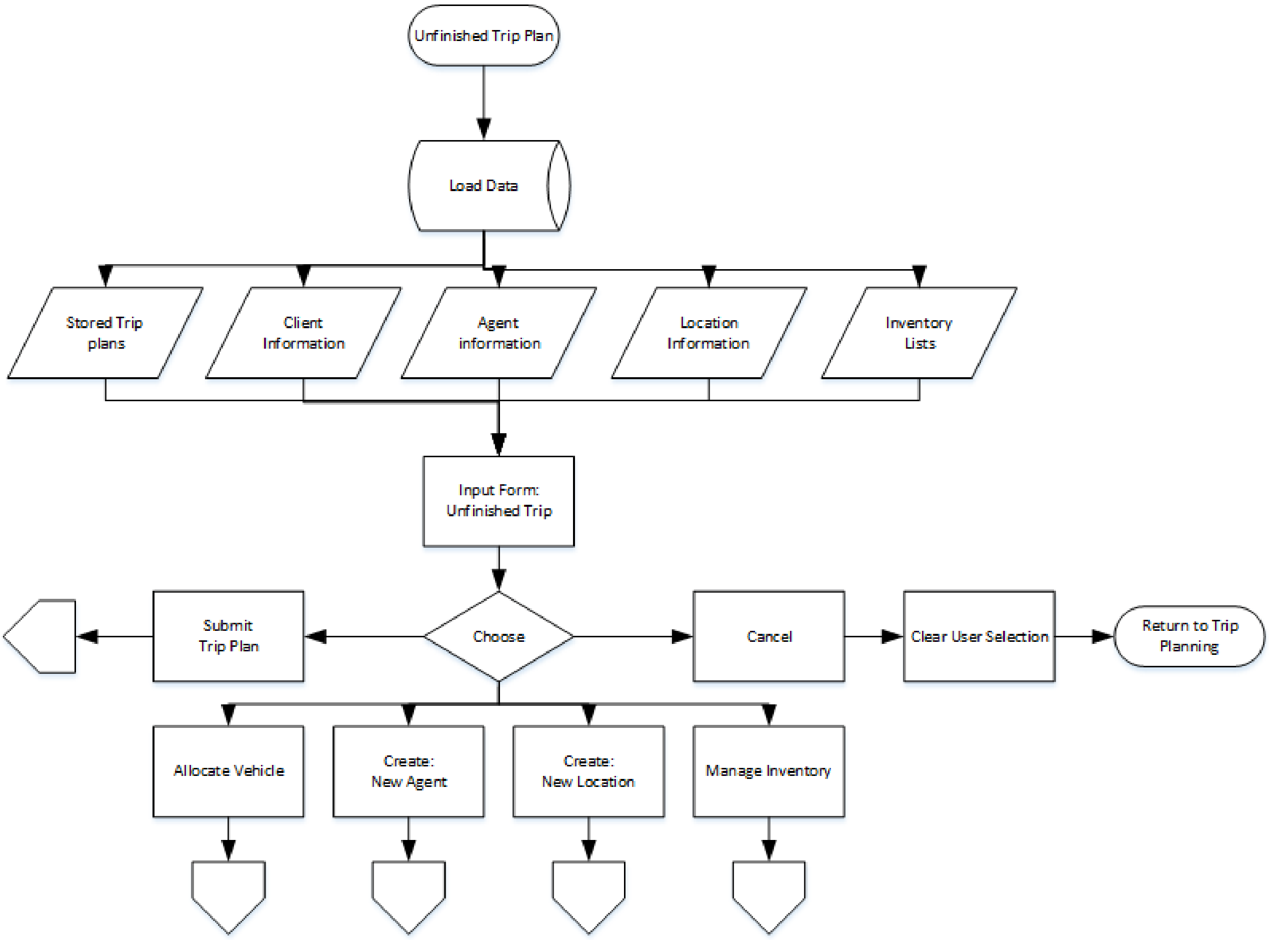


Figure 59: Unfinished trip completion flow

Once the trip plan has been completed and sensors configured to the defined parameters the user must link the sensors to specific positions inside the trailer. This function is required to92nalysablermation during the trip that is analyzable according to the position, otherwise, the information will not provide tangible data for any further purpose as historic and real-time temperature verification. This sensor placement process is defined in Figure 60 below. When the user loads the sensor placement page the platform automatically loads active completed trip plan identifiers from the database. The user can then select to place sensors either in selected tiers of the trailer or directly on the pallets themselves. From this user selection, the system calculates the position of the sensors, the length of the trailer supplied during the trailer information definition is used in this calculation and later in temperature analysis. The user is guided in this placement by means of visual trailer definition. The selection is stored to the database on click by selecting a sensor by sensors basis.

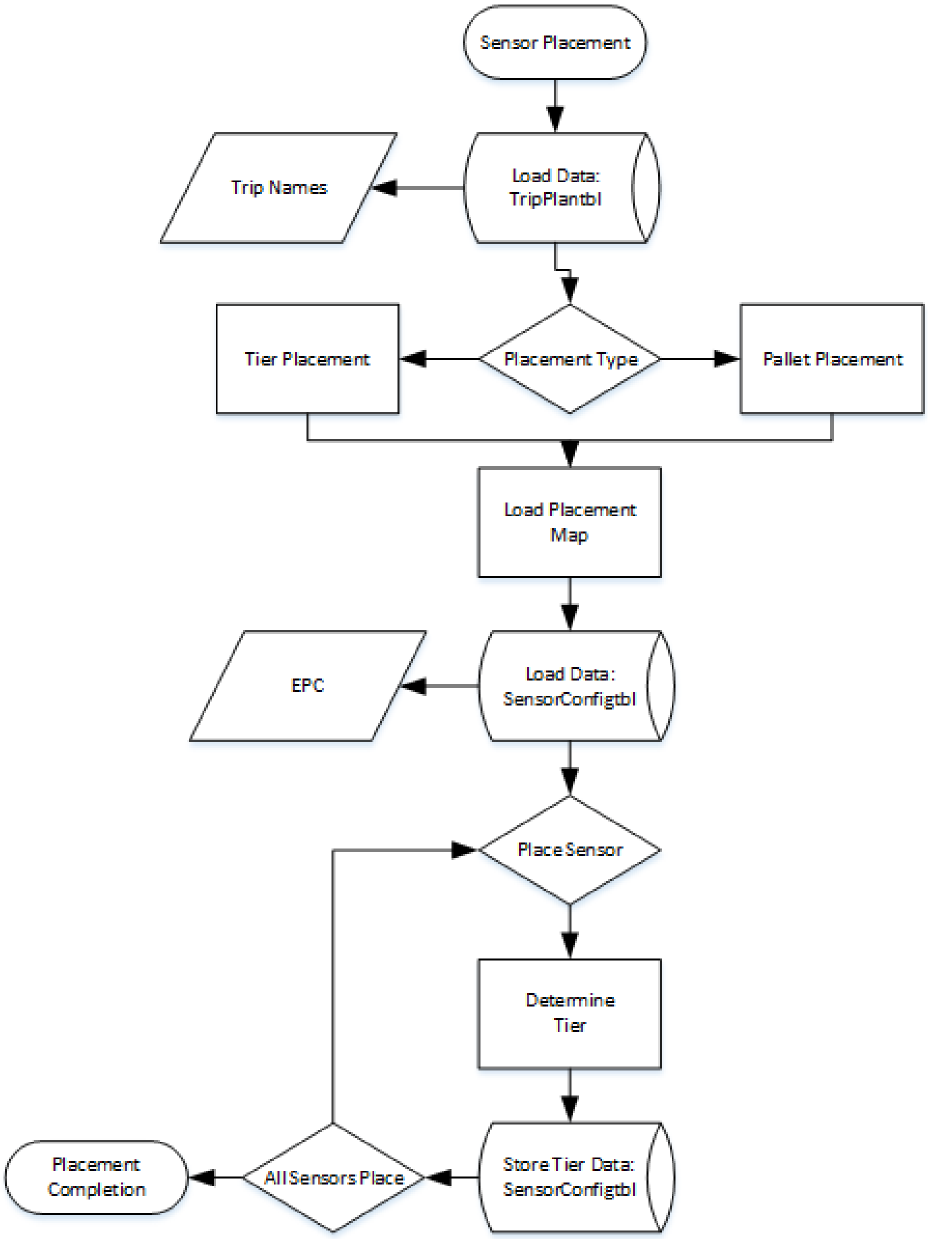


Figure 60: Sensor placement flow

Equipment Configuration

The design of the equipment configuration page is done focusing on three initial systems describe in chapter 4. The system is the Caen RFID BAP systems, the Piccolo Plus and the Ikaya active RFID solution. This process is shown in Figure 61 when the page is loaded the user can select between one of the three devices. The selection of the device will load the corresponding input page reflecting the ability of the selected system.

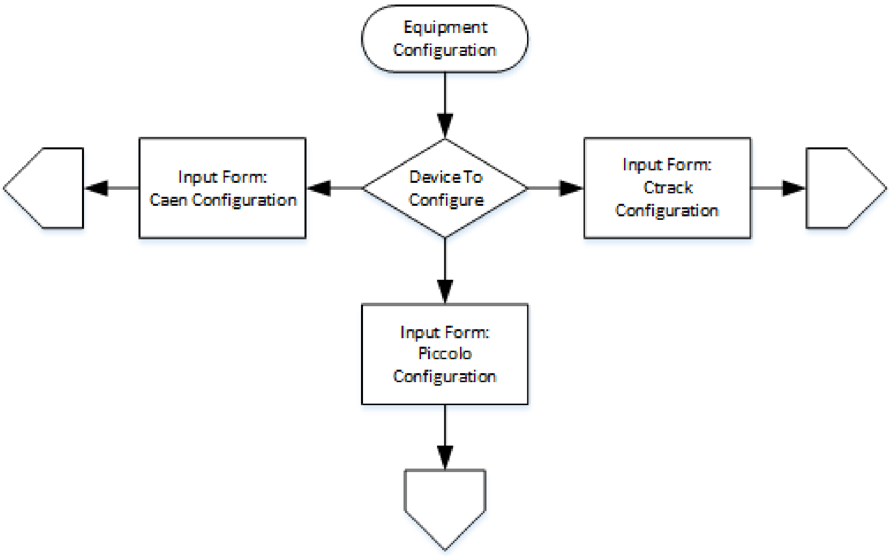


Figure 61: Configuration overview

I. Caen Configuration

The Caen RFID configuration is shown in Figure 62, once the configuration page is loaded by the user he can start to select the interrogator to use in the operational process. During the page load, process information is loaded to a table for all the sensors available for the Caen sensors. This is indicated in Figure 63. The user connects to the interrogator using a supplied connection address. The connection process is repeated an x amount of times using the connection address if no reply is received from the unit the software notifies the user to verify the information supplied. The connection is then used to detect sensors in the field of the interrogator. This detection process is indicated in Figure 64.

The sensors in the field of the reader are polled by an initial inventory process that ensures that a connection is established to sensors, a user definition of a number of sensors to be configured is used to ensure that all sensors are detected during this process. Once the sensors have been validly detected, the initial automated inventory process then retrieves the unique EPC number for each sensor. The user can then select a consignment id that loads the temperature parameters from the database as defined for the trip plan. The user only needs to define the sample rate if the default resolution is not suited to the users need. A single or all sensors detected can be configured with these same configuration parameters thus limiting the user input required. This process is depicted in Figure 65 below.

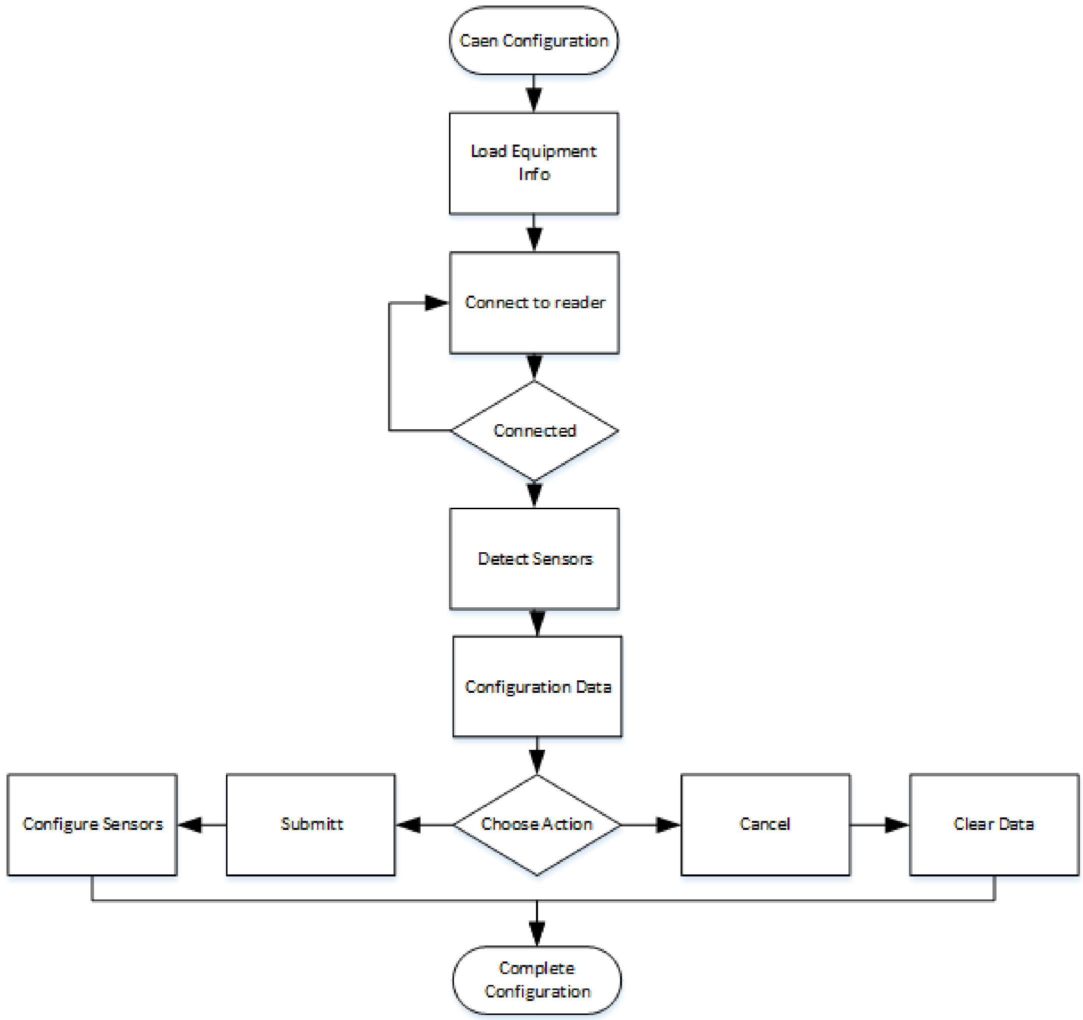


Figure 62: Caen sensor configuration flow

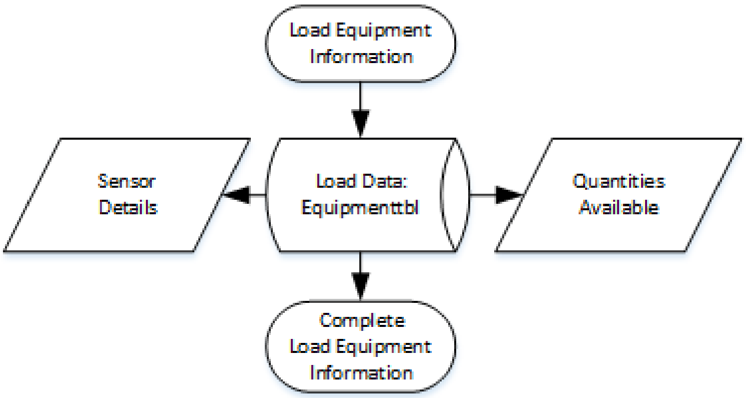


Figure 63: Load equipment information

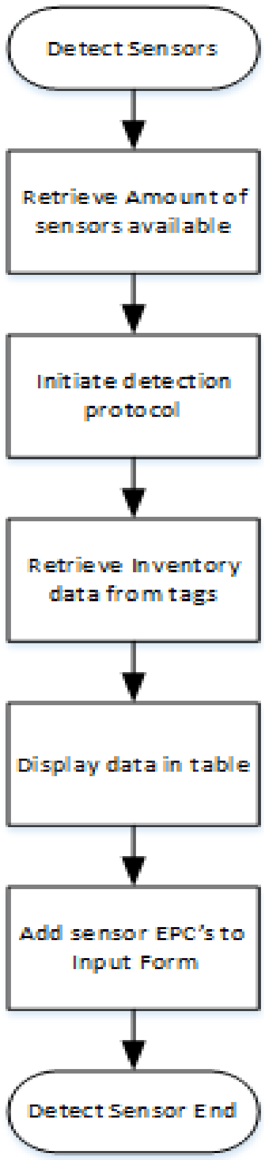


Figure 64: Caen sensor detection flow

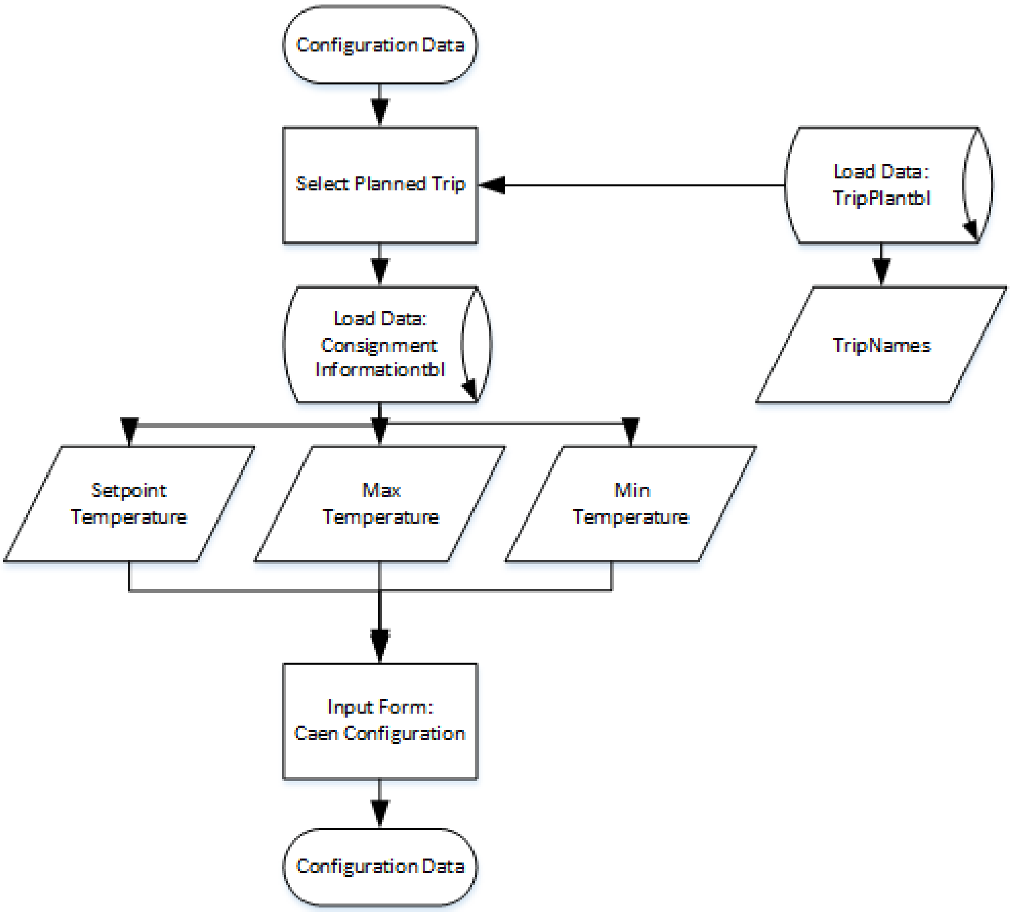


Figure 65: Caen data retrieval for configuration

The system automatically discerns the A927Z and RT0005 sensors by using the EPC codes and determines which protocol to users to configure the selected tag with the parameters. The configuration is verified before indicating to the user its success. On the successful configuration of the tags, the configuration is stored to the configuration table in the database for later use in the analysis. The configuration process on sensor level is shown in Figure 66.

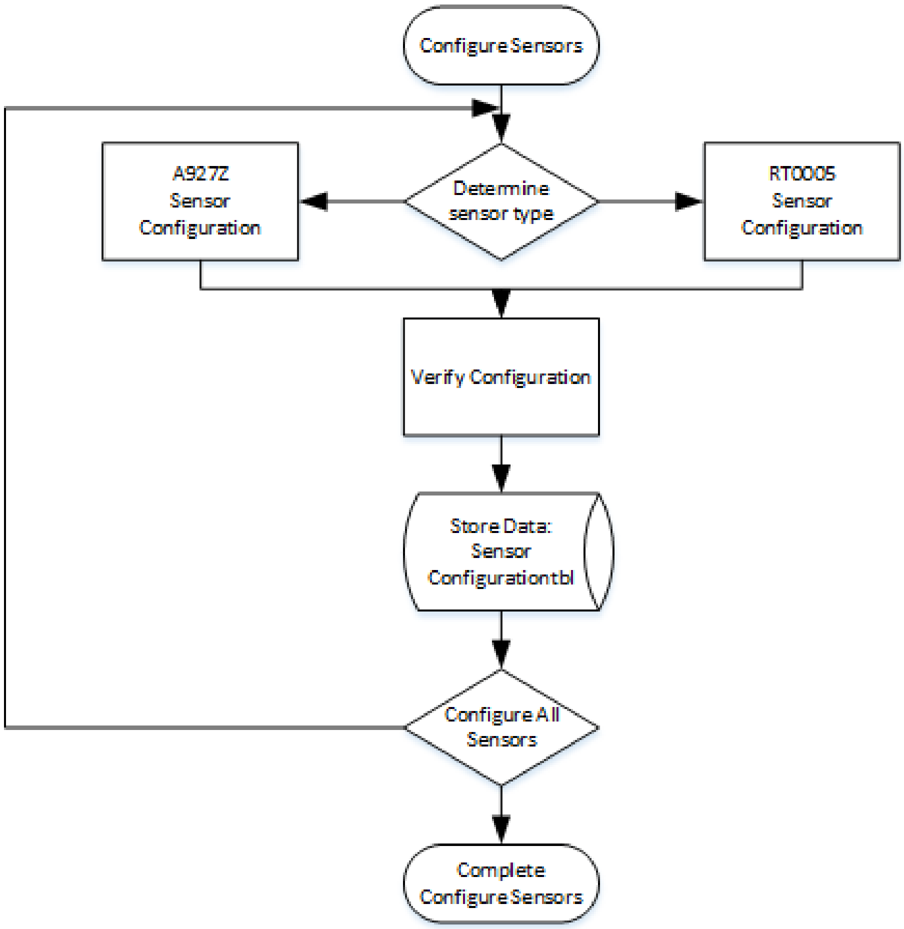


Figure 66: Caen Configuration flow

II. Ctrack Configuration

The Ctrack system consists of three units, the Ctrack unit itself that is responsible for tracking operation and the relaying of the information, the connected Ikaya system base station and the ikaya wireless sensor. The Ikaya protocol limits the sensor to 8 sensors and with a default sampling rate of 5 minutes. The sample rate can only be changed by directly changing the value in the protocol and uploading it directly to the unit.

The sensors are linked to the base station in the same manner once off. The configuration is done by an administrator on the purchase, thus providing limited configuration required before each trip from the user. On configuration before a trip, the user can define the polling rate of data from the tracking unit. The process for the ctrack units is shown in Figure 67.

The system must only be configured by linking the pre-defined sensors to the consignment according to the process previously discussed for sensor placement.

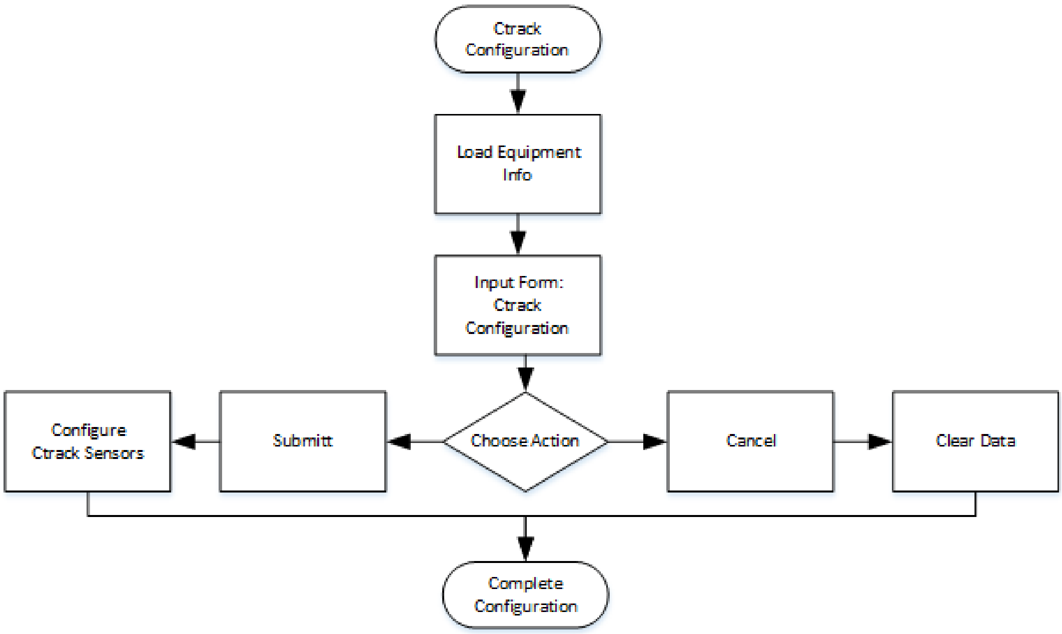


Figure 67: Ctrack configuration

III. Piccolo Configuration

The configuration page of the piccolo sensors allows the user to define the sample rate of each sensor for the trip. Further in the configuration process depicted in Figure 68, the configuration page allow sensors to register to the base station. This enables the unit to only have visibility to the defined sensors in memory. This configuration can be done according to user preference by means of direct contact or wirelessly through GPRS.

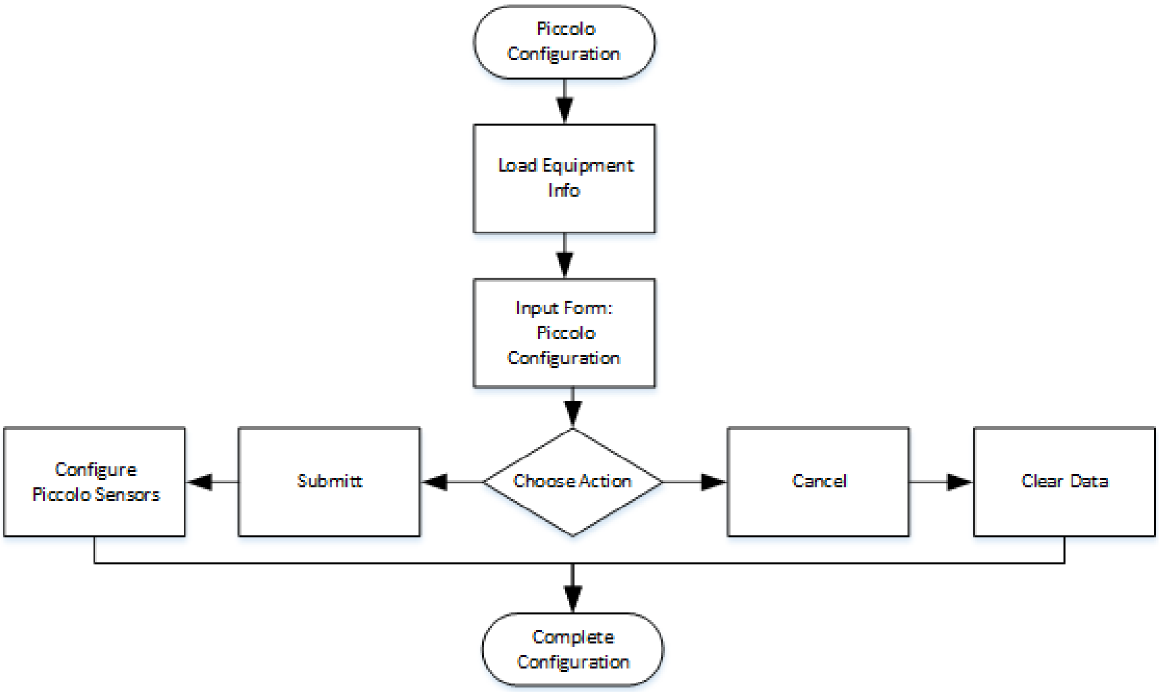


Figure 68: Piccolo Configuration

Data retrieval

Data will be retrieved by establishing a connection to the reader by means of a system-specific connection. The software uses the connection to read data either passively or in real time. The data is then pre-processed to define if all data needs to be retrieved from the sensors or the complete dataset. The read data samples are then stored to the database in the read data table before further processing. The data is analysed at this point to calculate the shelf life, mean kinetic temperature and temperature distribution in the trailer. The processed data is then displayed to the user for evaluation and is stored in the analysis table for reporting purposes using the consignment Identifier. This is depicted in Figure 69 below.

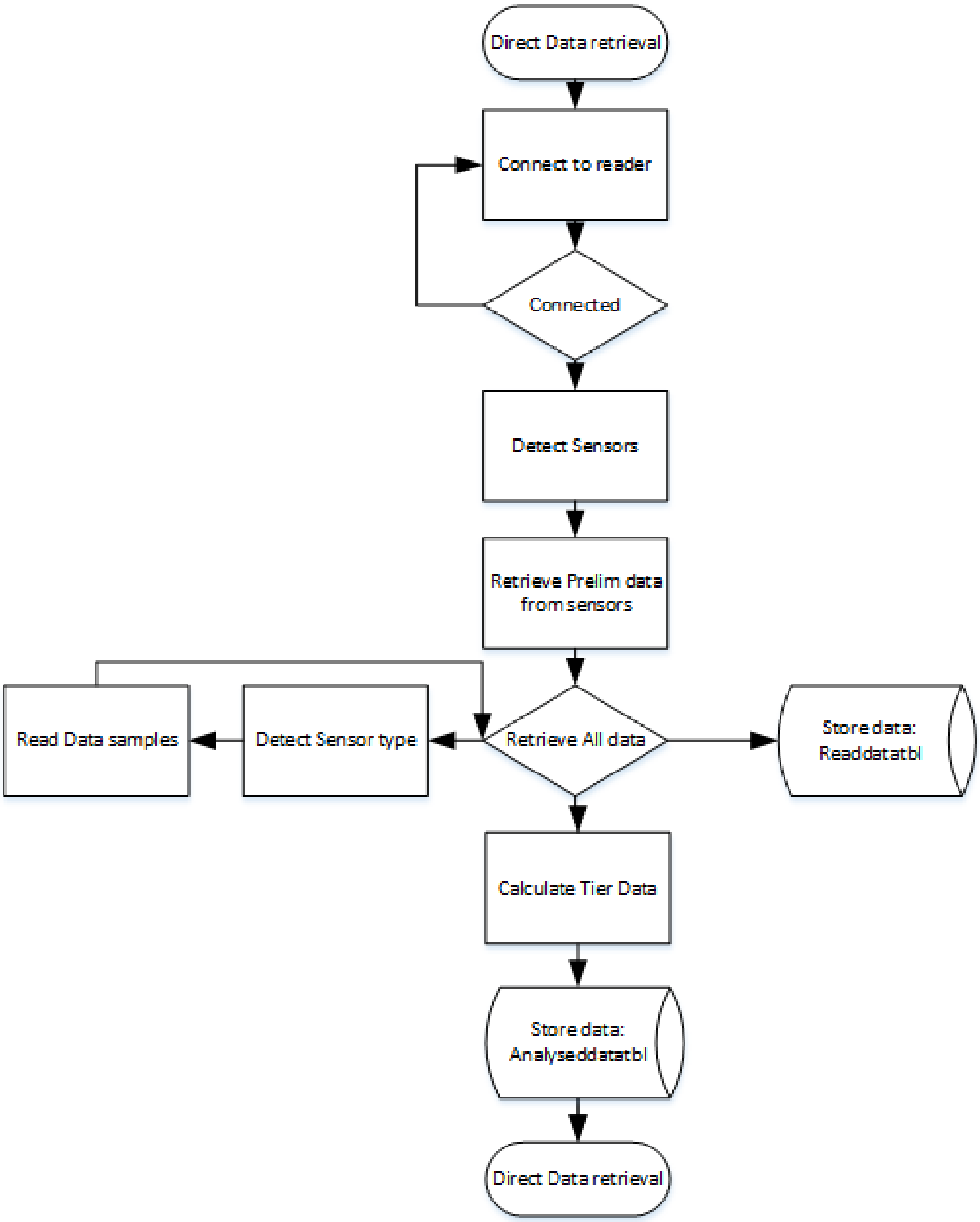


Figure 69: Caen direct data retrieval

Figure 70 defines the process for the real-time systems. The systems send data to the server in real time. The data relayed to the server is then processed and displayed on a GPS map which is linked to a table with the real-time temperature and shock values. The user can recall all values on request using the consignment identifier.

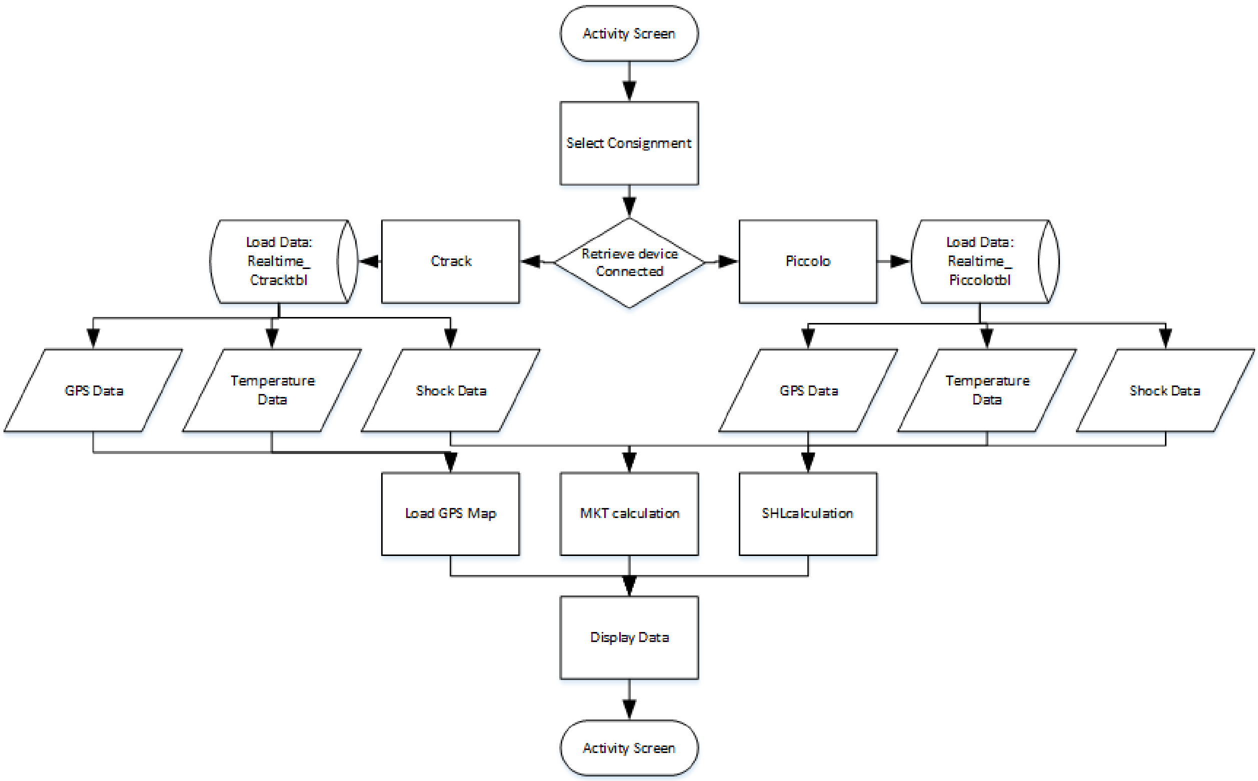


Figure 70: Activity screen real time data retrieval

Temperature Calculations

The basic temperature calculations are that of the mean kinetic calculation equation shown in equation 1. This calculation provides an accurate temperature average calculation using the activation energy of goods along with the temperature samples. This calculation immediately can provide the user with verification if the temperature was indeed maintained across the entire trip [51].

$$MKT = \frac{\frac{\Delta H}{R}}{-\ln\left(\frac{e^{\frac{-\Delta H}{RT_1}} + e^{\frac{-\Delta H}{RT_2}} + \ldots + e^{\frac{-\Delta H}{RT_n}}}{n}\right)} \qquad (1)$$

Variables:
ΔH = Activation Energy
R = Gas Constant (8.3144598(48) J mol^{-1} K^{-1})
T_n = Temperature Value ºC
n = Number of temperature samples

The process of calculating the mean kinetic value is depicted in Figure 72. The data retrieved for the sensors placed in the 5 different tiers is looped through and then used in the above equation along with the average activation energy calculation in the inventory linked to the trip plan.

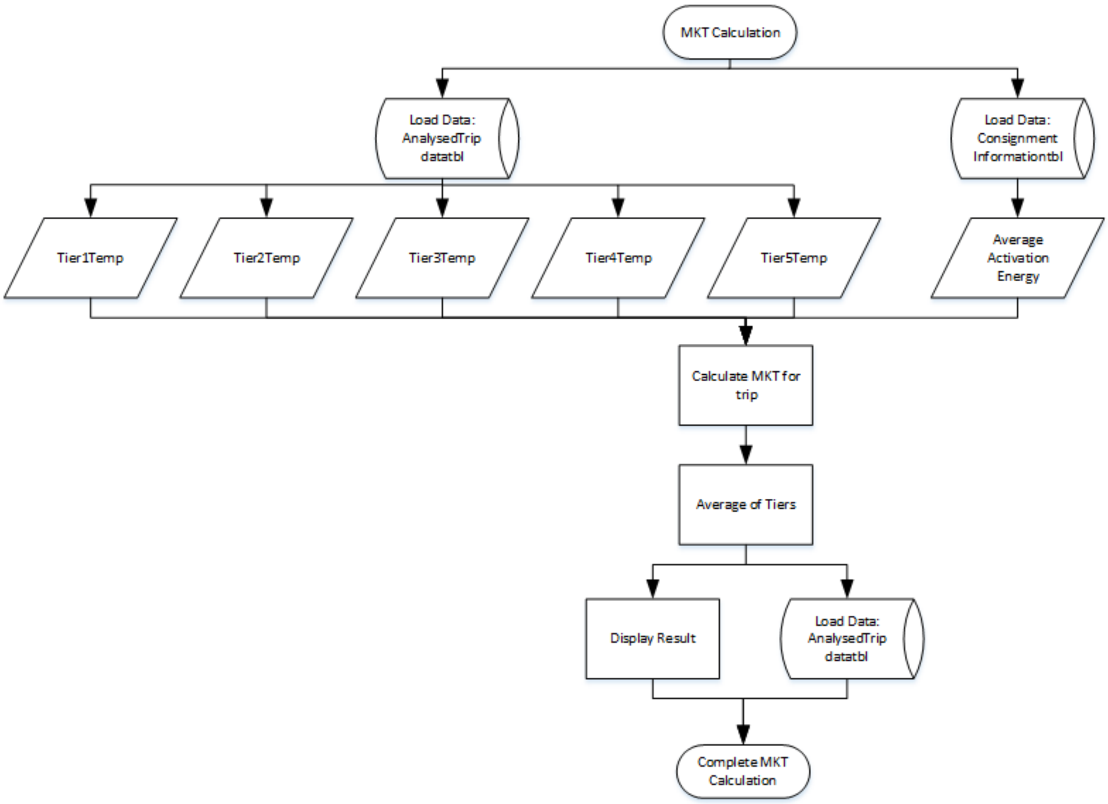


Figure 71: Mean Kinetic temperature calculation

The shelf life calculation is the next important calculation to estimate for what duration of time the goods will still be of a sufficient quality for human consumption. The values are retrieved from the inventory linked to a trip plan for the consignment. The equation is shown in Equation 2 which follows [52].

$$SHL_n = SHL_{ref} - \sum_n \left(Q_{10}^{\frac{(T_n - T_{ref})}{10}} * t_n \right) \tag{2}$$

Variables

SHL_{ref} = The reference shelf life remaining in hours
T_{ref} = The set point temperature
Q_{10} = Shelf Life at T°C / Shelf Life at (T+ 10°C)
t_n = Sample rate in hours

This calculation process is depicted in Figure 72, the optimal shelf life, shelf life @ a temperature of 10°C above optimal, the set point temperature and the sample rate of the monitoring process. The temperature collected from the varicose tiers is then used along with the values mentioned in the above equation.

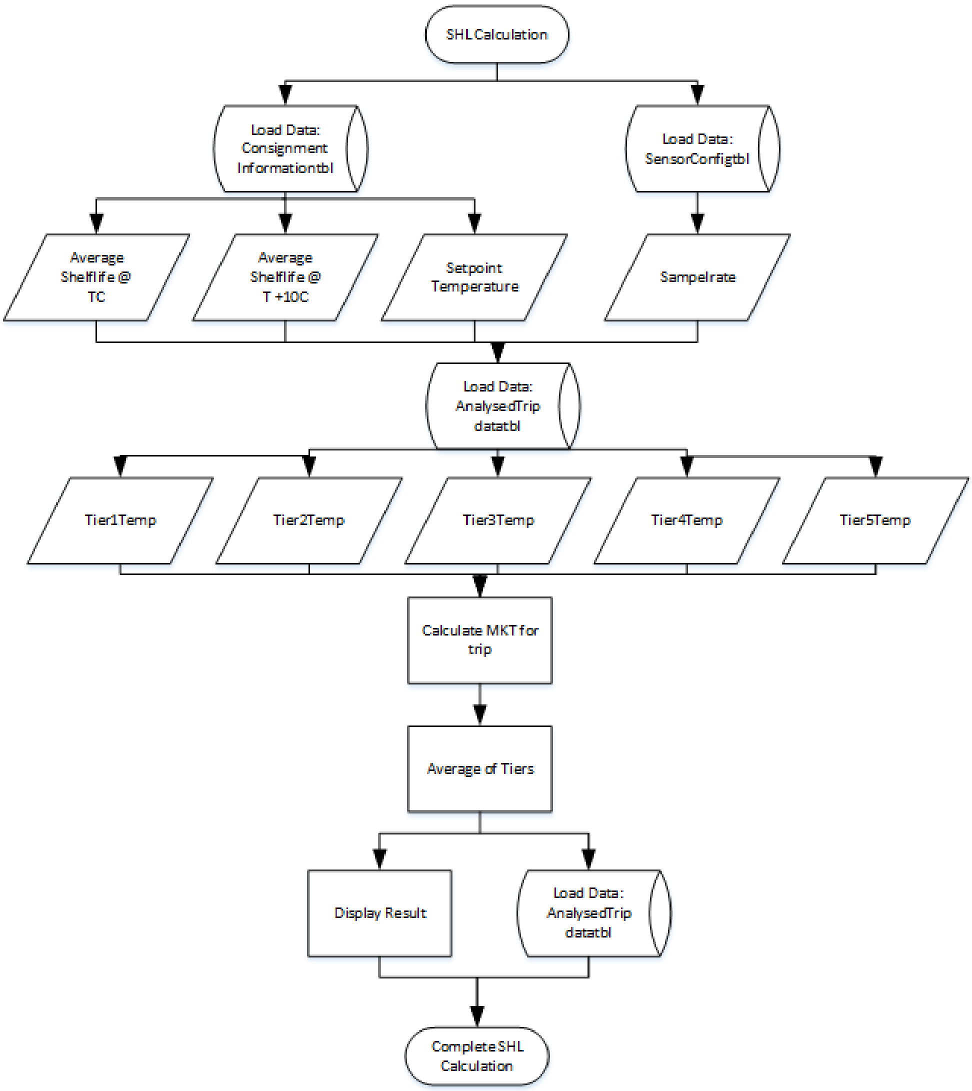


Figure 72: Shelf life calculations

5.4 Database requirements

5.4.1 Platform Requirements

The choice of database platform will have the fit within the chosen software environment, for this purpose the use of Microsoft SQL server 2008 will be suited. The VB.Net environment provides an SQL connector to the database to allow the simple exchange of information between the web application and database.

5.4.2 Tables and fields

The breakdown of the tables required to meet the functionality of the design defined in this chapter is given in this section. The database is designed to store data in a sufficient manner with as little as possible data redundancy as possible. This is accomplished using the 3rd normal form of the table design. The interconnectivity of the tables according to this design methodology of the relational database is shown in Figure 73.

Table 29: Database table definition

Table	Function
LoginTbl	Stores the login information of a user for the duration of the session
UserInformationTbl	Stores the personal information of user of the system, their preferences and login information
CompanyInformationTbl	Stores the details of the company, their capabilities and performance history
ConsignmentTbl	Stores data on the temperature thresholds of a consignment, perishability, ideal sampling rate and item information
TruckInfoTbl	Stores the information on the truck identity, performance and maintenance history
TrailerInfoTbl	Store information on the identity of the trailer, physical dimension and capacity.
SensorTbl	Store information on the sensor types and suppliers, available quantity of sensors and it specifications
SensorGroupTbl	Stores EPC number of the tags added to the group, quantity, consignment it is connected to and the individual responsible for placement.
RetrievedDataTbl	Stores the raw data retrieved from the sensor, company id and consignment id.
ReportsTbl	Stores the analysed temperature and time data of a specific consignment for the company and equipment used.

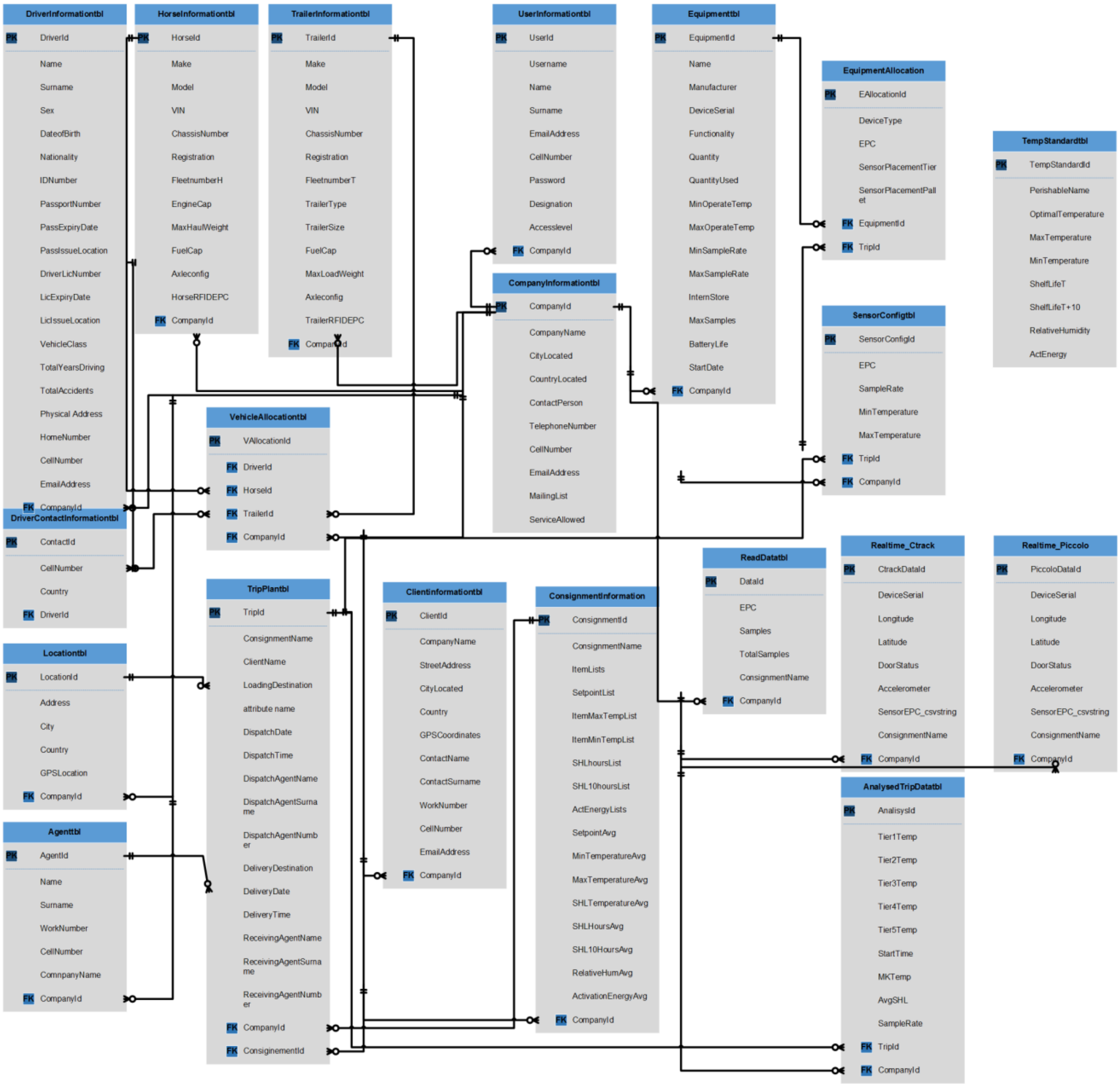


Figure 73: Database design and relationship between tables

5.6 Chapter Summary

In this chapter the conceptual design, operational and detail design of a software package that will enable better direct control for a cold chain has been discussed. The requirements and capabilities of this type of software have been investigated. It showed that there are three areas of control that must be maintained in the cold chain. This includes the temperature at your DC, from DC to the suppliers and then when delivery takes place at the specific supplier. The operation of these areas were defined in an operation analysis shows the process flow and the flow of information between different elements of a cold chain.

From this data, the functions required for software platform was defined to highlight the primary functions required and how the functionality influences each other in the overall control process. The best development platform for the goals of the cold chain software is defined as the Vb.net language used in the Microsoft Visual Studio environment linked with Microsoft SQL server 2008 for data storage. Through the implementation of these environments and the discussed data structures, widgets and tables a software platform can be developed effectively manage your cold chain.

Chapter 6: Data analysis and system evaluation

6.1 Chapter Overview

The design presented in the previous chapter has defined a software solution to the user requirements to solve the problem of effective CCM. In this chapter the temperature characteristics of the implementation environment, the usability of the sensing hardware in different configurations and conditions and the operational capabilities of this equipment will be investigated. The outcome of this investigation will indicate the degree to which different RFID systems are capable of addressing the user requirements to be used in conjunction with the software package designed in Chapter 5. The full experimental data file containing the results discussed in this chapter can be found by following the links depicted in Appendix C

6.1 Temperature Set Point Deviation analysis

In order to understand how the temperature environment behaves in real-world CCM applications, a number of experiments had to be conducted. The internal temperature deviations of a cold environment maintained in a temperature controlled trailer differs depending on multiple factors. In order to characterise this fluctuating environment, a set of experiments were conducted to accumulate the necessary data to make intelligent decisions regarding the placement of temperature sensors as part of operational CCM. As part of this analysis the environment was simulated using a software application in order to verify whether a limited set of sensors could provide sufficiently accurate temperature monitoring for operational purposes.

The accumulation of the data involved the monitoring of 10 different cross-border consignments from South Africa to countries such as Zambia and Mozambique, typically over a duration of 8 days for each trip. The operational process followed for each of these consignments corresponds to the generic models presented in Chapter 3. The data for these trips was collected by placing temperature data loggers and BAP sensors both on the periphery of the trailer and within the pallets themselves. The +50 Logtag tags, 12 Caen A927Z sensors and 8 Caen RT0005 sensors were placed in the consignment as shown in Figure 74.

The figure shows how the sensors were placed over the length of the trailer on both the sides and roof of the trailer. The sensors were placed at a 1.5m incremental distance from each other over the length. This orientation of the sensors placement provided a clear visibility of the temperature distribution in the trailer and cargo. The purpose of the refrigerated trailer is not to cool down the perishables from a warm condition to the set point but rather to maintain the temperature set point from the DC or loading bay. Thus, the temperature samples taken in the manner described above can be used to determine the effective temperature applied to the cargo relative to the temperature set point of the cooling unit in the trailer.

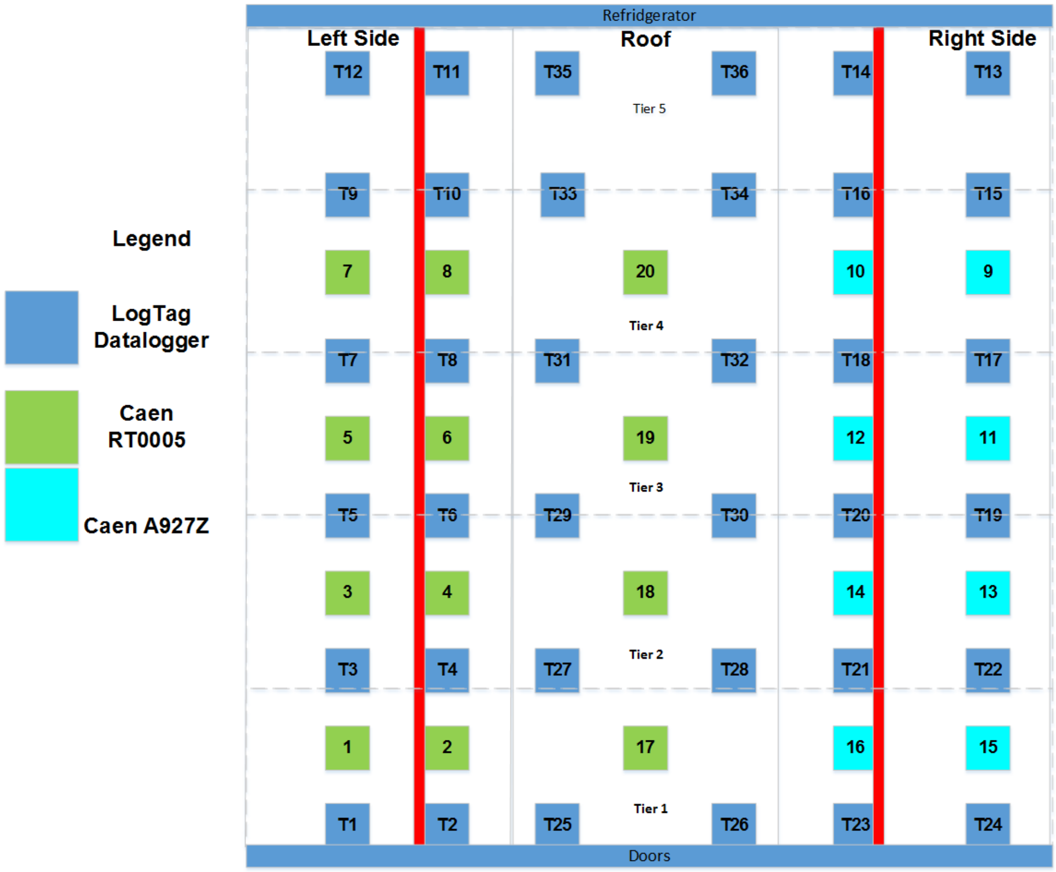


Figure 74: Experimental sensor placement for field evaluation

The temperature samples obtained for one of the trips is shown in Figures 75 to 77. The data depicted in the graphs shows the temperature fluctuations at three different heights over the length of the trailer in three-meter increments. The sensors placed at each of these sections in Figure 74 is averaged over the amount of sensors placed in the section to create five temperature sectors (or tiers), this defines the information captured in a more visually structured definition. The data in the figures displayed below is for a period of 8 days displaying both the delivery and return trips. The period indicated by samples between 1180 and 1480 shows the period during the trip where the reefer was shut down and temperature reflecting the external environment is depicted. From the figures it is evident that a large amount of variation occurs in the consignment over time even whilst the refrigeration unit is regulating the temperature. The fluctuations are caused by various factors, such as:

- Thermal conduction on the periphery due to solar radiation.
- Temperature leakage at the doors due to the weak sealant and wear.

- Thermal absorption of the items in the consignment which vary with factors such as packaging; pre-cooling and physical placement.

These factors must be taken into account in any temperature analysis of the CCM environment. In the figures that follow graphs are depicted from 0m to 15m, where the 0m is taken from the door of the trailer. Furthermore, three heights are also indicated in the graphs, as measured from the floor of the trailer towards the roof.

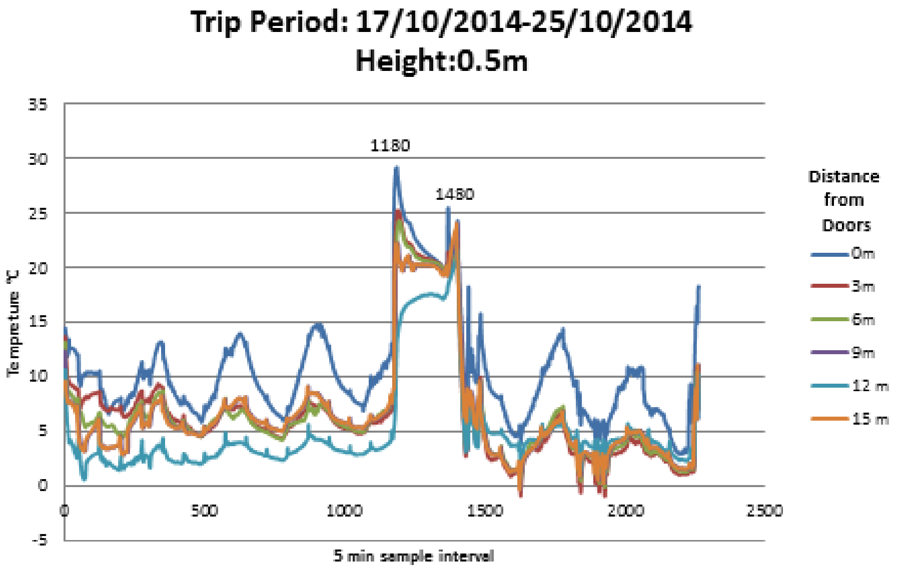


Figure 75: Temperature Fluctuation at height 0.5m

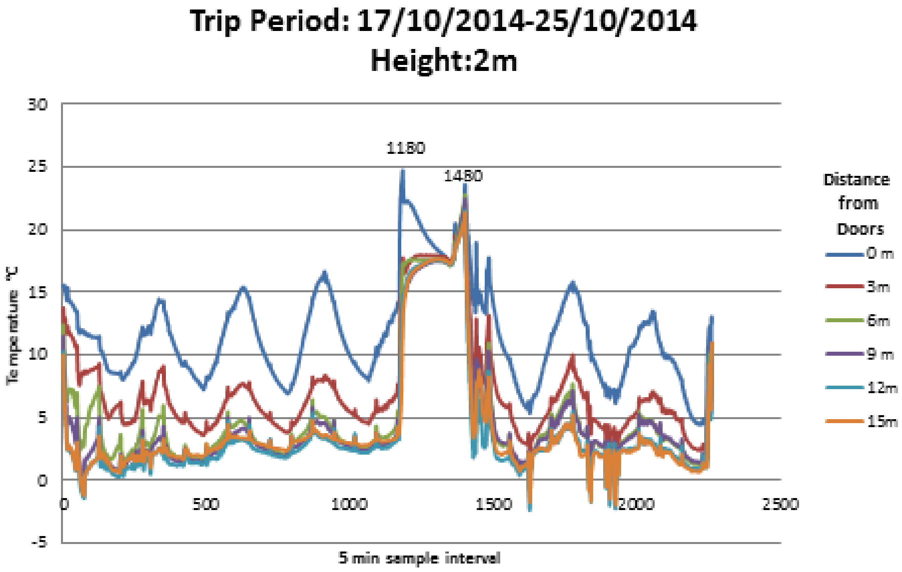


Figure 76: Temperature fluctuation at 2m

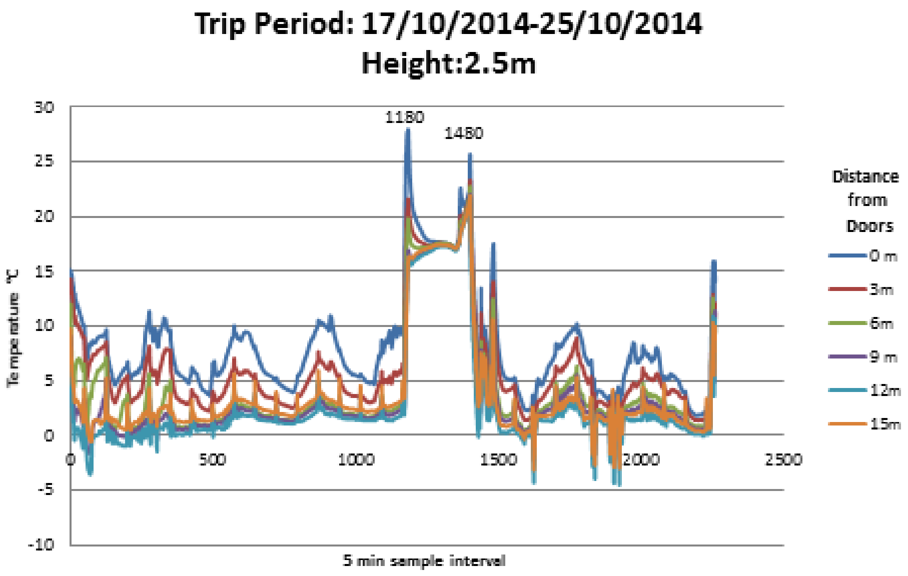


Figure 77: Temperature fluctuation at 2.5m

The data presented in the 3 figures above, for the 8 days, can be analysed further to provide us with concise information on the temperature fluctuations. This analysis was completed by dividing the 15.2m trailer into 5 tiers of 3m width and calculating the average temperature for the 3 heights in the trailer by using all sensors placed at that height in the specific tier. By doing this simple calculation, the temperature values for each tier in the trailer can be used to indicate how temperature is influenced by height and the thermal absorption of the items in the consignment.

Naturally the effect of thermal absorption for each consignment will differ depending on cargo type and packing configuration, as well as how it effects the temperature fluctuation in the tier where cargo is placed. The effect of this absorption is on average small when the goods are precooled to the required set point value before the loading process. From this point onward in the analysis this absorption will be considered as constant, thus not having a fundamental influence on the temperature fluctuations measured. This assumption can be made because in the ten cases analysed here the required precooling was indeed performed and the pallets were stacked and wrapped consistently. Figures 80 and 81 depicts the temperature fluctuations for the 5 tiers as discussed.

The figure that follows shows how the temperature fluctuates over the length of the trailer. It is evident from the three graphs that the temperature against the roof most accurately reflects the temperature of the refrigeration unit. The temperature in the trailer increases closer to the floor whilst a decrease is experienced closer to the roof where most of the airflow occurs. This is due to absorption of heat by the cooled air from the goods in the pallets loaded at the top of the stacks and the obstacle that the stacked pallets cause against the airflow of the refrigeration unit in the front of the trailer towards the bottom pallets and towards the trailer doors.

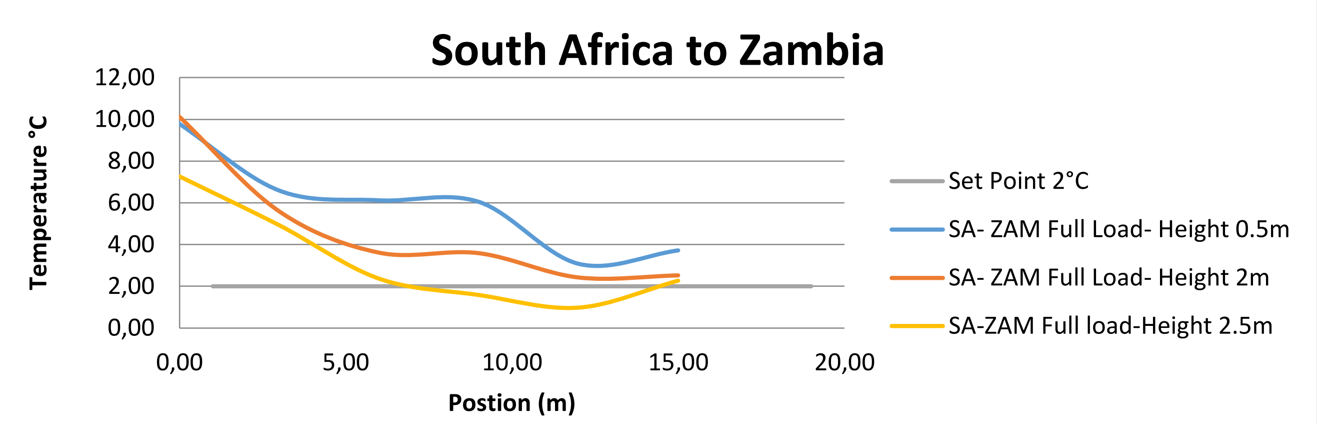


Figure 78: Average temperature fluctuation for consignment SA to ZAM- Full Load

Both these graphs indicate that that the greatest loss in temperature occurs at the doors of the trailer and up to 5m from it. This is due to leakage in the seal at the doors and thus making the first and second tier relative to the door the most vulnerable to temperature damage and increased tempo of degradation. The graph below for the return trip from Zambia to South Africa verifies this statement. It further shows the clear influence of the consignment on temperature distribution as this trip was loaded only quarter full in the tier closest to the refrigeration unit.

This statement can be explained based on the thermal absorption of the perishable goods in the consignment. In the initial full load two aspects adversely effects the temperature distribution excluding the effect of thermal loss at the doors and wall. The first is that the cooling unit can only disburse cool air from the front over the consignment; the second is the unique absorption of each pallet in the consignment due to packaging and placement on the pallets. Taking this fact in consideration, the influence of stacking configuration on temperature distribution can be clearly observed based on the differences between temperature distributions for the full and quarter loads. By comparing the two graphs it is furthermore observed that the first two tiers closest to the cooler are the least affected by temperature deviation, thus making it the safest position for perishable goods.

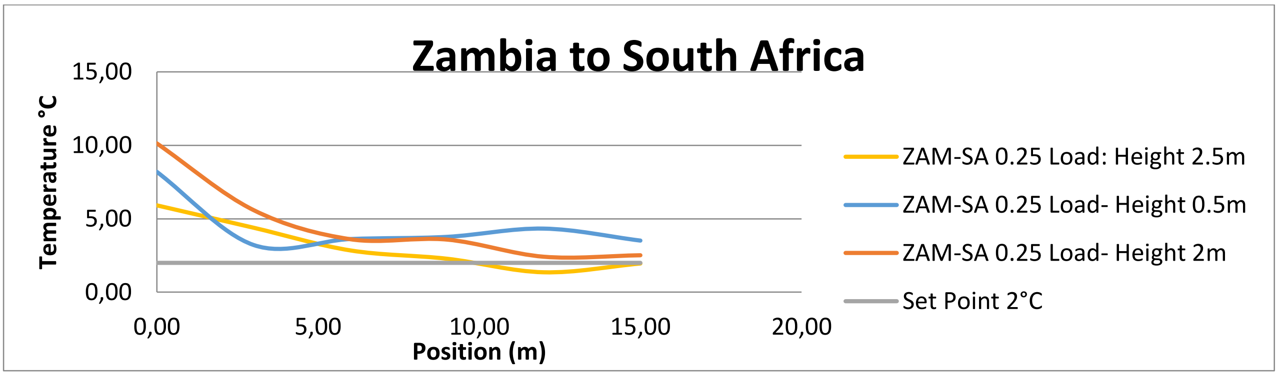


Figure 79: Average temperature fluctuation for consignment ZAM to SA- Quarter Load

Calculating the temperature deviation is the next logical step in analysing the temperature distribution in the trailer. Figures 80 and 81 display the percentage deviation from the set point at the 5 different tiers of the trailer interior; these deviations are expressed as percentages of the total allowed temperature deviation between the lower and upper thresholds. Both these graphs verify the deviation discussed in the previous paragraphs in this section.

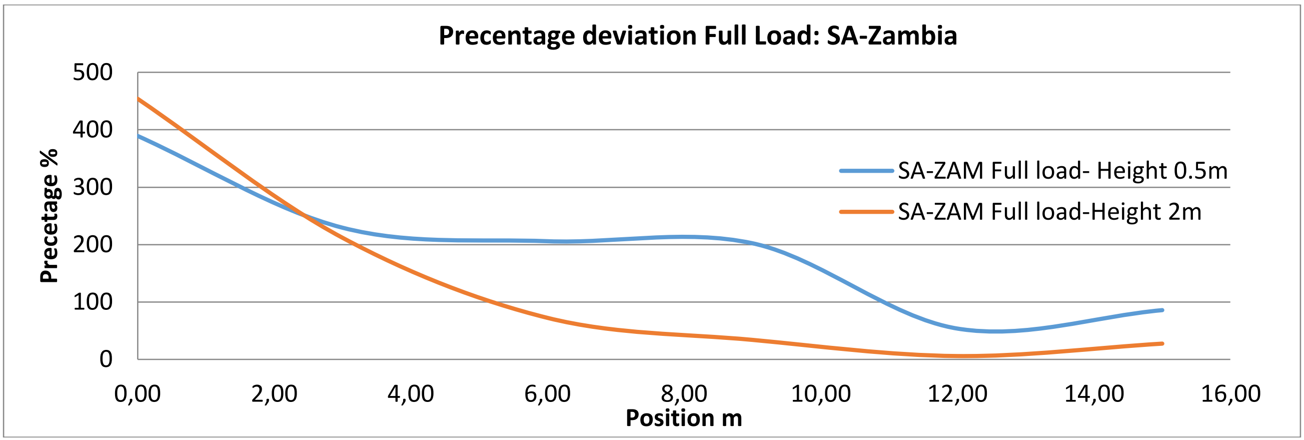


Figure 80: Percentage deviation on consignment SA to ZAM- Full Load

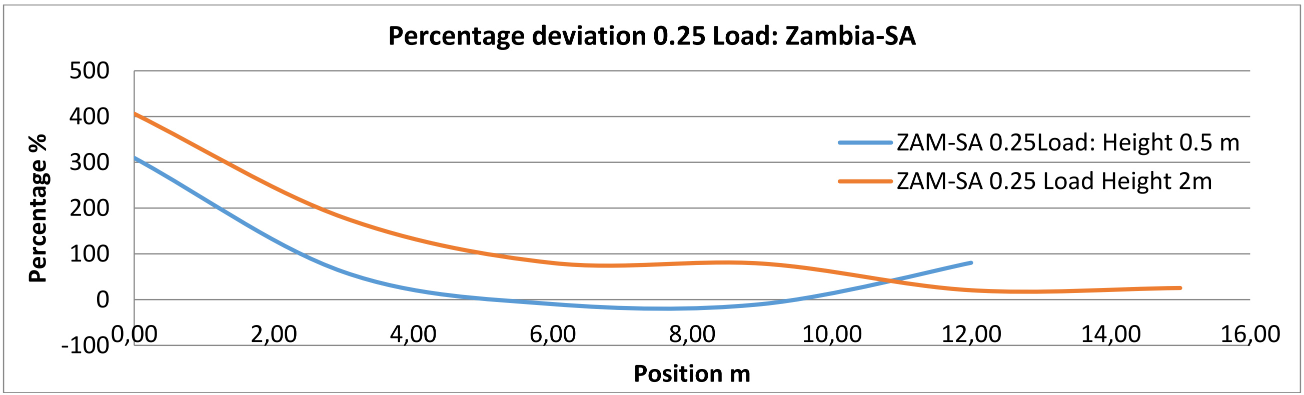


Figure 81: Perc–ntage deviation on consignment ZAM to SA - Quarter Load

When comparing these graphs of the captured temperature data to the rule of thumb for temperature distribution depicted in Figure 8 from Chapter 3, it can be seen that there is a far larger deviation in real world applications than the rule of thumb applied in the industry. From the observed temperature deviation it is now possible to calculate the effect of temperature on the degradation of the perishables being transported. Because each type of perishable good has a different tempo of degradation due to applied temperature, the type of goods will influence the effect of the above described temperature deviation.

The rate of loss of quality of the goods, using the variable temperature as observed for the field evaluation, can now be used to calculate the rate of loss in quality in the perishables. This rate can be calculated using the equation shown in Figure 84 below [53].

$$rate = \frac{\partial A}{\partial \theta} = kA^n \tag{3}$$

Where:

A=Quality factor at time θ.
k= the temperature and water activity constant.
n= the order of reaction that defines if the reaction rate is independent of amount of quality left.

Because the rate of deterioration is not a constant, as previously discussed, the resulting equation is exponential for n=1 and delivers the result as shown in Figure 82.

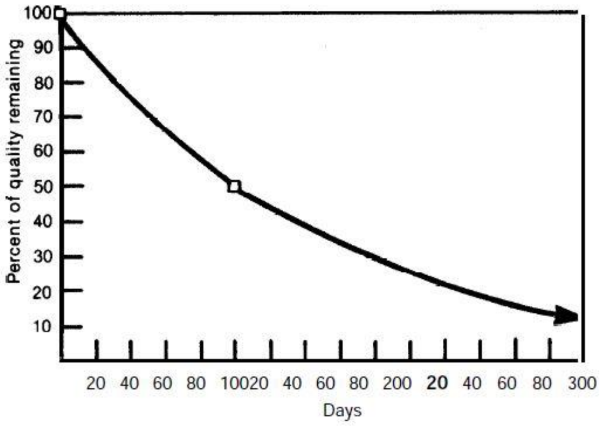


Figure 82: First order degradation [53]

The rate of this deterioration indicates the behaviour of temperature over time. This rate can be used to calculate the remaining shelf life and indirectly the amount of loss caused by the measured temperature fluctuation during transit. Using this variation in the temperature acquired from the sensors placed inside the trailer, a standard measure for the sensitivity of the cargo can be calculated using equation 4 [54] [52].

$$Q_{10} = \frac{rate\ of\ loss\ of\ quality\ at\ temperature\ (T+10^{\circ}C)}{rate\ of\ loss\ of\ quality\ at\ temperture\ T^{\circ}C} \qquad (4)$$

This rate in loss of quality is a standard that can be calculated for a specific type of perishable and the cultivar of the type of perishable, this equation can then be applied in the shelf life calculation as depicted in Figure 74 in the previous chapter. As the observed temperature fluctuations are so large during the transportation of a consignment, it is important to model this environment in order to calculate the effect of the immediate temperature on the quality of the perishables. The amount of cargo losses suffered for a specific level of environmental control can be used to determine to what extent packaging and cooling practices should be adapted to deliver goods of acceptable quality.

6.2 Environmental Temperature Modelling

The temperature data collected from the trips evaluated through the practical experiments, affords the opportunity to model the temperature distribution in the reefer [55]. This provides the necessary data to determine a mathematical formula that approximates the temperature fluctuations. Such a model can be used to determine the number of sensors required to monitor the cargo being transported within a required accuracy. By evaluating the data it was found that under normal operation the average temperature at any specific point does not deviate by more than 1.5ºC over a period of 30 minutes due to the thermal inertia of the cargo as seen in Figure 83. Each sample represented here is indicative of the difference between consecutive 30 minute samples. The samples were taken over three days for both the day and night periods and represents the temperature experienced by the goods in the tier closest to the door of the trailer.

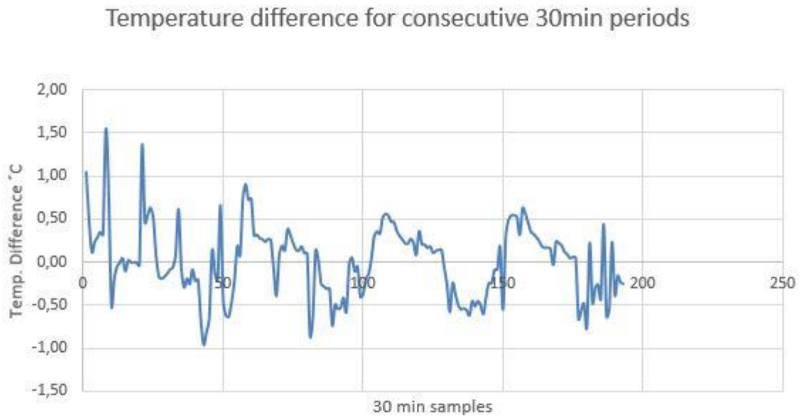


Figure 83: Temperature difference between consecutive 30min samples in reefer

The calculated variation as depicted in Figure 83, indicated that temperature at the most sensitive position in the trailer does not fluctuate by more than 1,5º C. Using this information it is seen that a sample rate of 5 min is sufficient to yield an effective representation of the temperature fluctuation within the trailer. The temperature samples used in the linear regression analysis that follows has been done using both the day and night data over a period of 6.95 day (167hours). Through this analysis the samples are used to calculate a single polynomial to model the temperature fluctuations within the trailer over position. This method was firstly applied to all the data samples for both the day and night, 2002 datasets as sampled over the length of the trailer, secondly the day specific data of 994 sampled datasets were used and finally night specific data of 1008 sampled datasets were used.

Before the multiline regression analysis was performed, a single line regression analysis was conducted using trendlines in Excel to determine what degree of the polynomial would provide a good fit for temperature as function of position within the trailer. It was found that 3rd, 4th and 5th order polynomials would be potentially representative of the data. These trendlines are depicted in Figure 84, where the red dotted line represents a general fit on the available datasets. These order polynomials will now be used as the framework in the linear regression analysis to statistically determine what degree polynomial provide the greatest correlation to the fitted data.

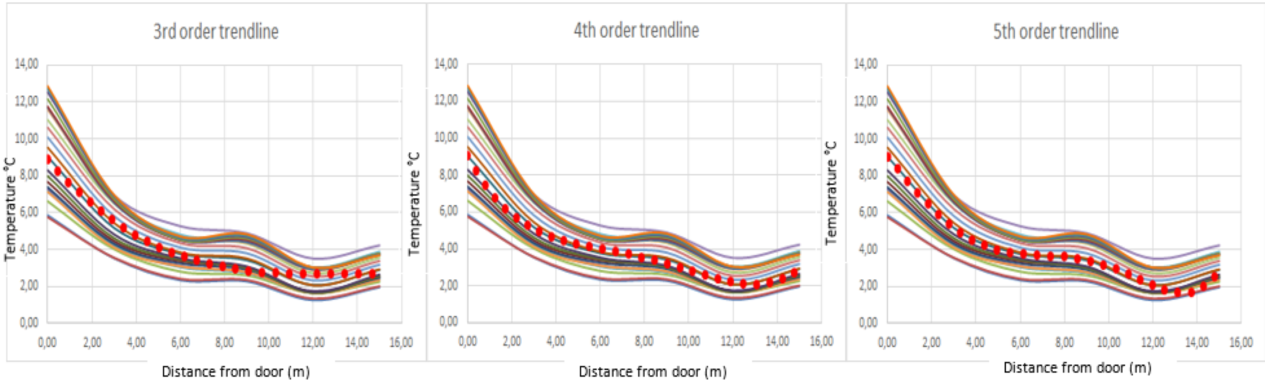


Figure 84: Polynomial order comparison

In linear regression we use explanatory variables x (regressors) to determine the outcome variables y. This requires the data to be represented in the form as depicted in equation 5 [56].

$$E(Y|x) = β0 + β1x + β2x^2 + \ldots + β1x^n \quad (5)$$

E(Y|x) = Expected value of Y for a given x

βn = Coeffients

x^n = Explanatory variable for x

This model thus provides a prediction for Y, for a given set of explanatory x variables that follows some linear slope.

It is important to note that this model provides a true mean for the result Y over the x values. It must be understood that this analysis does not deliver a precise measure for the extrapolation of predictions outside the range of x values provided in the datasets used. The resulting model is best applied in the interpolation of the x values represented in the datasets and the values between them. The Pearson correlation equation in Excel incorporated within the multiline regression analysis, as depicted in equation 6 below, is used in this chapter to correlate the data over the model. This correlation make it possible to determine what representation is provided by the model of the temperature within the reefer [60][61].

$$r = \frac{n(\Sigma xy) - (\Sigma x)(\Sigma y)}{\sqrt{[n\Sigma x^2 - ((\Sigma x)^2)][n\Sigma y^2 - ((\Sigma y)^2)]}} \quad (6)$$

Where:

r = Correlation coefficient

Σxy = Sum of the products of x and y

Σx = Sum of the x values

Σy = Sum of the y values

n = Total amount of samples

The correlation coefficient delivers a value between 1 and -1. A value of -1 indicates inverse correlation to compared values, a value of 0 indicates that no correlation exists between the data sets and a value of 1 represents a perfect correlation between the data sets. In order to provide the data in the form depicted by equation 5 over position in the trailer, each data sample as sampled at a specific time in the trailer for the 5 different tiers are transposed to datasets as depicted in Table 30.

Table 30: Position (X) for the resulting temperature Y

	X^1	X^2	X^3	X^4	X^5	Temp. (ºC)
Tier 0	0,00	0,00	0,00	0,00	0,00	15,02
Tier 1	3,00	9,00	27,00	81,00	243,00	13,92
Tier 2	6,00	36,00	216,00	1296,00	7776,00	12,53
Tier 3	9,00	81,00	729,00	6561,00	59049,00	11,00
Tier 4	12,00	144,00	1728,00	20736,00	248832,00	9,28
Tier 5	15,00	225,00	3375,00	50625,00	759375,00	10,57

In this table, Tier 0 represents the temperature at the doors, 0m; Tier 1 represents the mean temperature between 0m and 3m, Tier 2 between 3m and 6m; Tier 3 between 6m and 9m; Tier 4 between 9m and 12m and finally Tier 5 represent the temperatures between 12m and 15m. In the analysis it is important to establish a measure of the degree to which the equation fits the data. This measure calculated in this instance using the root mean squared error over the data. The generalised equation for this standard error calculation is as follows [57].

$$S = \sqrt{\frac{\sum_{i=0}^{n} {R_i}^2}{N-p}} \tag{7}$$

Where :

R= The residual of the data point calculated as $y_i - y(x_i)$

N= The amount of samples included in the residual calculation

p= n+1 where n is equal to the order of the nth order equation.

Using the excel 2013 data analysis toolpack's regression analysis tool, the above regression is performed on multiline data in the format listed in Table 30. The data samples for the combined day/night data over the seven days is used in this manner to calculate three linear regression models resulting in 5th, 4th and 3rd order polynomials. The results for these analysis is depicted in Table 31, 32 and 33 irrespectively. In these tables the coefficients column refers to βn values of the polynomial as depicted in equation 5. The standard error column refers to the standard error of the least mean squares of βn. The t Stat column is the result of the t-statistic for βn =0 against βn ≠ 0 and the P –value column the p-value test of βn =0 against βn ≠ 0. This P-value column is equal to the P{|t|>t-Stat} where t is a distributed random value for n-k degrees of freedom and t-stat used as calculated in the previous explained column [58]. The p-value represents a statistic measure to determine the significance of the calculated coefficient in the model. A P-value smaller than 0,05 indicates that the term is significant to the model and that the null hypothesis represented by βn = 0 can be rejected. A P-value larger than 0,05 indicates that the corresponding coefficient carries no statistical value and can be neglected from the model. The first statistics delivered in the regression of the temperature samples using 5 regressor values for position is listed in Table 31. Evaluating the P-values of the analysis it is seen that the P-value is smaller than 0,05 for all the terms thus delivering a significant 5th order polynomial for prediction of temperature over position in the trailer. Further evaluating the standard error it is seen that the X^1 term in the polynomial has the largest uncertainty in the size of X with a value of 0,1065.

Table 31: Combined Data - 5th order multiline linear regression analysis results

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	8,831726607	0,038770936	227,792452	0
X^1	-1,186048766	0,106514065	-11,135138	1,17E-28
X^2	-0,127304177	0,056674415	-2,2462372	0,024707
X^3	0,05813582	0,010464219	5,55567689	2,82E-08
X^4	-0,005626421	0,000793256	-7,0928202	1,39E-12
X^5	0,000169879	2,11066E-05	8,04859177	9,16E-16

Secondly the regression results for 4 regressors are listed in table 32 below. The P-values for this analysis indicated that each of the 4 terms provide significant value to model for each of the regressors. Further evaluating the standard error of each term's uncertainty is below 0,048 providing a stronger representative size of x than in the model line of the 5th order polynomial above.

Table 32: Combined Data - 4th order multiline linear regression analysis results

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	8,851384	0,038796566	228,1486458	0
X^1	-1,953123919	0,047687752	-40,95651059	0
X^2	0,312256969	0,015184918	20,56362606	2,25E-92
X^3	-0,025104745	0,001597242	-15,71755679	4,06E-55
X^4	0,00074403	5,29066E-05	14,06310686	1,44E-44

Thirdly, the regression results for 3 regressors representing position is listed in Table 33. The P-values are significantly lower than 0,05 indicating that each term of the 3rd order polynomial has a strong significance in the model to represent the output temperature. The individual regression terms further does not deviate by more than 4% from the repressor data sets.

Table 33: Combined Data - 3rd order multiline linear regression analysis results

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	8,748070052	0,038405514	227,7816138	0
X^1	-1,379157541	0,024866419	-55,46265151	0
X^2	0,106585684	0,004119236	25,87511017	1,1E-143
X^3	-0,00278383	0,000180316	-15,43859745	2,92E-53

Comparing the regression statistics as listed in Table 34 of each of the equations represented by tables 31, 32 and 33 it is seen that the 5th order polynomial represents 61,598% of the variation in the data samples. This equation provides the best representation of the data when comparing it to the 61,391% and 60,756% representation of the 4th and 3rd order polynomials irrespectively. Further at the standard error of the 3 models it is seen that the equations provide a sufficiently narrow 95% prediction interval.

Table 34: Combined Data - Regression analysis statistics

Regression Statistics			
	5th order	*4th order*	*3rd order*
Multiple R	0,784849239	0,78352814	0,779459456
R Square	0,615988327	0,613916346	0,607557044
Adjusted R Square	0,615828402	0,613787726	0,607458998
Standard Error	1,734755704	1,739357015	1,753550229
Observations	12012	12012	12012

During the collection of the data it was observed that the time of day has a large influence on the temperature experienced by the cargo. This is due to the thermal exposure of the sun during the day and the lack of this exposure during the night. In order to incorporate this observation into the model the data is spilt into the two periods, day (6AM to 6PM) and night (6PM to 6AM) to obtain a single model for each period that defined the data with a greater degree of accuracy. Firstly we will evaluate the data for the period captured during the day. Evaluating the regressions results for 5 regressors it is seen that the quadratic x coefficient has a P-value greater than 0,05 thus indicating that this term has little statistical value for the predication of the output temperature and can be neglected, the other terms though fall within the usable range. Further evaluating the standard error of each term it is found that the X^1 term has the highest uncertainty in x with a value of 0,158.

T–ble 35: Day Data - 5th order multiline linear regression analysis results

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	9,650788	0,057535	167,7364	0
X^1	-1,41514	0,158065	-8,95288	4,55E-19
X^2	-0,07386	0,084104	-0,87816	0,379892
X^3	0,054055	0,015529	3,480958	0,000503
X^4	-0,00561	0,001177	-4,76452	1,94E-06
X^5	0,000175	3,13E-05	5,589165	2,38E-08

The regression results for the analysis with 4 regressors is listed in Table 36. Evaluating the P-values of each term it is seen that the values is close to zero thus indicating that each variable in the polynomial has a strong statistical significance for interpreting the output temperature. Furthermore the standard error on each term is small thus delivering a relatively strong model for calculating the temperature within the trailer during the day.

T–ble 36: Day Data - 4th order multiline linear regression analysis results

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	9,671045	0,057566678	167,9973	0
X^1	-2,20562	0,070759496	-31,1707	9,7811E-198
X^2	0,37912	0,022531511	16,82619	4,18219E-62
X^3	-0,03173	0,002370002	-13,3866	2,7553E-40
X^4	0,000956	7,85032E-05	12,18023	9,94655E-34

The regression results for three regressor values is listed in Table 37 below, the over results indicated by the low P-value and standard error for each variable shows that this model also provide a statistical significant model for the represented data.

T–ble 37: Day Data - 3rd order multiline linear regression analysis results

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	9,538272	0,05722	166,6956	0
X^1	-1,46799	0,037048	-39,6241	5,3E-305
X^2	0,114802	0,006137	18,70601	6,38E-76
X^3	-0,00304	0,000269	-11,3178	2,13E-29

The comparison for the three polynomials delivered by the analysis is listed in Table 38. The R squared value indicates that the 5th order model represents 62,157% of the data thus delivering a 0,998 % improvement above the general model. The 4th order model 61,959% representation of the data an improvement of 0,567% above the general 4th order and finally the 3rd order model provides 61,012% representation of the data delivering an improvement of 0,257% above the general 3rd order model. Overall the 5th order day model provides the best representation of the data between the day and general equation delivered by the regression analysis.

T–ble 38: Day Data - regression analysis statistics

Regression Statistics			
	5th order	*4th order*	*3rd order*
Multiple R	0,788401	0,787142	0,781103
R Square	0,621576	0,619592	0,610121
Adjusted R Square	0,621259	0,619337	0,609925
Standard Error	1,813964	1,818561	1,840905
Observations	5964	5964	5964

Now evaluating the night period of the data independently, 5 regressors are firstly used to deliver the regression results listed in Table 39 below. The P-values of this result indicates that all the variables are statistically significant and can be included in the model.

Tab–e 39: Night Data - 5th order multiline linear regression analysis results

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	8,024041	0,045892	174,8472	0
X^1	-0,96014	0,126077	-7,61553	3,03E-14
X^2	-0,18001	0,067083	-2,68337	0,007308
X^3	0,06216	0,012386	5,018534	5,36E-07
X^4	-0,00564	0,000939	-6,01089	1,95E-09
X^1	0,000165	2,5E-05	6,595091	4,61E-11

The regression results for 4 regressors are listed in Table 40 below the p-value is negligible small thus indicating a strong statistical significance of each variable.

Tab–e 40: Night Data - 4th order multiline linear regression analysis results

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	8,043107	0,045961	174,9973	0
X^1	-1,70413	0,056494	-30,1645	2,5E-186
X^2	0,246323	0,017989	13,69283	4,73E-42
X^3	-0,01858	0,001892	-9,8167	1,41E-22
X^4	0,000535	6,27E-05	8,53295	1,78E-17

The regression results for the 3 regressors are listed in Table 41, the small P-value along with small errors on the coefficients shows the 3rd order polynomial to provide a statistically significant representative model of the data.

Tab–e 41: Night Data - 3rd order multiline linear regression analysis results

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	7,96884317	0,045397112	175,5363	0
X^1	-1,291554834	0,029393269	-43,9405	0
X^2	0,098483392	0,004869129	20,22608	4,5E-88
X^3	-0,002530686	0,000213142	-11,8732	3,71E-32

The statistical comparison of the results for the night data regression are listed in Table 42 below. Using the R squared statistic it indicates that 66,944% of the data is represented by the 5th order model an improvement of 5,346% above the general model. The 4th order model delivered a model representing 66,944% an improvement of 5,315% above the general equation. Finally the 3rd order equation represented 66,305% of the data an improvement of 5,533% above the general 3rd order model. Overall all the 5th order model represents the largest percentage of the data.

Tab–e 42: Night Data - Regression analysis statistics

Regression Statistics			
	5th order	*4th order*	*3rd order*
Multiple R	0,818198	0,816742	0,814282727
R Square	0,669447	0,667068	0,66305636
Adjusted R Square	0,669174	0,666847	0,662889114
Standard Error	1,457017	1,462131	1,470791383
Observations	6048	6048	6048

The influence of the environmental temperature during the night and day becomes clear when comparing the results of Table 42 and Table 38 to the results of the combined datasets as listed in Table 34. Thus in order to obtain the best prediction of temperature at a certain point within the trailer, it is required to define a separate model for each of these periods.

The models developed up to this point used only location in the trailer as input to predict the temperature at those locations. If it is assumed that in practice at least two temperature sensors will be used, one at the chiller and one at the doors, then a further improvement can be implemented to deliver more accurate temperature predictions at all other locations. This can be accomplished by normalising all temperature values with respect to the minimum at the chiller and the maximum at the doors, and then fitting a regression model with location as input variable to the normalised temperature data. Normalisation in essence is the process of bring all experimental data into proportion with each other. This can generally be accomplished using equation 8 below [59]

$$X_{i,0\ to\ 1} = \frac{X_i - X_{min}}{X_{max} - X_{min}} \quad (8)$$

X_i = Temperature at each tier.

X_{min} = The minimum temperature Tier 5.

X_{max} = The maximum temperature Tier 0.

$X_{i,0to\ 1}$ = The data point normalised between 0 and 1.

By normalising the temperature values in this manner it is required that a minimum of two sensors would need to be installed within the trailer for any given consignment. The first would be installed at the door, Tier 0, where the maximum amount of temperature deviation from the set point occurs. The second would be installed at the cooling unit in the front of the trailer, Tier 5, where the minimum amount of deviation where the lowest temperature deviation from the set point is expected. This methodology was applied to 2002 datasets as sampled over the six Tiers within the trailer, T0 to T5. The same excel linear regression analysis was now performed upon the normalised data values for the combined, day and night datasets. The regression results for these analyses are listed in Table 43, Table 45 and Table 47 irrespectively.

In Table 43 the results for the linear regression for 5, 4, and 3 regressors are tabulated. The small P-values indicate that all variables used are significant for calculating the in trailer temperature. Further evaluating the standard error on each coefficient is below 1% indicating a strong correlating model relative to the normalised data.

Table 43: Normalised combined data: Regression analysis results

	5th Order Results			*4th Order Results*			*3rd Order Results*		
	Coeff.	*Standard Error*	*P-Val*	*Coeff.*	*Standard Error*	*P-Val*	*Coeff.*	*Standard Error*	*P-Val*
Intercpt.	1	0,002002	0	1,003284	0,002053	0	0,986151	0,002173	0
X^1	-0,20505	0,005499	4,7E-288	-0,3332	0,002524	0	-0,23802	0,001407	0
X^2	-0,02004	0,002926	7,82E-12	0,053396	0,000804	0	0,019288	0,000233	0
X^3	0,009679	0,00054	7,48E-71	-0,00423	8,45E-05	0	-0,00053	1,02E-05	0
X^4	-0,00094	4,1E-05	2,4E-114	0,000123	2,8E-06	0			
X^5	2,84E-05	1,09E-06	1,6E-145						

The regression statistics for each of the models delivered by analysis over the combined normalised data datasets is listed in Table 44 below. These statistics indicated that the 5th order model explains 94.23% of the data, whilst the 4th and 3rd order models explains 93,906% and 92,29% of the data irrespectively.

Table 44: Normalised combined data- Regression statistics

Regression Statistics			
	5th order	*4th order*	*3rd order*
Multiple R	0,970733	0,969053	0,963955
R Square	0,942323	0,939064	0,929209
Adjusted R Square	0,942298	0,939044	0,929191
Standard Error	0,089561	0,092053	0,099214
Observations	12012	12012	12012

The regression results for the day specific datasets are listed in Table 45 below. This p-values indicate that the all the variables have a strong statistical significance in each model. The X2 variable of the 5th order equation is the highest value among the P-values but is still below the threshold of 0,05 for statistical insignificance. This significance is further enforced by the low standard error calculated for each of the coefficients in the 5th, 4th and 3rd order temperature models.

Table 1: Normalised day data - Regression analysis results

	5th Order Results			*4th Order Results*			*3rd Order Results*		
	Coeff.	*Standard Error*	*P-Val*	*Coeff.*	*Standard Error*	*P-Val*	*Coeff.*	*Standard Error*	*P-Val*
Intercpt.	1	0,002924	0	1,003208	0,002991	0	0,981719	0,003272	0
X^1	-0,23086	0,008033	3,3E-170	-0,35604	0,003677	0	-0,23666	0,002119	0
X^2	-0,0099	0,004274	0,020593	0,061833	0,001171	0	0,019055	0,000351	0
X^3	0,008425	0,000789	2,3E-26	-0,00516	0,000123	0	-0,00052	1,54E-05	3,3E-227
X^4	-0,00088	5,98E-05	1,22E-48	0,000155	4,08E-06	2,7E-282			
X^5	2,77E-05	1,59E-06	2,69E-66						

The regression statistics for the normalised day data are listed in Table 46. The R square value indicates that the 5th order model explains 93,949% of the data 0,283% less than the general 5th order model. The 4th order day model explain 93,6415% of the data, 0,264% less than the general 4th order model. The 3rd order day model intern explains 92,105% of the data. The low standard error on each of the models indicate that the normalised data is populated in a sufficiently narrowband along the line of the corresponding model. Overall the day specific normalised data delivered a less accurate model than that delivered by the general linear regression for the combined datasets.

Table 2: Normalised day data - Regression statistics

Regression Statistics			
	5th order	*4th order*	*3rd order*
Multiple R	0,969276	0,967685	0,959718
R Square	0,939495	0,936415	0,921058
Adjusted R Square	0,939444	0,936372	0,921018
Standard Error	0,092188	0,094498	0,105284
Observations	5964	5964	5964

The final linear regression is performed on the night specific period of datasets, these regression results are listed in Table 47 below. The small P-values in results indicate that the all the regressors variable used in to calculate the models provide a statistically significant value to model, this is again reinforced by the low standard error on each of the standard errors.

Table 45: Normalised night data - Regression analysis results

	5th Order Results			*4th Order Results*			*3rd Order Results*		
	Coeff.	*Standard Error*	*P-Val*	*Coeff.*	*Standard Error*	*P-Val*	*Coeff.*	*Standard Error*	*P-Val*
Intercpt.	1	0,002701	0	1,003359	0,002781	0	0,990521	0,002861594	0
X^1	-0,1796	0,00742	1,3E-123	-0,31068	0,003418	0	-0,23936	0,001852796	0
X^2	-0,03004	0,003948	3,21E-14	0,045075	0,001088	0	0,019518	0,000306924	0
X^3	0,010915	0,000729	8,61E-50	-0,00331	0,000114	3,6E-172	-0,00054	1,34354E-05	0
X^4	-0,001	5,53E-05	8,58E-71	9,25E-05	3,79E-06	2,8E-125			
X^5	2,9E-05	1,47E-06	4,02E-84						

The regression statistics for the night regression analysis is tabulated in Table 48 below. The 5th order model explains 94,66% of the data whilst the 4th order model explains 94.31% of the data and the 3rd order model only 93,76% of the data. The night implicit models in Table 48, offer 5th order correlation improvement of 0,431%, a 4th order improvement of 0,413% and a 3rd order improvement of 0,859% above the data explanation delivered by general equations calculated in Table 46 above. From this comparison it is evident that the night specific models offer a greater explanation of the data between 6PM and 6AM than that of a general equation over both evaluated periods of the day. The overall best model for this night period is provided by the 4th order linear regression model.

Table 46: Normalised night data - Regression statistics

Regression Statistics			
	5th order	*4th order*	*3rd order*
Multiple R	0,972953	0,971182	0,968302
R Square	0,946637	0,943194	0,937608
Adjusted R Square	0,946593	0,943157	0,937577
Standard Error	0,085755	0,08847	0,092711
Observations	6048	6048	6048

Table 47: Regression model correlation results

	Correlation of models to captured sample data			
		5th order	4th order	3rd order
Direct Temperature Models	General Equation	0,896888	0,895816	0,892509
	Day Equation	0,905051	0,903125	0,899344
	Night Equation	0,88303	0,8877	0,884767
Normalised Temperature Models	General Equation	0,977424	0,977998	0,974556
	Day Equation	0,959009	0,977578	0,974489
	Night Equation	0,968252	0,977823	0,974616

The 18 equations calculated through linear regression analysis and discussed in this chapter was now each applied to a captured data set of 2000 sample sets from an alternative trip than used in the regression analysis. Each set consists of 6 sampled temperature values over the 5 Tiers as measured at 0m, 3m, 6m, 9m, 12m and 15m. In order to statistically measure to what extent the modelled temperature represents the sampled data beyond the analysis presented in this chapter the method of correlation is applied using Excel as depicted in equation 6.

The correlation coefficient delivers a value between 1 and -1. Where a value of -1 indicates inverse correlation to compared values, a value of 0 indicates that no correlation exists between the data sets and a value of 1 represents a perfect correlation between the data sets. The correlation coefficients for each of the calculated regression models are depicted in Figure 85. In this figure the blue graphs indicate the 5th order equations, the green graphs indicate the 4th order models and orange graphs indicate the 3rd order equations.

The graphs in each set contain the equations for both the normalised and direct data models for the general, night and day analysis. From this comparison it is seen that each model provides a positive correlation to the captured data. Furthermore when comparing the correlation of each model it is seen that the general equation of the 4th order normalised general model provides a correlation coefficient the closest to 1, with a correlation of 0,9779982630. It can also be clearly seen that much better correlation between actual and modelled variables is obtained when the temperature value at the doors is known and normalised temperatures in between the chiller and the doors are modelled as function of location, compared to the situation where the temperature at the doors is unknown. This demonstrates the value of having access to at least one additional measured temperature value, in addition to the chilling unit set point temperature.

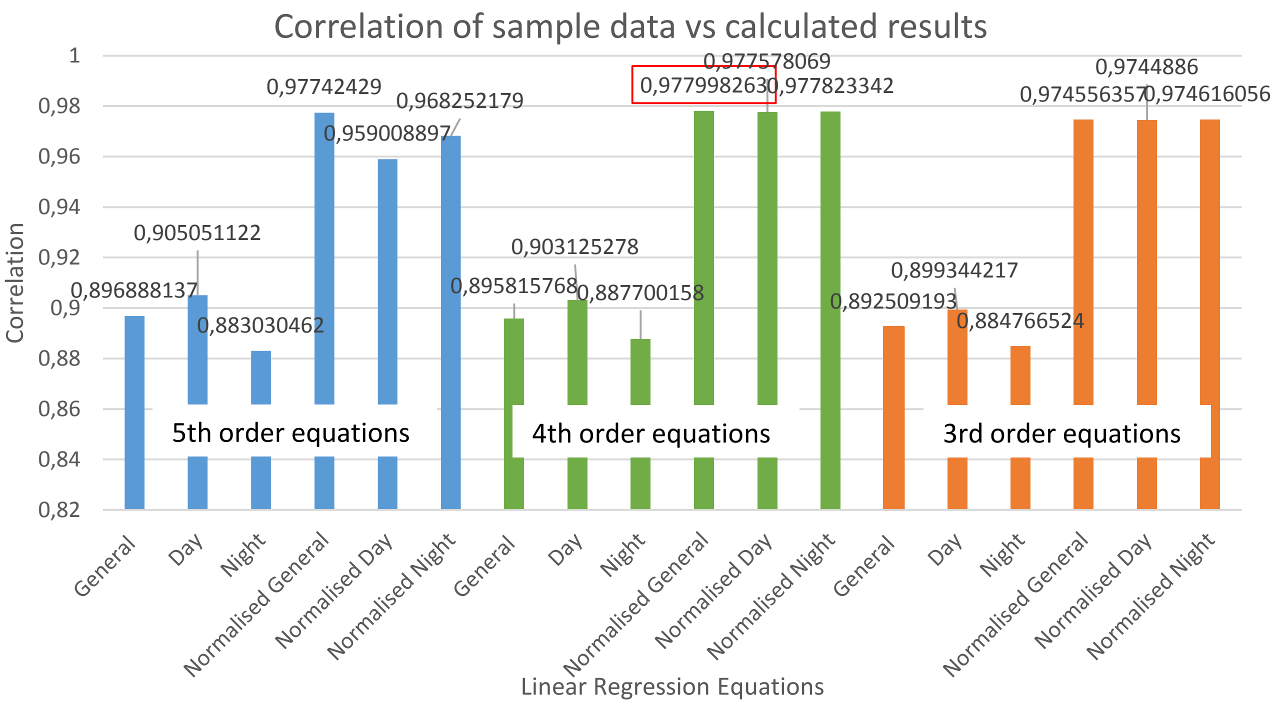


Figure 85: Comparison of correlation coefficients of analysed data models.

The analysis presented in this section, delivered 18 different position models that each modelled the temperature within the reefer. As it is evident from the comparison in Figure 85 the model that can best be used to calculate the temperature at any time within the trailer is the 4th order normalised equation. The de-normalised equation that can be used for this purpose is depicted by equation 9 below.

$$y(x) = (T_0 - T_n) * (0.00012x^4 - 0.00423x^3 + 0.0534x^2 - 0{,}3332x + 1.00328) + T_n \qquad (9)$$

Where:

T_0 = Temperature at position at Tier 0 (ºC)

T_n =Temperature at position n closer to the cooling unit (ºC)

x = Position in trailer between sensor T_0 and T_n (m)

This equation requires a minimum of two sensors to be placed within the trailer to extrapolate a temperature approximation within the trailer for the position between the used sensors. Although this model provides a good fit to data and representation of the temperature within the trailer it does not take all aspects of the environment into account. Improvements can be made to this model by including the specific time during the day when this calculation is done as well as the external ambient temperature at that time to only name two. The inclusion of these factors in further analysis of the temperature environment and improvements to the developed model is beyond the scope of this study and will not be included. These improvements can be made in future studies to provide a greater accuracy of the temperature at any time within the trailer as experienced by the perishables being transported.

6.3 Temperature distribution inside a Pallet Sock

The temperature fluctuations inside the trailer and the uncontrolled temperature at many loading bays require further measures to be taken to avoid damage to perishables. The use of pallet socks serves this purpose of preventing thermal leakage from the perishable on the dollies. Dollies are small trollies similar in dimension and purpose to general pallets providing the benefit of ease in mobility due to the mounted wheels. Although pallets socks are implemented in various links of the supply by industry players such as Woolworths the benefit of using these resources have not be clearly quantified. In order to gain a better understanding of pallets socks and its use alongside RFID temperature sensors further investigation is necessary. Firstly we need to study what effect the pallet sock has on the perishables with regards to temperature preservation. Secondly if a sensor is placed in the pouch of the sock it must be determined how it will influence the RF readability thereof and finally if the temperature in the pouch accurately reflects the temperature inside the pallet sock.

To obtain the before mentioned results an experiment was conducted where a single mock cargo parcel was configured. This parcel consisted of 10 stacked crates that were placed on top of a dolly and covered by a pallet sock. The crates were populated with 500ml filled water containers to simulate water based perishable cargo. Sensors where placed at different heights internally between the containers and on the outside of the crates. Further sensors were also placed on the exterior of the sock as well as within the pouch of the sock and on the exterior thereof. This provided a three dimensional perspective of how temperature reacts relative to the environment and the actual effect the sock has on temperature preservation. The parcel was then moved into a cold room at the Potchefstroom Woolworths branch for a 1 hour period and then removed and placed into direct sunlight for a period of 30min; this process was repeated 5 times.

When measuring the temperature distribution within the pallet sock over its 2m height it was found that the temperature differs by no more than 0,25 ºC over the height of the sock when within the cold-room. The internal temperature of the pallet sock never differed by more than 1.5 ºC from the temperature of the cold room environment, this number correlates with the results depicted in Figure 85 above. When the parcel was removed from the temperature environment it provided the perishables with isolation for an approximate period of 15 minutes at a room temperature of 25 ºC before the perishables goods on the exterior of crates within the sock reflects this temperature.

There does indeed exist a difference between the internal temperatures of the pallet sock relative to the temperature measured within the pouch on the exterior of the pallet sock. The pouch reflects the external environmental temperature after an average of 5 minutes exposed to 25ºC as measure with a accuracy of 1.5 ºC . This is a third of the time it takes for the cargo to reflect this same temperature without the use of the pallet sock.

This result was compared to the field study data discussed in section 6.1 where sensors were placed on and within pallets without a pallet sock. The pallets in these field experiments were removed from the cold room and placed within the loading bay where in many instances the goods were exposed to direct sunlight for periods longer than 20 minutes. From the data it was evident that the perishables on the exterior of the pallet parcel would reflect the environmental temperature after an average period of 7 minutes. For both these experiments the temperature controlled environment was set to 4 ºC, with a threshold temperature of 2 ºC above and below this set point to maintain a minimum cargo degradation effect. Comparing the field result to that of a sock covered parcel it is seen that there is a clear improvement in the influence of temperature on cargo in the short term. This thermal buffer that the sock provides to delay temperature effects by 15 minutes longer than without the application of the sock ensures that the goods can be moved safely to a temperature controlled environment during the loading/off-loading process with little to no damage incurred by perishables in the consignment.

The results further indicated that the internal and external temperatures display a non-linear relationship with respect to both time and temperature. It is important to note that benefit of the pallet sock depends on the isolation material used on the inside of the pallet sock, the cargo packaging type and the thermal properties of the cargo. The cargo temperature will remain within the specified limit from the cold storage temperature after a specific time and will take a specific time period to reach the allowed threshold. If the temperature relationship between cargo temperature and temperature in the pouch is known, you can derive the cargo temp from the sensor measurement in the pouch. This can help to indicate when the cargo is expected to reach the threshold temp after if left cold storage, alternatively you can estimate how long it will still take to reach the threshold. An equation could be derived to provide a method to calculate this, but for the purpose of this study this calculation will not be included.

In summary the pallet sock provides the ability to preserve the temperature of the cargo for periods longer than is possible without its application. This allows for goods to be safely handled in the loading-bay with little degradation to the cargo and its possible shelf life to the consumer. The sensors placed within in the sock could not be read effectively at a distance due to the foil line of the sock. The best readability was obtained with the sensor placed on the exterior of the sock inside the pouch. As stated before a sensor placed in this position would reflect the ambient temperature within a third of time it takes the internal cargo to reflect the same temperature. By deriving the true cargo temperature from the pouch temperature the pallet sock can therefore be used in combination with RFID sensors placed in the pouch of the sock. This configuration of sock to sensor allows the ability to monitor the temperature of the cargo to a relative degree of accuracy whilst providing a thermal buffer against immediate temperature fluctuations. This can thus provide the necessary monitoring capability as per the user requirements discussed in Chapter 3.

6.4 RFID system evaluation

6.4.1 The system evaluation

The purpose of the evaluations done on the equipment in this section was to determine how the system would function in a specific environment over a period of time and what the influence of the environment would be on the system's functionality. During the evaluation the following aspects were observed and documented:

RF-enabled tags

1. The range of communication between interrogator and tag
2. The time elapsed to retrieve a reading from the tag
3. The influence of the environment on the communication range
4. The effect of multiple interrogators on each other and their data retrieval capabilities
5. The data retrieval capabilities from alternative vendor tags measured according the distance and angles it can be detected at.

Temperature sensor tags

1. The measurement accuracy of the sensor
2. The data storage capability and sample rate of the sensor tag
3. Data retrieval from multiple tags in environment
4. The effect of the temperature on the communication ability of the tag

GSM enabled systems

1. The influence of the environment on data forwarding
2. The operational data costs of the system
3. The operational simplicity of software tools

From these evaluations, the suitability of each system for a certain scenario can be quantified and the limitations of each system defined.

6.4.2 Environmental Requirements

In order to effectively evaluate each system and retrieve optimal results, the environmental parameters were strictly controlled as far possible. The following aspects were kept valid during the evaluation of the range testing of the RF-enabled tags.

1. The testing area was cleared of any objects or materials that could interfere or cause any obstructions to the RF signal.
2. The surface was uniform and non- conductive with a low reflection coefficient.
3. The test was completed in a time frame where the environmental temperature did not fluctuate more than 5°C during the testing time.
4. The evaluation area was not influenced by the wind and other static sources that could interfere with the RF signals between the reader and the tag.
5. No other RF sources were placed within a 20m radius of the interrogator, in order to limit their effect.

This environment was modified according to the specific conditions of the scenario to be tested and serves as the baseline for the range testing operations. The evaluation sensing capabilities of the tags were done in a temperature controlled environment. The following parameters were adhered to as far as possible.

1. The evaluation area was void of any alternative RF sources.
2. The temperature was adjustable for the range of 0°C to 15°C.
3. Only objects of a non-metallic nature were placed within the evaluation area.

6.4.3 Evaluation Methodology

During execution of the scenarios in section 6.5.1 a standard methodology was followed to ensure that each test adhered to the same evaluation parameters. The methodology is as follow:

1. Prepare a clear radius with no obstructions of 15m around the placement point of the reader
2. Mark the terrain with increments of 0.5m up to the cleared radius
3. Repeat this on procedure for every 45° starting from 0° (the direction of maximum radiation) to 180°.
4. Fix the reader with its central point to a height of 1.8m from the ground and place at the centre of the prepared terrain.
5. Place the tag against a non-metallic surface at an equivalent height

6. Start testing 0.5m from the reader and increase the distance with this amount for every successive measurement.
7. Document the distance of each reading
8. Repeat steps 6 and 7 for 5 different sensors of each brand tested.
9. Adjust the sensor placement with 45° and repeat steps 6 to 8
10. Continue measurement of tags, until the maximum distance is reached or the reader is no longer reading data from the tag. The distance represents the length of the reefer trailer, 15.2m, focused on in this study.
11. When the 5 sensors have been individually tested, steps 4 to 7 must be repeated again with the reader at 20cm lower than the original position. This procedure must be repeated for the reader height of 1.8m to 1m relative to the ground. These heights correspond to the height of the redline, which is the highest loading position allowed, and the mid-level height of the reefer.
12. During evaluation, no changes may be made to setup, with the angle, range and height the only variables

The evaluation setup is shown in Figures 86 and 87. Figure 86 depicts the area and division of this area into functional units for testing purposes. Figure 87 depicts the relation between placement of the interrogator and the tag.

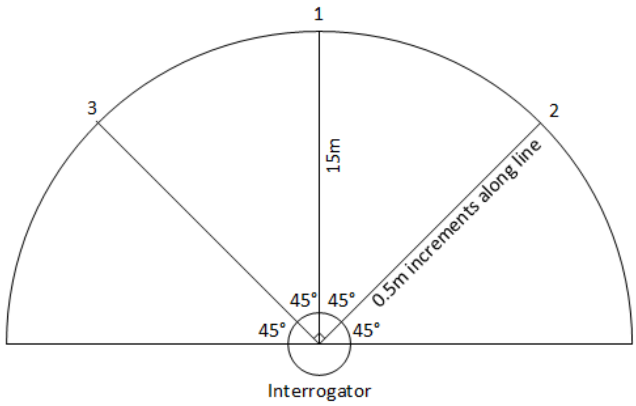


Figure 86: Evaluation Area

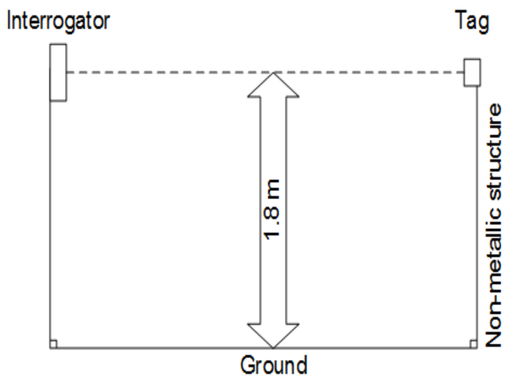


Figure 87: Relational setup of interrogator and tag

Once the standard test was completed the viewing angle of the interrogator was adjusted so that the antenna direction was 45° downwards (direction 2) and then 45° upwards (direction 3). The individual directions of the interrogator are shown in Figure 88.

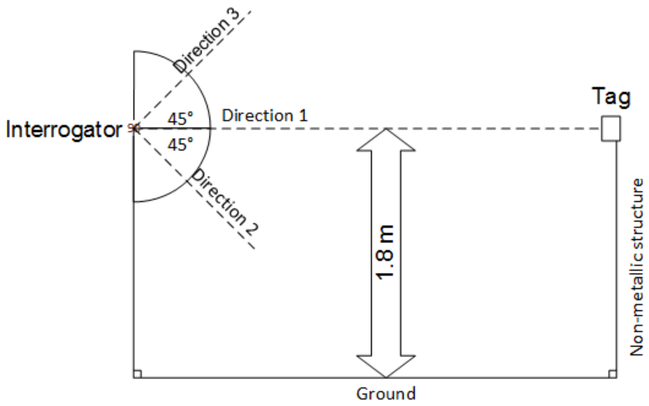


Figure 88: Vertical rotation of interrogator

6.4.4 Evaluation scenarios

The evaluation of the hardware was done by testing all systems in each of a number of different operational environments. Each scenario tested how the specific setup would influence the RF capabilities of the RFID tags from different vendors.

Range Evaluation

1. Free space evaluation

The scenario consists of the tag being fixed on a non-metallic structure with a low reflection coefficient. There were no obstructions of any kind placed between the interrogator and the tag.

1.1 Exterior of consignment packaged in boxes

This scenario aimed to simulate the placement of a tag on a consignment of boxes that includes items with a low liquid concentration. The boxes will be stacked to a height of approximately 2m and the sensor placed on the boxes at the height of 1.8m. The methodology defined previously will be followed from this point.

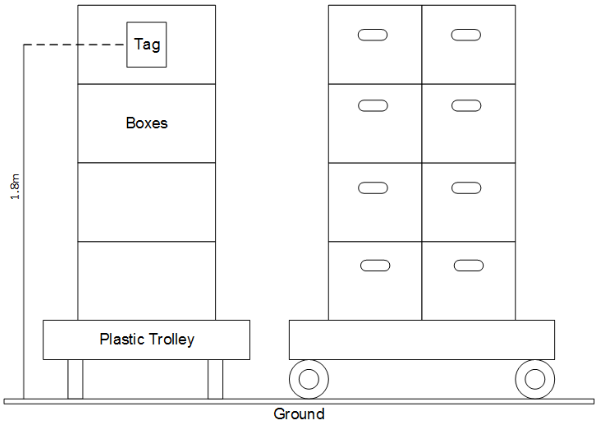


Figure 89 depicts this scenario.

1.2 Exterior of pallet sock

The pallet sock is placed over 10 crates stacked on top of each other, the crates have no contents and were separated by polystyrene. This is similar to the configuration for the experiments conducted as described in section 6.4. The tag was placed against the outer surface on the pouch in the middle as depicted by Figure 90 below. The standard evaluation procedure was then followed to retrieve the corresponding data.

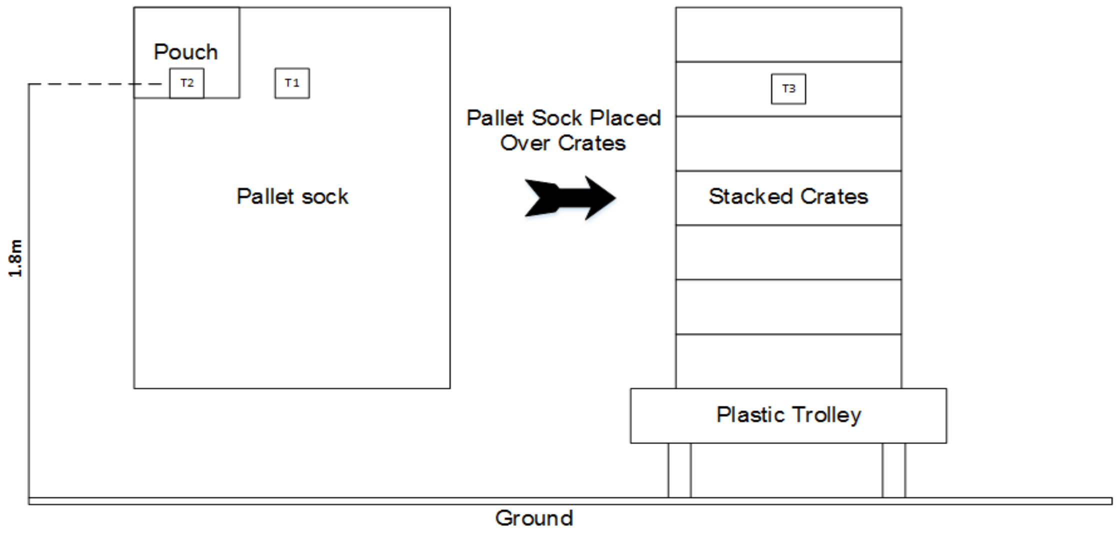


Figure 89: Pallet Sock and crate setup

1.3 Internal pallet sock pouch evaluation

The tag was placed inside the plastic pouch of the pallet sock at the set position to align horizontally and vertically with the reader. The position is depicted by block T2 in Figure 90. The methodology in 6.5.3 was then repeated on the externally placed tag.

1.4 Internal pallet sock evaluation

The tag was placed against the exterior of the crate at the set height of the methodology. The pallet sock was then placed over the stacked crates and the communication ability of the tag was then measured. This test measured the influence of the pallet sock on the RF capability of different tags. The tag placement on the crates is depicted by tag T3 in Figure 90 above.

1.5 Internal water based consignment evaluation

The tag was placed in the centre of the water based consignment; the consignment was emulated by using plastic bottles filled to 90% capacity. The tag placement is shown in Figure 91 below. The standard methodology for the evaluation criteria was followed during the test.

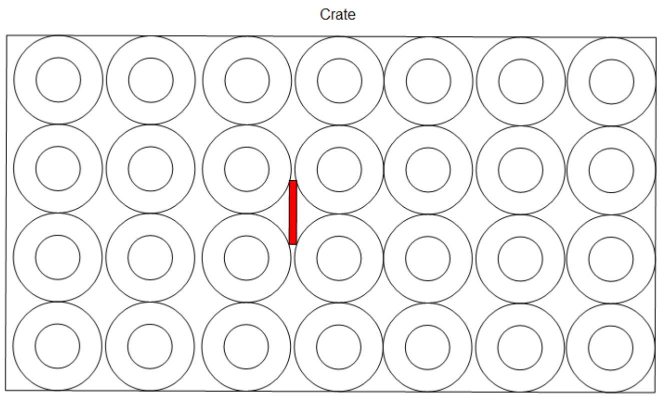


Figure 90: Container with water bottles and tag

The tests were each completed three times with the following parameters:

1. The plastic bottles were evenly placed in the crate with no liquid and no pallet sock
2. The plastic bottles were filled with water and evenly placed in the crates. Again the pallet sock was not added.
3. The pallet sock is now placed over the crates with the water filled bottles

In each evaluation, the sensor was placed at the original placement position in the same configuration to ensure uniformity.

Temperature evaluation

a. External temperature evaluation

The tag was placed against the outer surface of the pallet sock at a central position. The tag was then allowed to monitor the ambient temperature for the duration as stipulated earlier. The placement of the tag is indicated as T1 in Figure 90.

b. Within the pallet sock pouch

The tag was loosely placed inside the pouch of the pallet sock before the start of the evaluation. The placement is indicated as T2 in Figure 90.

c. Internally placed sensor on consignment within pallet sock

The tag must be placed against the crates of the consignment with the pallet sock placed over the consignment. This tag placement is indicated as T3 in Figure 90.

Each tag was accompanied by a LogTag data logger to verify the accuracy of the data recorded by the individual tags included in the evaluation. Once the evaluation is completed the data was stored to excel format and analysed against each other to draw the appropriate conclusions on the influence of the pallet sock and consignment on the temperature measurement.

6.5 Systems Evaluated

6.5.1 The system included in the evaluation

The systems included in this evaluation are listed below in Table 50. The systems selected are representative of passive, battery assisted and active RFID tags. The evaluation of the systems will provide answers to the research questions posed in Chapter 1 of this document and following the methodology of section 6.5.

Table 48: RFID systems to be evaluated

Company	Reader	Tag
CSL	CS461 4 port reader	CS6720 passive UHF RFID tag with no temperature measurement capability
Caen RFID	Slate R1260I RFID UHF desktop reader	RT005 semi-passive UHF logger tag/ A927z semi-passive UHF tag
Caen RFID	R4300P demo kit with GPRS	RT005 semi-passive UHF logger tag/ A927z semi-passive UHF tag
Yrless International	Base Station	Temperature Tags
Wireless Links	Picollo Plus	Active RFID Tag -2.4GHz
Ctrack	iS200	iKaya Active RFID Tag-433MHz
LogTag	Cradle Interface via USB	LogTag

It is noted that LogTag has been included in the table above although it has no RF communication capability. This addition is because this device is used for temperature reference to determine if the RF sensor combination of the other devices does indeed capture accurate temperature data.

6.5.2 Results

The observation results presented in the following sections were obtained using the methodology described in section 6.4. This methodology was applied in free space, metallic containers and in a reefer at Lonrho Logistics.

This provided the information to determine the readability, stability and range of RFID devices shown in Table 50. In the tables that follow the external header refers to sensors placed on the periphery of the pallets and internal to sensors place between the goods in the cargo as depicted by Figure 93. Each table show two essential types of information firstly the average readable distance a sensor can be read at with a relative angle to the reader and the second the orientation of the sensor relative to reader when the before mentioned readings where obtained. The information acquired from the pallet sock experiments will not be included in the general evaluation but is used to make evaluations discussed in 6.4. The selected devices used in these experiments provided a spectrum of RFID enabled temperature monitoring equipment to supply an answer to the question on the usability of RFID for CCM.

Free space evaluation

The evaluation of the sensors in free space is required to establish a baseline for the use of the specific type of RFID system in an unobstructed environment. Figure 92 shows the environment where this evaluation has been completed, with pallet sock and crates.

Figure 91: Free space test terrain

In Table 51 the results obtained in this evaluation are listed; the linear; 45º and 90º maximum distances of readability for the standard operational power of the systems are indicated. The optimal orientation of the sensor is a 0º orientation being a direct frontal view of the sensor relative to the antenna of the reader. The last column in the table represent the orientation angle of the sensor to the reader and the sensor orientation that has been found to be the best.

Table 49: Free Range Test Results

Company	0º Range (m)		45º Range (m)		90º Range(m)		Optimal Reader Angle
	External	Internal	External	Internal	External	Internal	
CSL	5	5	4	4	4	4	0º
Caen RFID A927Z	8,7	8,7	6	6	4,8	4,8	45º
Caen RFID RT005	8,7	8,7	6	6	4,8	4,8	90º
Yrless International	450	450	450	450	450	450	0º
Wireless Links	15	15	13,6	13,6	12	12	0º
Ctrack	16	16	14	14	10	10	90º

Applying the same methodology as above the content inside the crates are replaced by water filled containers. The processes were then repeated and results were obtained. The results are listed in Table 52 that follows. The results clearly indicate that water based content has an adverse effect on the readability and read range of the sensors, this is due to RF absorption caused by the liquid.

Table 50: Free range test results for water based content

Company	0º Range (m)		45º Range (m)		90º Range(m)		Optimal Reader Angle
	External	Internal	External	Internal	External	Internal	
CSL	3.2	2.9	3	2.3	3	2.2	0º
Caen RFID A927Z	5.7	5.5	5.5	5.2	2,5	2.5	45º
Caen RFID RT005	5.7	5.5	5.5	5.2	2.8	2.5	90º
Yrless International	300	300	300	300	300	300	0º
Wireless Links	9.5	8.3	8.6	8.2	9.8	9.3	0º
Ctrack	12	11.5	10	9.6	8	7.7	90º

The results obtained from the free range tests showed that passive RFID tag is the least effective solution with regards to read range. The inlays used in the passive tags are similar to that used in the BAP tags and the readability depends on the energy produced by the interrogator. The tags have the ability to be effectively used for document traceability and cargo traceability, configured by either a long range interrogator or handheld reader for this purpose. The BAP sensors have a slightly better read range than that of purely passive RFID tags as they do not need to be powered by the reader; their read range is determined by the ability to backscatter to the reader. From the results, the most effective use for the Caen BAP sensors is the passive monitoring of the cold chain (i.e. recording temperatures while in transit with recovery of the data only after recovering the tags). This fact is derived from the poor performance in terms of read range when inserted into the cargo, thus making BAP tags' most effective use for passive temperature recording.

The active RFID solution from Yrless have the best read range between the solutions, the active RFID tags use its large battery to boost the RF capability of the sensor to reach beyond 450m.This type of RFID sensor although providing large communication distances is however not ideal for the use in reefers. The long read range is unnecessary for the purpose of CCM monitoring and may in fact result in undesirable cross-reads when many reefers are processed in close proximity to each other. Lower cost sensors with shorter read range can rather be used. The 2.4GHz active RFID sensor from Wireless links and the 433MHz active RFID sensor from Ikaya used by Ctrack are both shorter read range active RFID solutions. These two systems provide similar reading capability as seen from this evaluation, although both types have no internal storage capability.

They are therefore suitable solutions for the implementation of real time CCM where a reader is permanently installed inside each reefer. In the further evaluation done in the field, only three of the above systems will be included. These systems are the BAP RFID system from CAEN operating at 900MHz, the Active RFID solution from Wirelesslinks operating at 2.4GHz and the active RFID solution from IKaya operating at 433MHz.

Metallic Container Evaluation

The evaluation in the metallic container was completed with the purpose of establishing the usability of temperature sensors in an environment with a metallic periphery. In these experiments the content was the same water filled containers as used previously. The environment is depicted in Figure 93 below. This environment was not equipped with a cooling unit and was used to determine the effect of the metallic container on the readability of the sensors with the reader placed at the front of the container.

Figure 92: Evaluation in metallic container

The result obtained from this evaluation are listed in Table 53. From the results, it is evident that in some cases the metallic surface of the empty container enhances the readability of the sensors placed against the periphery. This effect can be attributed to the reflection caused by the surface of the container with little attenuation of the interrogator signal broadcasted.

Table 51: Metallic Container RFID Results for water based consignment

Company	0º Range (m)		45º Range (m)		90º Range(m)		Optimal Reader /Sensor Angle	GSM En.
	External	Internal	External	Internal	External	Internal		
Caen RFID A927Z	9	8.6	8	6.8	6.5	5.4	45º	No
Caen RFID RT005	9	8.6	8	5.6	3.7	2.3	90º	No
Wireless Links	10	7	8.6	6.6	9.8	8.2	0º	Yes
Ctrack	15	14.6	13	12	12	11.4	90º	Yes

Operational field evaluations

The operational environment was evaluated at two LSP's that transport perishable goods to various clients. The vehicles used in the evaluation are shown in Figure 94 below. The purpose of the evaluation is to determine how effectively the three selected systems representing different types of RFID systems can function in a real word application.

Figure 93: Operational evaluation at LSP sites

In the evaluation the following two operational scenarios were considered; for both evaluations the cargo was fully filled at a height of 1,8m:

1. Sensors placed on the internal periphery of the trailer to evaluate the temperature inside the pallets, using the equation discussed in 6.3. This scenario evaluates the influence of the cold cargo filled environment on the free space readability of RFID sensors. The sensors were placed above the red line in the reefer.

2. Sensors placed inside the pallets to measure the temperature experienced by the perishables on a per pallet basis.

This scenario evaluates the influence of water-based perishables on the readability of the RFID sensors. The sensors where placed at random position in the pallets at heights approximate heights of 0,5m, 1m and 1,6m.

The results for scenario 1 are listed in Table 54 below. When compared with results obtained during the free space evaluation it can be seen that there is a decrease in the free space readability, this is due to the RF absorption of the perishable goods. This reduction, although effecting the readability of the sensors is still usable in the temperature environment and can be an effective tool in data collection.

Table 52: Reefer periphery RFID results for actual consignment environment

Company	0º Range (m)		45º Range (m)		90º Range(m)		Optimal Reader / Sensor Angle	GSM Enabled
	Sensor on Walls	Sensor on top of Consgn.	Sensor on Walls	Sensor on top of Consgn.	Sensor on Walls	Sensor on top of Consgn.		
Caen RFID A927Z	7.9	5.2	7.9	5.2	4.5	3.6	45º	No
Caen RFID RT005	7.9	5	7.9	5.9	2.7	1.9	90º	No
Wireless Links	12	8.6	11	7.2	8.2	7.4	0º	Yes
Ctrack	14	13.8	12.3	12	11	10	90º	Yes

The environment for the evaluation of scenario 2 is shown in Figure 95, The sensors were placed inside the pallets between the perishables, the sensors were then read from varies positions in the trailer to obtain the data to evaluate the usability of the sensors for in cargo monitoring.

Figure 94: Fully loaded reefer evaluation

The data evaluated for this scenario is listed in Table 55. From the data it is clear that the perishables have a large attenuation effect on the readability of the sensors. The best system from the evaluation is the 433MHz system followed by the 2.4GHz system making these two types of active RFID devices the best solution for real-time temperature tracking, whilst the 900MHz BAP RFID devices is a best-suited solution for passive temperature monitoring with the ability of non-contact data retrieval at the client or DC site. Real time communication capability is possible with the GSM/GPRS tracking unit that must communicate with the tags placed within the first 4.5m from the back of the trailer if the placement is not possible on the outside of the trailer, this only applies for units where the RFID reader is built into the GSM unit such as the Picollo system. Closer to the front of the trailer too much interference occur due to the metallic container and the cooling unit disturbance. This was verified by placing the GSM sensor at different positions inside the trailer relative to the cooling unit and doors. The ability to communicate was measured when the cooling was on and off. During the test period when the unit was on no data was received from the devices in the 5m closest to the cooling unit with improvement with movement closer to the doors. The doors of the trailer was closed during both communication evaluations.

Table 53: Reefer Internal pallet sensor placement

Company	Linear Length (m)	45º Length (m)	90º Length (m)	Optimal Reader Angle	GSM communication ability
Caen RFID A927Z	4,5	4	6,5	45º	No
Caen RFID RT005	4,5	4	3,7	90º	No
Wireless Links	6,5	5,5	3	0º	Yes
Ctrack	8,5	7	8	90º	Yes

6.6 Chapter Summary

The evaluation of RFID based CCM systems within the operational environment was discussed in this chapter. The typical temperature control inside a reefer trailer is unreliable as in the worst case the temperature can fluctuate from the set point by more than 4 times the allowed range in the backward half of the trailer. This validates the problem statement presented in Chapter 3 for the operation of cold chain logistics of perishable goods.

The further evaluation of this temperature environment showed that a mathematical model could be created to model the temperature inside the trailer as function of time and position. Using this model for the deviating temperature environment it is possible to use fewer sensors to provide the required visibility in the trailer.

The evaluation of different RFID sensing systems showed that the 433MHz active RFID tag provides the best ability to monitor the cargo in real time; the 2.4Ghz active RFID also provide an alternative to this system and with its relatively small tag sizes provide an excellent solution for sensor placed on pallets. The 900MHz BAP RFID system presents the best solution for on-sensor logging of temperature data with wireless retrieval of such data collected in transit after completion of the trip.

Chapter 7: Software Implementation

7.1 Chapter Overview

In this chapter, we will look at the implementation of the design presented in chapter 5. The design implementation presented in this chapter depicts the graphical user interface that provides a user-friendly connection to the functionality designed for CCM. Using the data from the evaluations presented in the previous chapter the cost to the end user and the return on investment that can be expect if the solution was to be implemented is calculated.

7.2 Software Implementation

The implementation of the design presented in Chapter 5 is depicted in this section. The implementation has been completed successfully using this design and all functionality has been incorporated as per the design. The implementation can be viewed loading the solution in Appendix C under code and using the username Nardus and password VanEyk. The operational files and vb.net code for each page can also be found by following the link depicted in Appendix C at the back of this document. An overview of this implementation can be viewed following this link: https://www.youtube.com/watch?v=t4Giz9O46lY&feature=youtu.be

The software and company information is protected by the use of password access. This function allows only users and clients pertaining to a specific company to gain access to the data and information relevant to them and not interfere with other users and their data on the system. The user provides a username and password to the system as shown in Figure 96, after verification a session key is generated and access is granted to the system. If either the session key has expired or the user tries to log into pages of the system illegally he is immediately diverted to the login page.

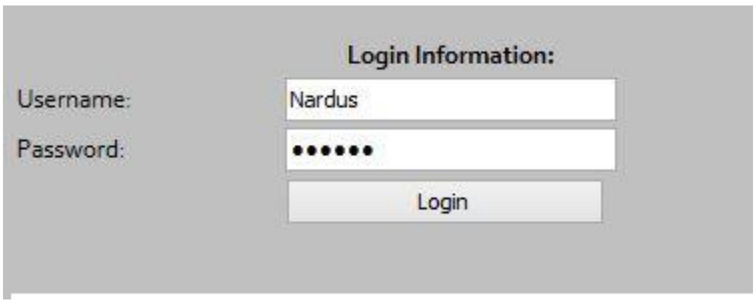


Figure 95: Login Page

Once the correct user credentials have been provided to the system, the user is directed to the home page of the system as depicted in Figure 97. This page provides a landing platform for a user to work from and navigate to the required function of the system.

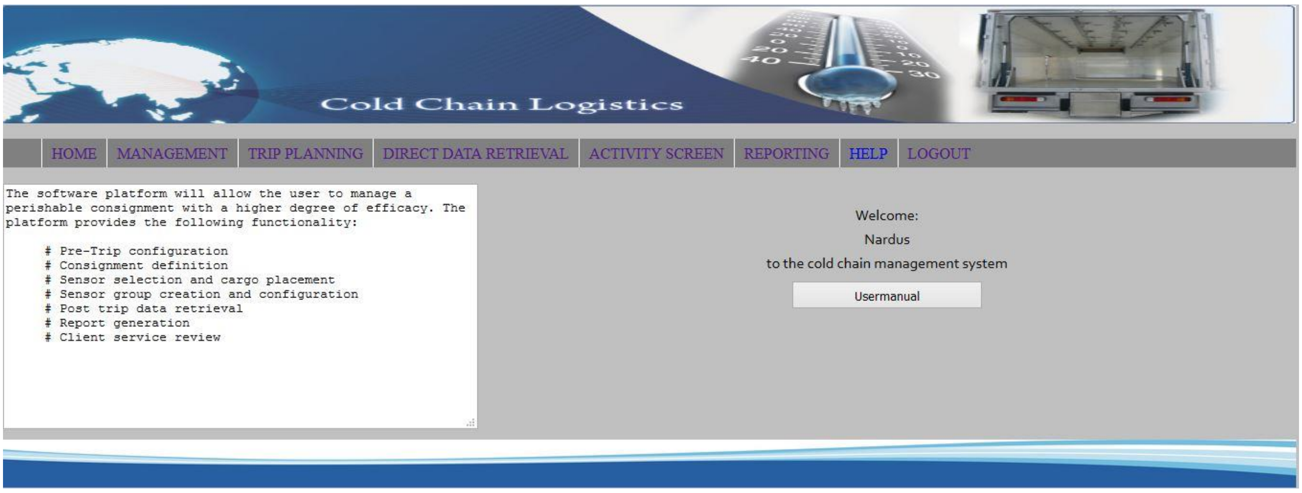


Figure 96: Home Page

Using the master page method, uniformity is provided through the whole system. On each page, the navigation menu depicted in Figure 98 is used. On click, the user is diverted to the appropriate page of operation and he/she can continue with the functionality provided by the selected page.

Figure 97: Navigation Menu

Starting from the left, management is the first function the user can call to navigate away from the homepage. The management page provides the user with the ability to manage stored data in the system and add new operational information. The user can select from a list to view information pertaining to:

- User Information
- Client Information
- Driver Information
- Horse Information
- Trailer Information
- Equipment Information

Once the user has selected an option from the list and clicked the view button the information is tabulated to a grid table as is depicted in Figure 99 for the option of horse information. The user can also add new information to the database for use in different parts of the system by using the navigation toolbar on the right of the page. The user can then add the information from the list above and manage inventory configurations for use in trip planning. The options presented here reflects the entities that can be seen as the critical building blocks of any cold chain logistic scheduling mechanism.

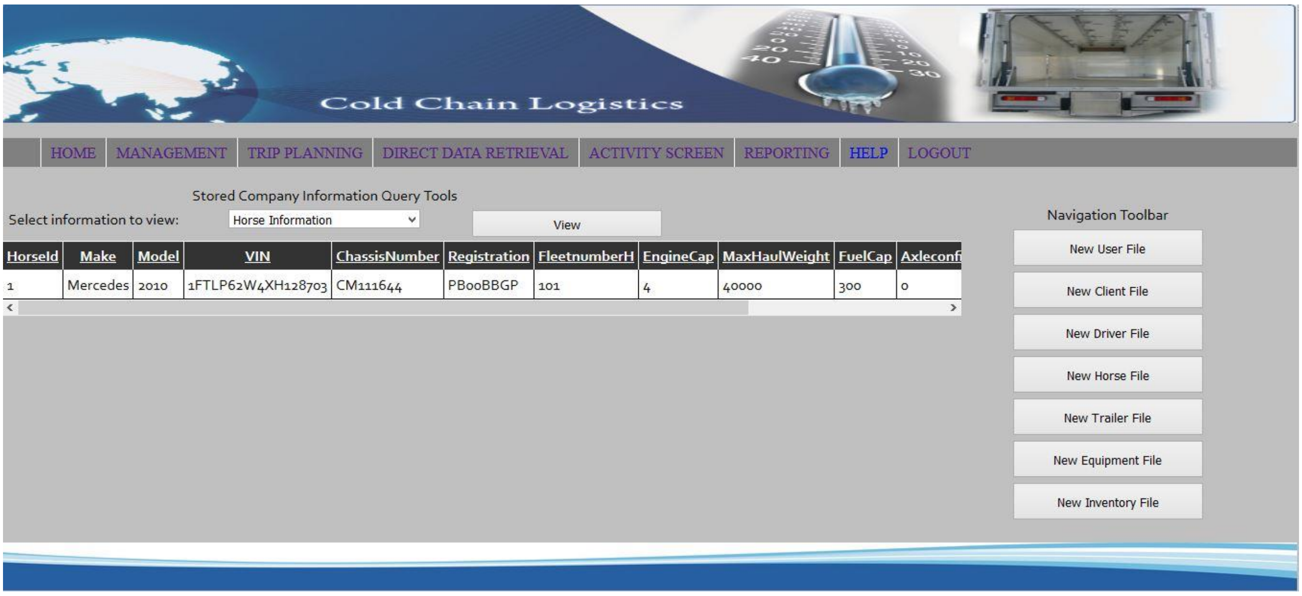


Figure 98: Management Page

User Information:

When a new LSP elects to start using the software, the administrator creates a new company and a high-level user of the system. The company can then use this information to create new users of the system using the New User File button. The user is then directed to the user information page with the widgets depicted in Figure 100. The logged in user can then create users with different levels of access to the system:

- Company Admin: A full access user that can perform all functions of the system
- Manager: This user can access all functionality of the system, but cannot remove any stored data from the system.
- General User: Can only view information on the system, but cannot alter information of any kind on the system. This can generally be used by clients to view reports for consignments being delivered to their sites.

The user credentials for access control according to this defined level is then provided in the system and the company the user works for is also automatically added. Once the user information has been submitted to the database with valid information the identity is immediately active and the user can access the functionality of the software.

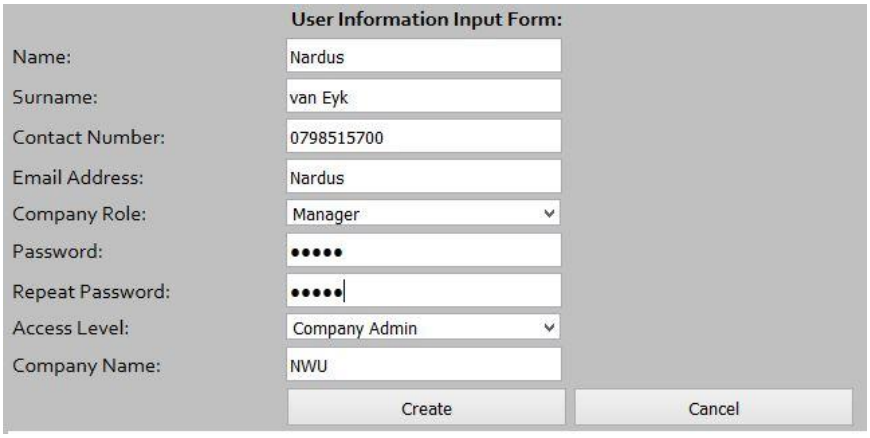


Figure 99: User Information Page

Client Information:

The client information form depicted in Figure 101, allows the user to create new clients that make use of an LSP's services. The client information is a critical segment of data to link a consignment to a company and gather historical information on the operation of the company. The location and contact information of the client must also be provided at this stage.

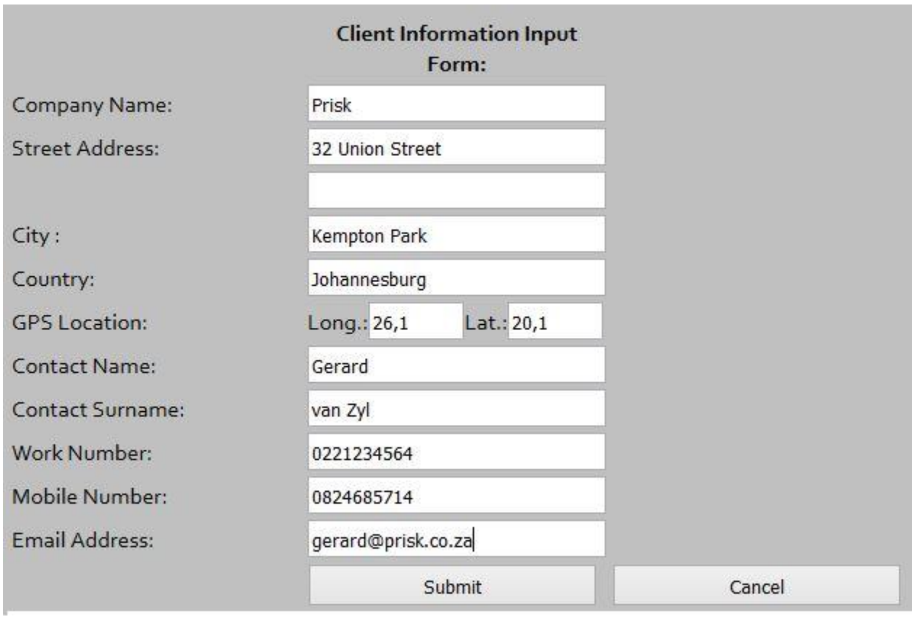


Figure 100: Client Information Page

Driver Information:

Any company providing logistic information has a set of drivers performing the logistic duties for the company as per the operation discussed in Chapter 3. The information provided on the Driver information page depicted in Figure 102 provides the LSP with information to track and communicate with the driver. Many drivers for international transportation does not use the roaming capabilities of local SA networks but rather use country specific sim cards, in this case, the foreign sim card number can also be added to the driver information. The page further provides information on the drivers licensing and passports and their corresponding expiry dates. This provides an important warning for LSP's in the planning process to avoid using a driver that has invalid documentation before or during the trip.

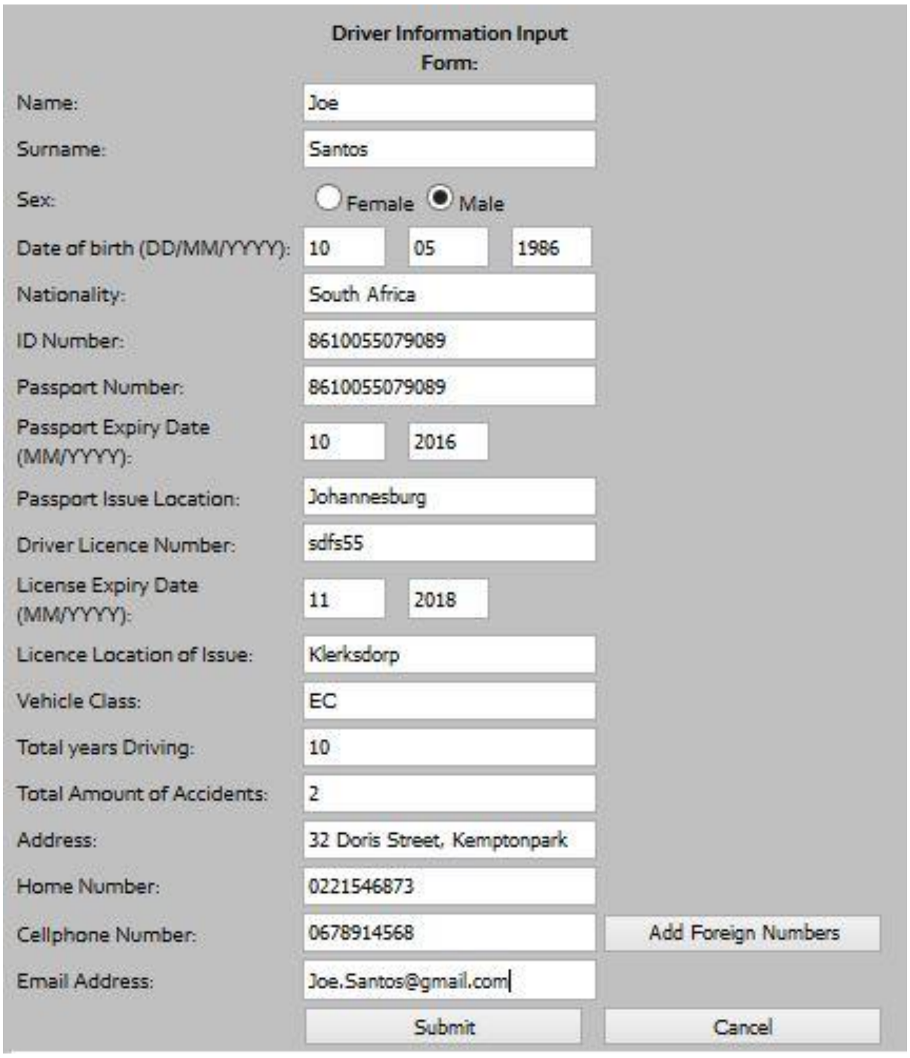


Figure 101: Driver Information Page

Horse Information:

The horse information provides the user with the general information on the vehicle to identify it uniquely in the LSP's fleet. The legal capabilities and limitations of the company are also provided in the input page depicted in Figure 103. This information is later used in the trip planning section for a client to make the best use of resources available to the client.

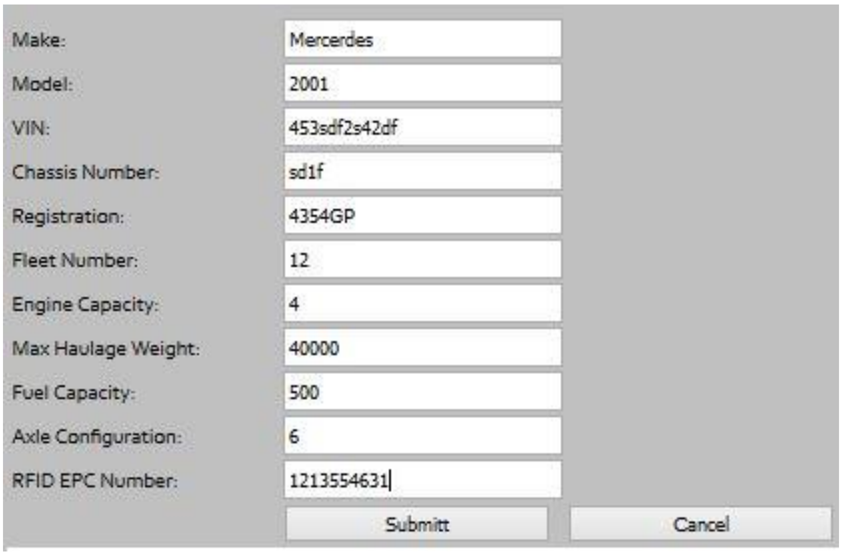


Figure 102: Horse Information Page

Trailer Information:

The trailer information input form depicted in Figure 104, similar to the horse information table, defines a trailer uniquely. The type of trailer is also defined using the fuel option to differentiate between reefers and general trailers. The haulage capabilities are also provided here.

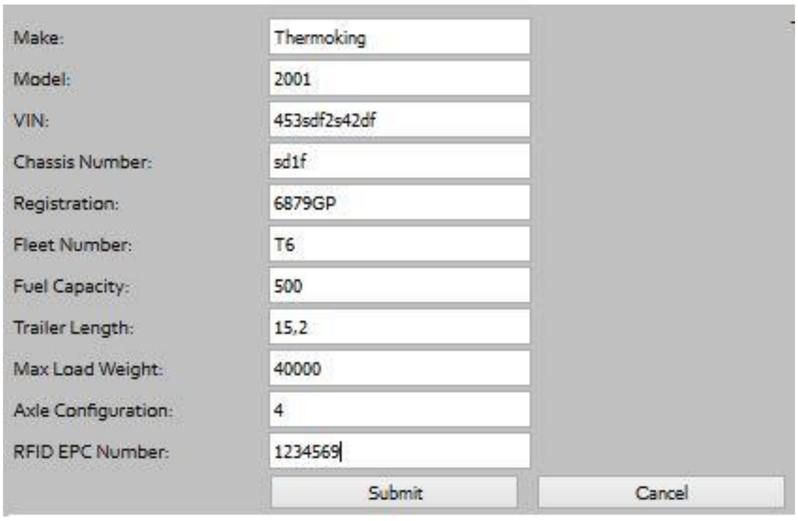


Figure 103: Trailer Information Page

Equipment Information:

When a company acquires new equipment (either readers or new types of sensors) the information is provided to the system using the new equipment information button. On the equipment information page the user can choose to add to different types of information:

New Group: Information pertaining to a specific type of equipment, the capabilities, and specification as well as the quantity of devices purchased. The specification can be used to define what type of system is the most applicable for the type of consignment being transported. The input form to the aid the user in the entry of system specific information is depicted in Figure 105 below.

New Sensors: Sensors added to the system can be provided with custom names by linking the EPC code of the sensor to the name defined. The purpose of this function is to simplify the use of the sensors by shorter and easier to read names than the standard EPC code. The page aiding the development of this custom name is depicted in Figure 106 below.

Using these pages the user provides the relevant system information to make effectively use of the available equipment to improve the cold chain of goods delivered by providing accountability of the chain and maintaining the temperature requirements set by the client.

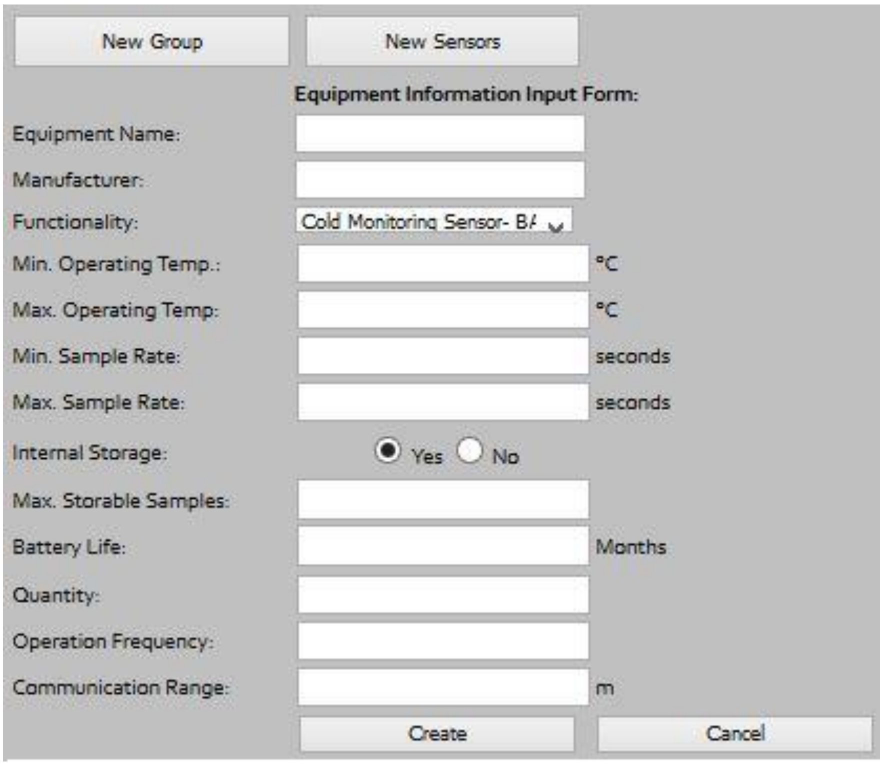


Figure 104: Equipment Group Page

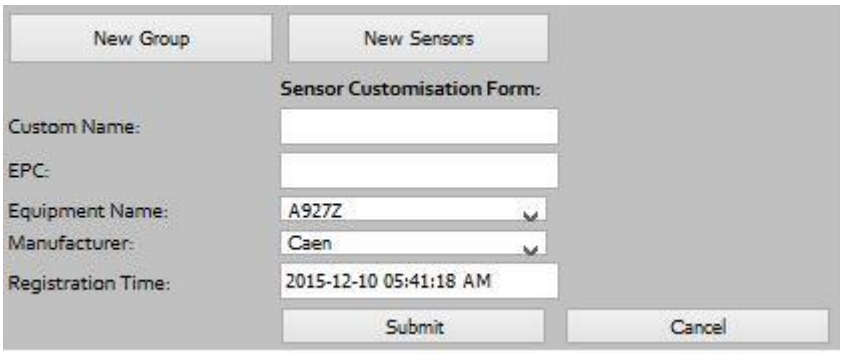


Figure 105: Custom Sensor Naming Page

Inventory Information:

This page allows the user to define an inventory to be delivered, on access the user can select to define new inventory or input temperature standards. Each perishable type of cargo has a different rate of degradation and temperature requirements to allow for the maximum shelf life and quality of goods to reach the consumer. The temperature standard page depicted in Figure 107 indicate the specifications for a specific type, for example, tomatoes. The values populated here will be used to calculate the temperature constraints of the goods in the consignment as well as the predicted shelf life and mean kinetic temperature.

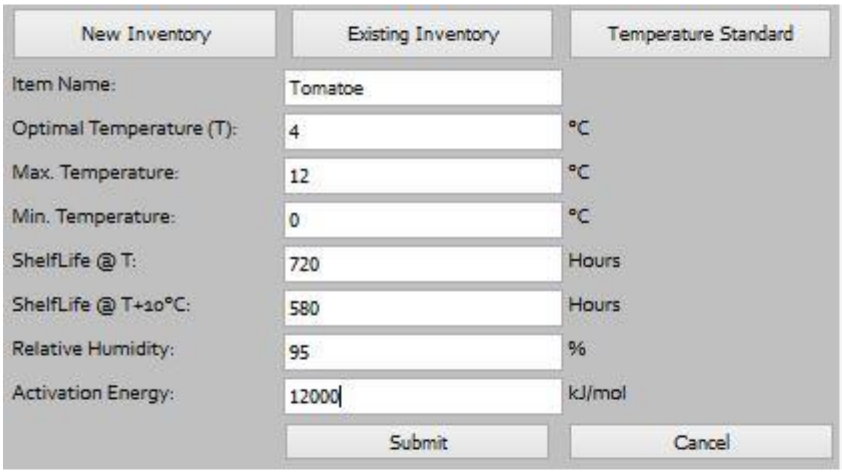


Figure 106: Temperature Standards Page

Using the perishable standards defined for the different goods, an inventory list can be created as depicted in Figure 108. The list automatically calculates the most perishable good in consignment and define this as the temperature requirement for the trip to which all sensors will be configured as well as to be used for the calculation of the temperature.

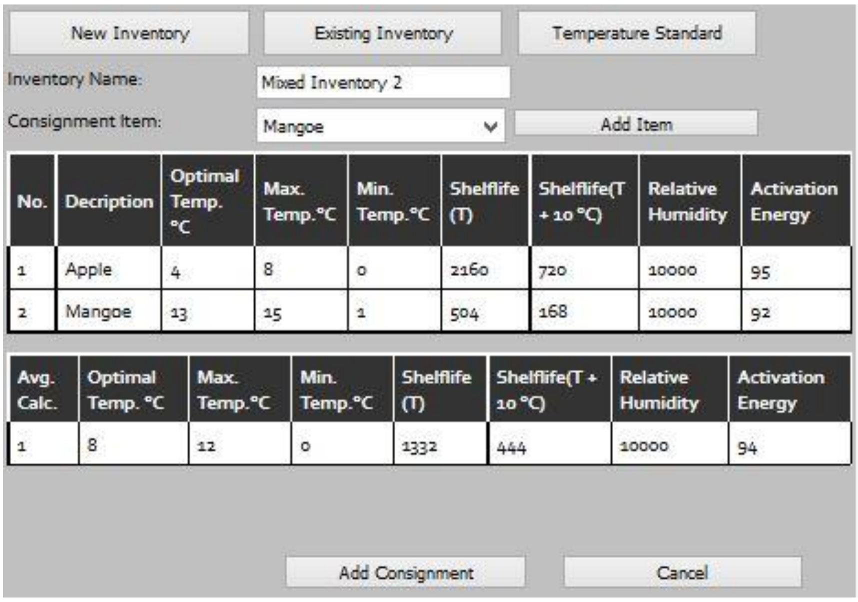


Figure 107: Inventory Creation Page

The values defined in the various areas of the management function can now be used and reused once the LSP receives a delivery request. The values are combined to form a logical plan that integrates the requirements from the client with the resources (horses, trailers and monitoring equipment) that the LSP has on hand for the required period. This is accomplished through the trip planning methodology that guides the user through the creation of a trip plan. When selecting the trip planning option from the main menu the user is presented with four options:

New Plan:

A user can create a new trip plan from scratch completing all the information available to the LSP at the time of the creation of the plan. At this stage of the planning process, the LSP has often not yet been provided with all the details of the trip by the client. In such a case not all the information can be provided and only the information available is saved to the database for completion at a later stage.

Unfinished Plan:

When the user receives the remainder of the information from the client the already created plan can be completed. The user can recall the information provided previously by selecting the consignment for which the trip plan was created. On selection of this option, all information stored to the database is recalled and the corresponding fields are populated.

Quick Plan:

In the scenario where the user does not desire to define a complete trip plan with all the details as depicted in Figure 110, the user may define the basic thresholds of the perishable consignment or make use of default values predefined in the system. This data is then stored to the system and sensor configuration can commence using these values. The purpose of this method is to save time in the configuration process and thus operational cost when the application is scaled up.

Sensor Placement:

The sensor placement option provides the user with the ability to link sensors configured for the consignment to specific positions in the reefer. This is an important step to make it possible for the system to effectively model the temperature environment and to enable simple section evaluation to ensure the required temperature thresholds were indeed maintained. This function is normally accessed from the configuration page but can also be accessed from the placement directly from the trip planning page to complete the planning process.

The complete full trip planning page with the widgets of both the new trip and unfinished trip pages are depicted in Figure 109 below. The trip planning page accepts the client information; loading information; delivery information; inventory and vehicle allocation to form a complete detailed summary of information defining a clients' trip. The page allows the users to navigate from the page and define new information for the fields in a structured manner when the information is not yet available on the database of the company.

When all the required information has been provided and submitted to the database a summary is added to the page listing the information of the trip plan. This completion activates the option to configure sensors using the details provided in the trip plan. When the user chooses to configure the sensors by clicking the button control the user is diverted to the configuration page that will be discussed later in this section.

The page to configure a quick trip plan is depicted in Figure 110. On loading the page the default parameters for perishables, fruit, and vegetables are loaded from the database. The user is allowed to alter these defaults and the edited values will become the new default parameters for the company. This enables a user to only define a company default once; this will save processing time when creating trip plans for all future trips using this process.

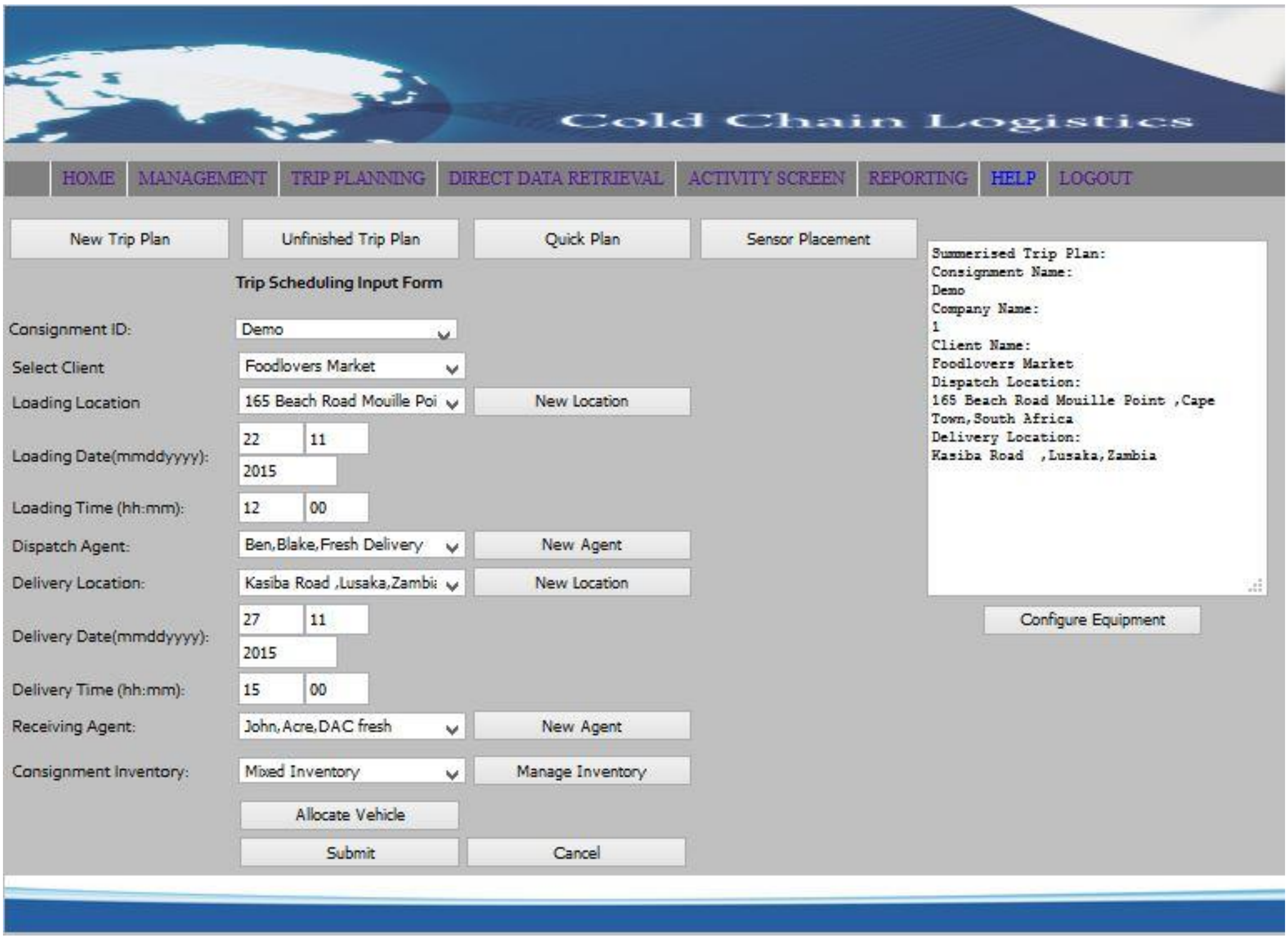


Figure 108: Trip Planning Page

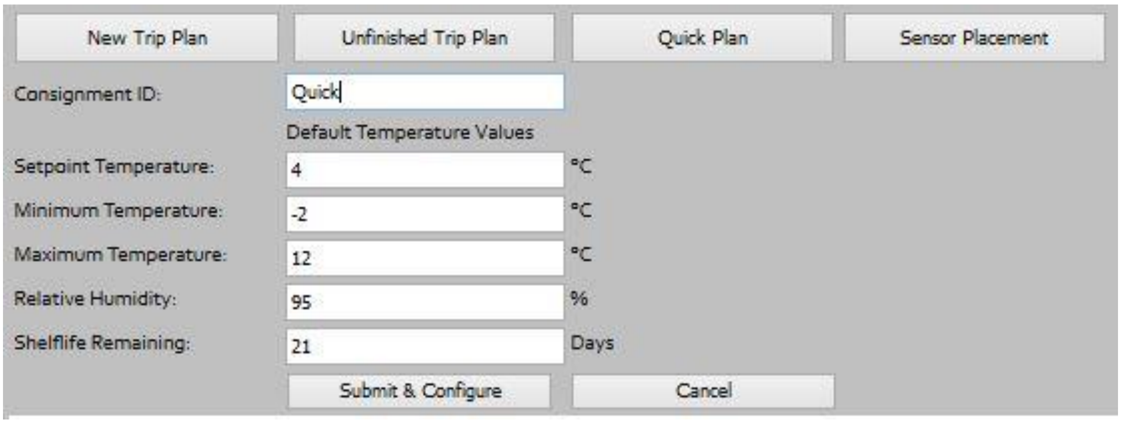


Figure 109: Quick Plan Page

After a trip plan has been completed and the user has elected to configure sensing equipment he/she is diverted to the page depicted in Figure 111. On this page the user must select a manufacturer of equipment available to the company as defined in the new equipment option under Management.

Once the user has selected a manufacturer the corresponding configuration page for the equipment available to the company is enabled. In the example shown in Figure 111, the configuration page for the Caen RFID sensor tags is displayed. On this page, the sensor usage information of all the equipment falling under the selected manufacturer is listed. The configuration of x amount of sensors updates the list of resources available to the user thus aiding in the operational control of the system.

The BAP system that represents the passive monitoring capability requires the system to connect to a reader. In order to accomplish this, the user selects from a list of available readers to the company and connect using the appropriate technology. The CAEN solution, in the case evaluated and included in the evaluation at this stage, presents two types of readers. The first is an Ethernet reader and the second is a USB device. The reader tries to connect using a specified IP address or loops through a list of COM ports independently.

Once a communication port has been found and a connection has been established the software provides the user with a message to indicate the connection success along with information pertaining to the reader. The user is then required to detect the sensors that are in the field of the reader. According to the results presented in the previous chapter, a minimum of 5 sensors should be used to gain a representative temperature image of the consignment; the number of sensors selected in practice is however completely at the discretion of the user.

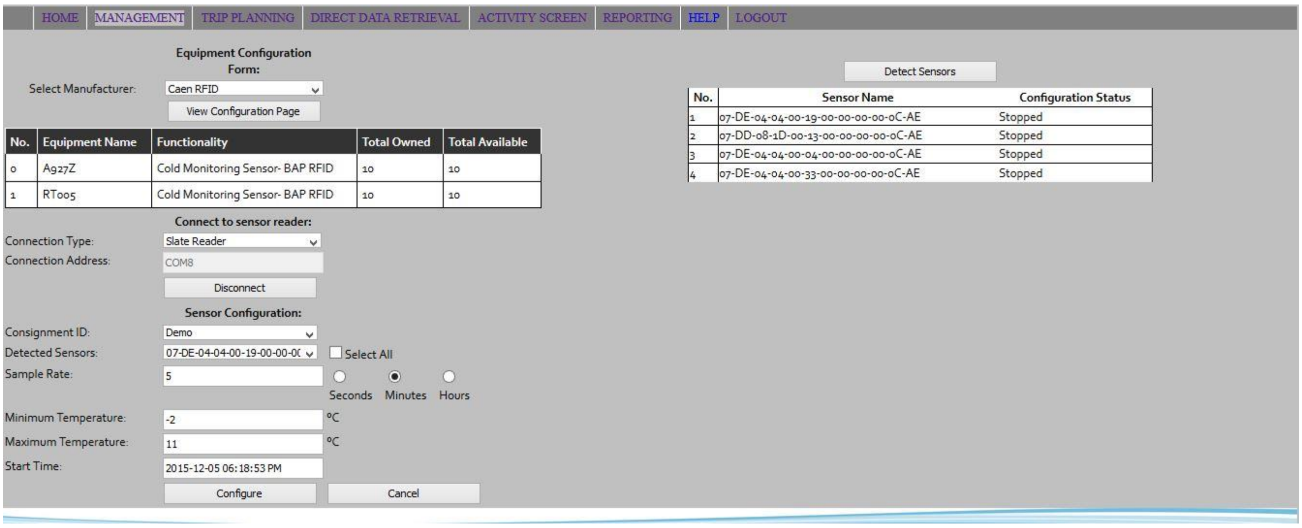


Figure 110: Sensors configuration page

When the user selects the detection button the software enquires from the user the amount of sensors chosen to be configured; the input method shown in Figure 112 is used. The protocol was written to ensure that the RFID sensors are indeed detected, the selected amount is then looped in a factor of five to ensure positive identification does indeed take place. The loop continues for this factor of time to ensure that a stable read is obtained for the sensors in view of the reader. If all the processes have been completed and not all the sensors as per the user's selection have been detected the software notifies the user and he/she may restart the process if required.

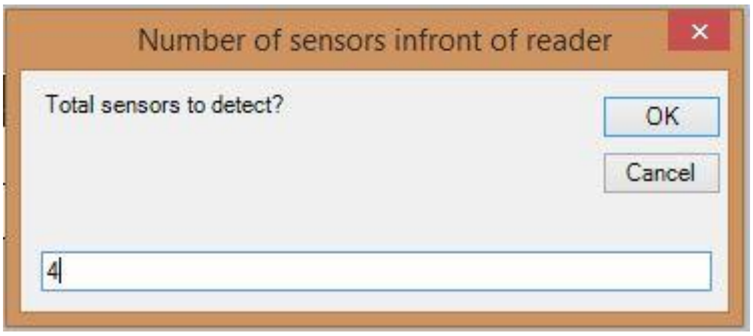


Figure 111: Amount of sensors to detect

Each sensor that has been detected is queried to supply its EPC number and the configuration status automatically. The EPC number is replaced by a custom name if the user has defined it in the management page. The configuration status has two states: either it is in the stopped configuration meaning the sensor has been reset, cleared of all data and logging disabled or in the configured state. In the second state, it indicates that the sensors have been successfully configured and data logging has been started.

Still on the configuration page depicted by Figure 111, after the sensors have been detected the user can change the selection of the consignment for which the sensors must be configured. The consignment selection is automatically set to the trip plan from which the user navigated to reach the configuration screen. The data for the temperature threshold is queried from the database as defined in the inventory or the quick plan functions. The sample rate for the BAP sensors is set as default to 5-minute intervals, but can be altered according to the users resolution needs. The start data for monitoring is retrieved from the system and can be altered if required, this value indicates the moment in time when the sensors will start the monitoring process.

The user may select to either configure a single sensor or all detected sensors with the configuration of the parameters defined. The software evaluates the type of sensor selected and determines the configuration protocol to use for the configuration process. As with many types of RFID and other sensors they have proprietary configuration methodologies due to factors such as the physical components and firmware of the devices.

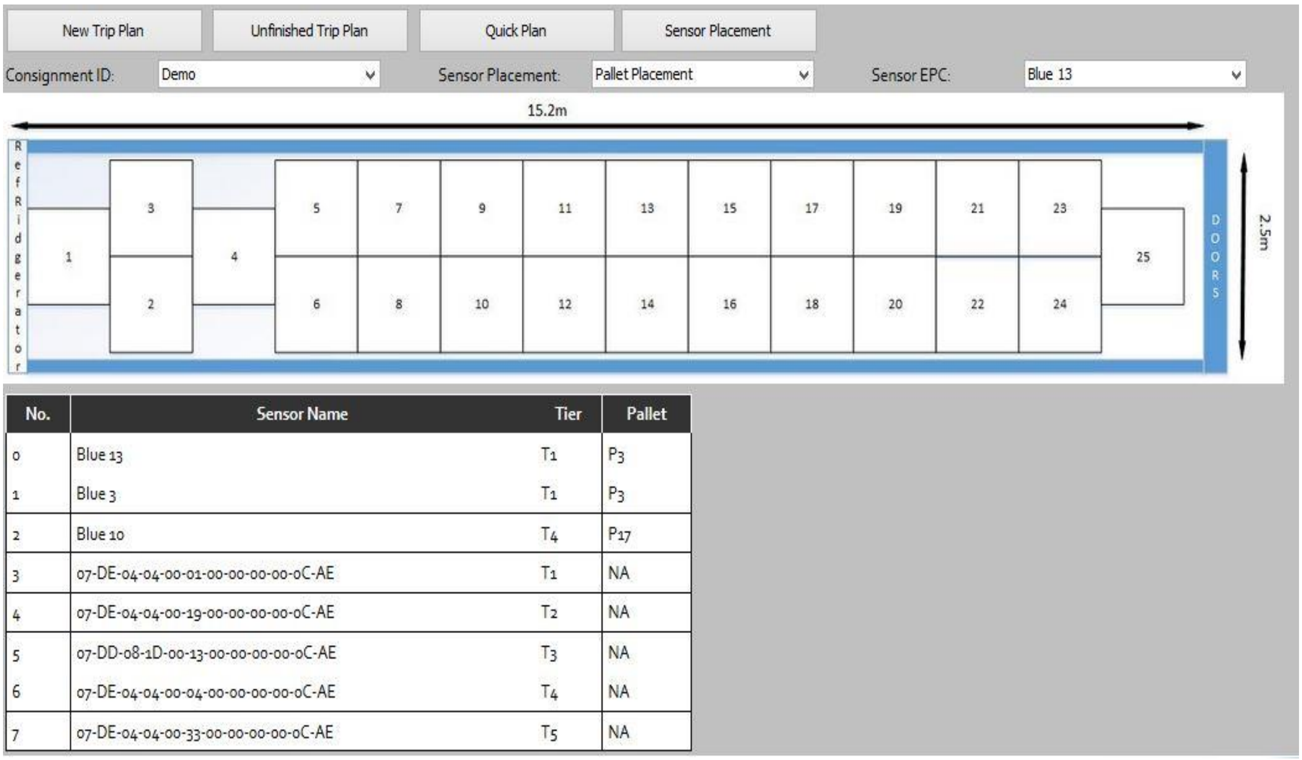
In the case of CAEN, the RT005 and AZ927 follows this paradigm. For this reason, a protocol runs for the specific device, developed using an SDK or API for the device, to configure the device correctly with the corresponding parameters. In order to ensure interoperability with various devices from other companies, this same method must be followed as is the case for the Piccolo system. Other systems such as the IKaya system offered by Ctrack does not provide the ability to directly interface in this manner and third party software is required to configure the sensors with the above parameters. Although the configuration methodologies differ from manufacturer to manufacturer and the devices they offer, the ability to utilize the data through the use of a database-driven software package such as the CCM software will still be available, thus making the interoperability of most devices possible.

Once the sensors have been configured with the parameters required to effectively monitor perishables goods, the software will guide the user to link the sensors to the consignment. This inquiry is depicted in Figure 113; if the user chooses to continue he is diverted to the sensor placement page.

Figure 112: Sensor Placement linking inquiry

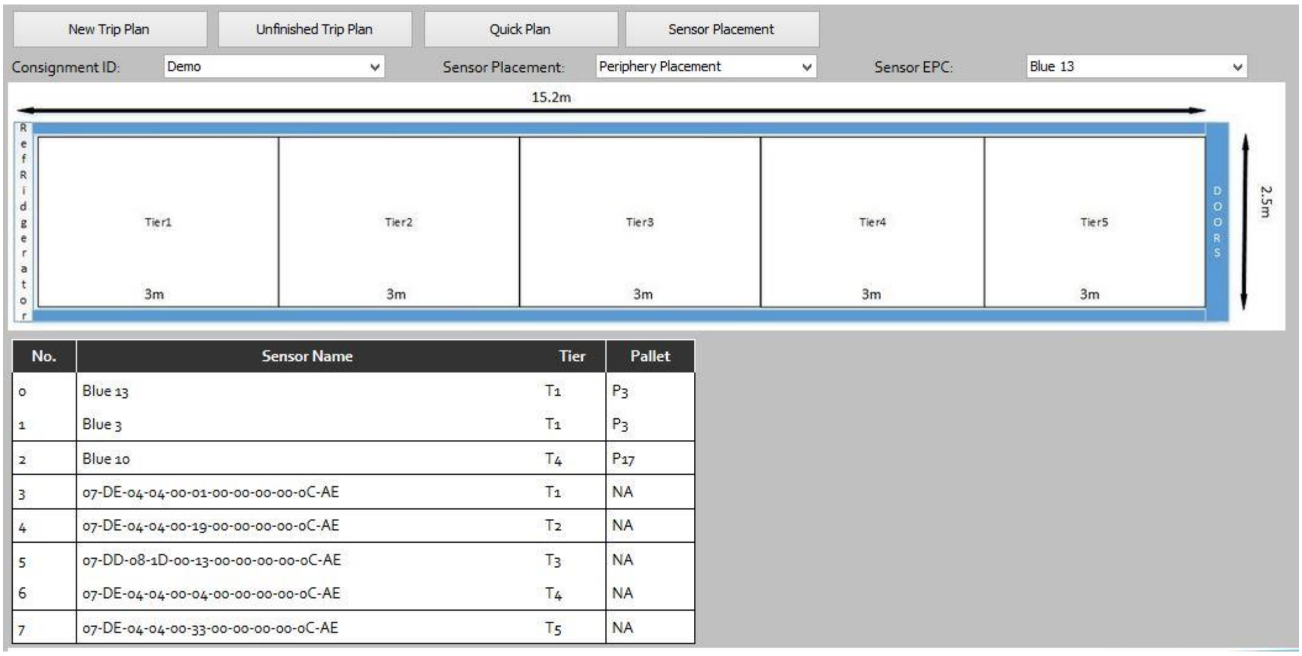
On the sensor placement page, the user is presented with three selection categories: Consignment selection to define to which consignment the goods must be linked; what configuration to use and the sensor to link to the chosen position. From the research conducted in the field and documented in chapter three, it has been seen that two scenarios exist for the usage of a sensor in a perishable consignment. The first is the scenario where a consignment is monitored on a per pallet basis by directly placing the sensor in/on the pallet or inside a pallet sock and secondly the scenario where the sensors are placed on the periphery of the trailer.

Figure 114 depicts a general configuration of pallets in a 15,2m reefer: 25 pallets are spaced in equal spacing over the length of the trailer with the exception of the area where the link is made to the horse. By selecting a sensor from the list of sensors configured for the trip and clicking on any pallet it links the sensor to the pallet. The trailer is further divided into five equal tiers over its length, and the section is added from the position of the pallet selected. Figure 115 depicts the operation for scenario 2 above where no sensor is placed at pallet level. By clicking on any tier of the image, the sensors are automatically linked to the consignment at that tier. When a link has been completed the position and information thereof is populated to the grid view beneath the reefer consignment configuration image.



No.	Sensor Name	Tier	Pallet
0	Blue 13	T1	P3
1	Blue 3	T1	P3
2	Blue 10	T4	P17
3	07-DE-04-04-00-01-00-00-00-00-0C-AE	T1	NA
4	07-DE-04-04-00-19-00-00-00-00-0C-AE	T2	NA
5	07-DD-08-1D-00-13-00-00-00-00-0C-AE	T3	NA
6	07-DE-04-04-00-04-00-00-00-00-0C-AE	T4	NA
7	07-DE-04-04-00-33-00-00-00-00-0C-AE	T5	NA

Figure 113: Pallet Placement Page



No.	Sensor Name	Tier	Pallet
0	Blue 13	T1	P3
1	Blue 3	T1	P3
2	Blue 10	T4	P17
3	07-DE-04-04-00-01-00-00-00-00-0C-AE	T1	NA
4	07-DE-04-04-00-19-00-00-00-00-0C-AE	T2	NA
5	07-DD-08-1D-00-13-00-00-00-00-0C-AE	T3	NA
6	07-DE-04-04-00-04-00-00-00-00-0C-AE	T4	NA
7	07-DE-04-04-00-33-00-00-00-00-0C-AE	T5	NA

Figure 114: Tier Placement Page

On completion of the sensor placement function, the software side of the operational process to plan a consignments delivery is completed. The next step is the physical placement of the sensors at the positions defined in this step. For passive monitoring devices such as the RT005 and AZ927 from CAEN, this will be the last contact until delivery or return to the DC.

The Wireless links and the Ikaya sensors, on the other hand, have no internal storage capability and data must be relayed in real time to the system via the reader and is displayed on the activity screen of the software platform. At this time, the real-time monitoring functionality for each of these devices are handled by separate software packages that were developed to evaluate its functionality in controlled environments. As the design is based on the specifications defined in Chapter 5 for each of the units, integration into the main CCM package can be achieved with limited further effort. For both these systems the real time information is populated to a google map, such as depicted in Figure 116 and data displayed on the side for manual verification by the user.

During the implementation evaluation, specifically for cross-border operations, it was seen that GSM network stability is a major issue as the network may be down for varying periods of time. In the case of the standard Ctrack configuration the data received from the IKaya base station as collected from the sensors may be lost during this period as the data needs to be streamed to the server as soon as it is received because the Ctrack unit's memory is used for the storage of GPS data during this period as per its design. On the other hand, the Piccolo Plus can store up to 5000 samples on its internal memory containing both temperature samples and GPS locations. The only factor would be a delay in the relay of data to the main system.

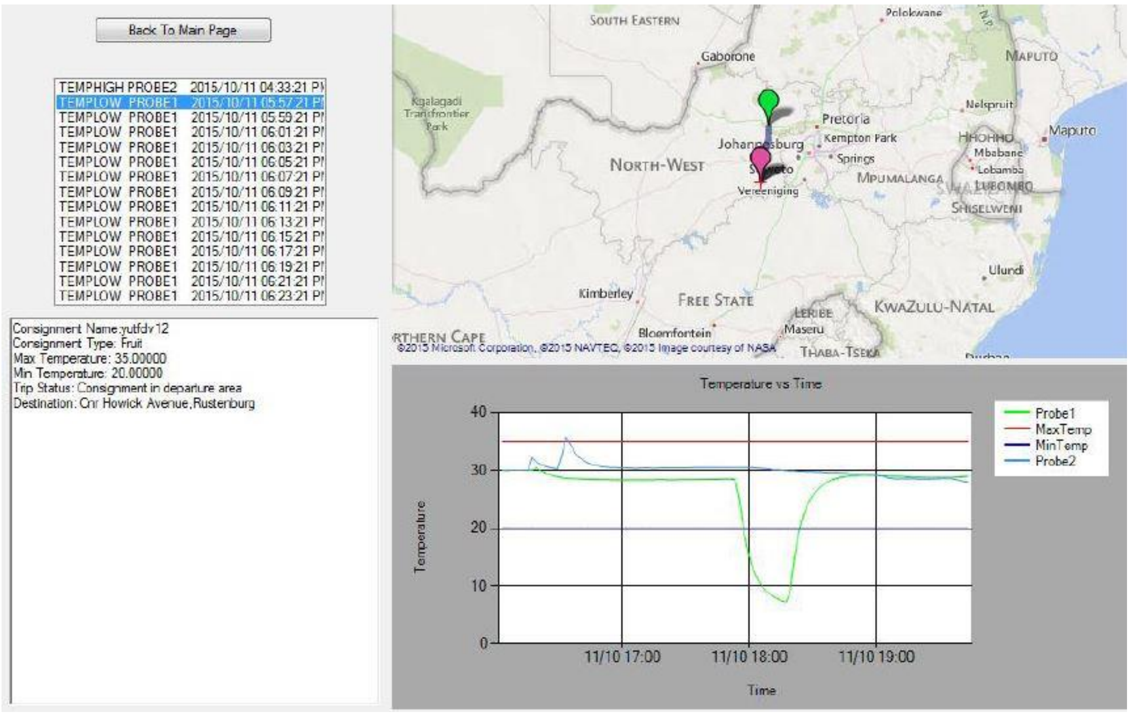


Figure 115: Real-time data retrieval screen

In the case of the passive data retrieval from sensors, as depicted in Figure 117, a similar approach is taken to that defined for the configuration functionality. The reader and sensor detection methodology are the same for both processes.

When opening the page for direct data retrieval, the user is required to select the consignment for which the information needs to be acquired. After the selection has been made the list of corresponding sensor placements in the consignment is displayed on the page. When the reader detects a sensor during the data retrieval process, preliminary data is read from the tags. The data displayed includes the following: whether a limit was triggered; the number of sensors; the sample rate and the final temperature value. The user finally has the ability to read one or all the detected sensors, the data is then populated to a spline graph where the maximum and minimum temperature is indicated. The graph provides a visualization of the temperatures vs. time for all samples.

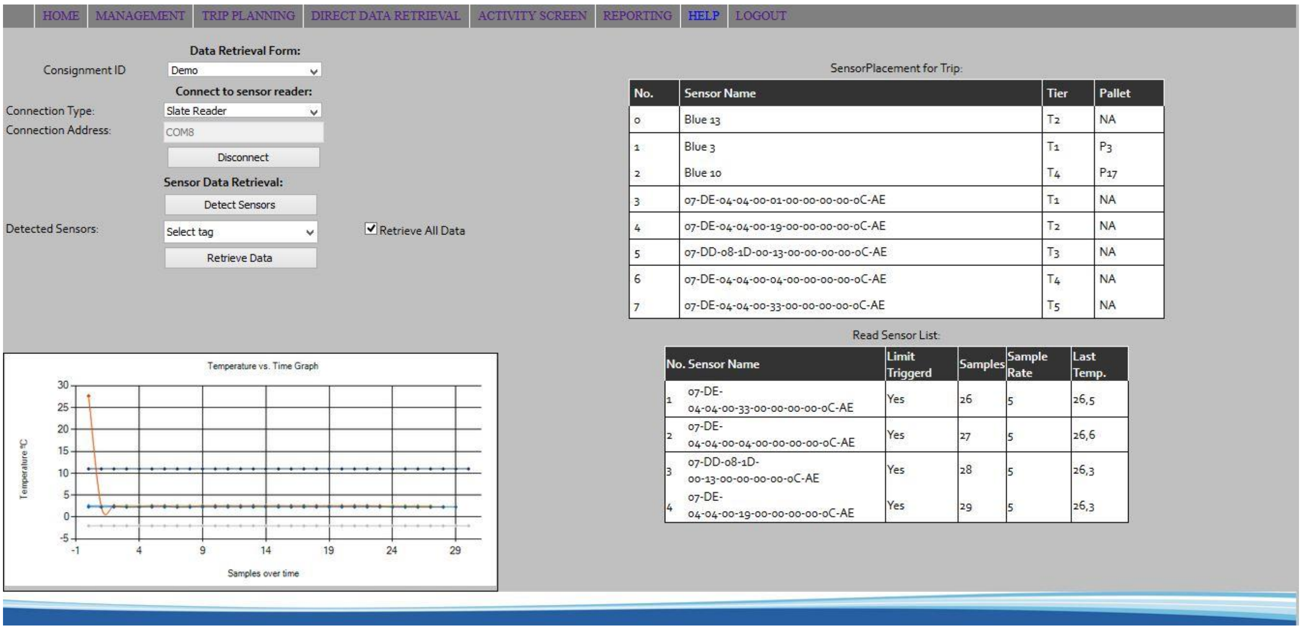


Figure 116: Data Retrieval Page

After the reading process the software analyses the data that was retrieved. Firstly it calculates the effective mean kinetic temperature for each tier of the trailer. Using this value the average mean kinetic temperature for the entire consignment is calculated. Finally using this MKT value and the parameters defined in the inventory page of the consignment the predicted remaining shelf life at delivery is calculated. The data is then stored to an analysis table in the database.

The data collected from the analysis and that which were defined in the trip planning phase is populated to a Microsoft report viewer that allows the user to browse and save to PDF general reports as depicted in Figure 118 below. In the case where a quick plan was used and not all fields were defined, the report will indicate NA fields in these areas.

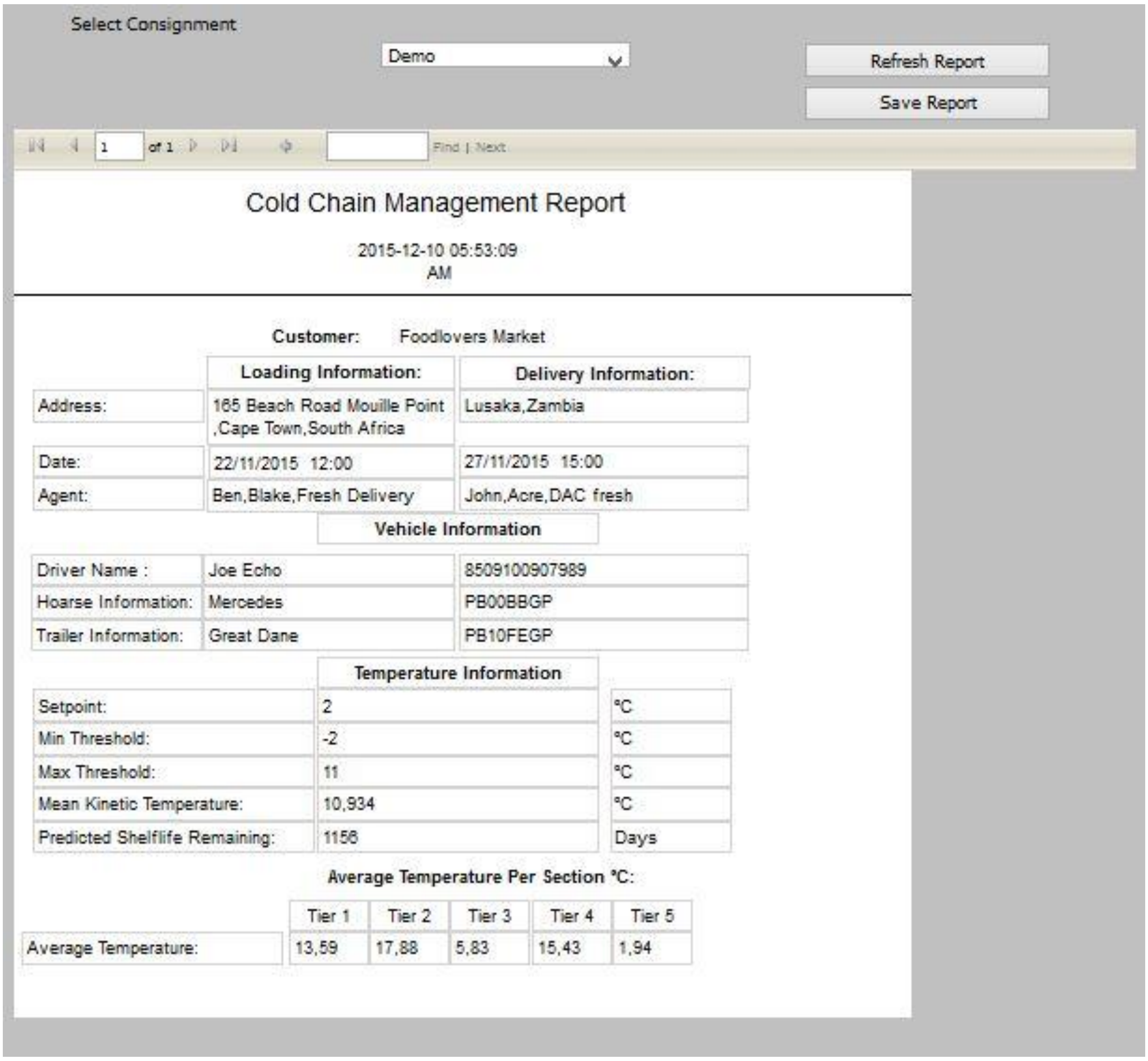


Figure 117: Reporting Page

The software platform as discussed in this section represents a solution to the problem of effective cold chain management using RFID-based devices. By using the design presented in Chapter 5, the software provides a logical structure to aid the LSP in the CCM management process. It was seen that the software provides five essential functions to the user:

1. The first is the management of information stored in the database reflecting the operational elements available to the LSP.
2. The second is the ability to easily use this information and resources in constructing a trip plan for a client by applying CCM standards to deliver a consignment in the best condition.
3. The third is the configuration and connection of sensors to a consignment using the parameters defined in the trip plan.

4. The fourth is the background analysis functions that use the samples gathered during the trip to provide a logical result that is usable and relays information on the performance of the cold chain.
5. The final function is simplistic reporting to present the details of the trip in a logical manner, but only presenting the necessary information as not to overwhelm the user with irrelevant complex data.

The software design was entered into the 2015 MTN mind to machine challenge as a solution in the area of logistics. The design was judged on elements of functionality and its ability solve the problem identified in the industry, in this case, the improvement of cold chain logistics to result in fewer losses and better quality of goods using RFID sensors as a tool. The software solution was nominated by a panel of five judges from industry as one of the five best solutions meeting this criterion from the 45 solutions entered into the competition.

The software was further reviewed by an industry professional from Professional Risk Solutions situated in Johannesburg. On this review the functionality was evaluated in general and its suitability for implementation in the field of cold chain logistics along with its applicability for use along with the thermal protective pallet socks. From this review, it was evident that the functionality incorporated is indeed essential to the operation of cold chain logistics, with a logical flow to aid in the improvement of CCM processes. The preferred systems for ideal operation will be those of Ctrack and Wireless links as these provide real-time monitoring to which an LSP or client can take immediate action.

The final evaluation of the implementation of the software solution as a tool for improved CCM was conducted at the logistics division of Lonrho. In this evaluation the route depicted in Figure 4 was followed. It was observed that the real-time systems provided a considerable benefit above the passive monitoring system. Although the real-time systems such as Ikaya and Piccolo provided greater visibility in the field, these systems experienced significant difficulty in cross-border monitoring due to network coverage problems.

In this case, both MTN and Vodacom were evaluated by using them on the same cross border route. This field application indicated that MTN provided on average a more dependable coverage capability. MTN compared to Vodacom provided 5% more coverage over the total monitoring period. This figure was obtained by comparing the network during the trips accompanied between JHB and Zambia during 2014 and 2015. The consignment was visible 60% of the time over the entire route using MTN, this directly compares to the results discussed in [21]. This may be improved by making use of satellite communication rather than GSM/GPRS; this aspect of system operation was not the focus of this study but is mentioned here as a possible improvement. When looking at the implementation capability of the software using one of the three systems evaluated it was seen that the core functionality of the software does indeed function correctly, but further detail such as points of interest along the route, better alarming mechanisms and more detailed reports would greatly benefit the CCM process.

7.3 Conclusion

The purpose of this chapter was the investigation into the implementation of a software design using VB.Net, by implementing a web forms approach with an object oriented design methodology. The implementation presents a web application that provides the user with a tool to manage cold chain logistics in the industrial environment. The software aids the user to manage resources, plan trips, configure equipment, analyse data and create reports relaying the data in a structured meaningful manner. The implementation was evaluated in different formats, with an added field evaluation to gauge the usability of the design as a solution for improved CCM.

It was seen that the use of the software indeed can provides the benefit of planning capabilities for CCM. It was found that some improvements could be made on the functionality and reporting capabilities to further improve the designs applicability in the industry. During this evaluation, it becomes evident that the Ctrack unit provided the best solution when focusing on readability between the base station and the sensors followed by the Piccolo tags. The BAP tags were largely influenced by the environment and readability was compromised in some instances. The evaluation further indicated that real-time data transfer for an international route is limited due to fluctuating network coverage that delivers only a 60% overall visibility on the route. The network coverage is improved for local operation in the country.

The chapter indicated that the implementation of an interpretable RFID-based CCM platform is indeed a functional possibility to aid in the improvement of cold chain logistics and the decrease of perishable losses.

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Chapter 8: Cost Benefit Analysis

8.1 Introduction

The implementation evaluation presented in the previous chapter showed that the software and the RFID systems can be useful in the improvement of cold chain logistics. In order to quantify the true benefit that the implementation of the system will have for the end-user and the losses experienced in the industry, it is necessary to perform a cost benefit analysis (CBA). In this chapter, the benefit of the installation of different types of RFID system will be evaluated with regard to their cost and relative effect. The percentages used in the calculating completed this chapter has been determined from research completed in all the preceding chapters. The results of the calculations will be used to evaluate the expected improvement and reduction of loss in perishables and the internal rate of return that a company can experience due to the effective use and implementation of cold chain monitoring systems.

8.2 Cold chain operational values

The research done in the preceding chapters various aspects of the cold chain has been evaluated. During this evaluation certain values was obtained for the value of a consignment and the losses that can occur during the transportation of such a consignment. In this section the general value of a consignment will be calculated to numerically indicate wat value of a consignment is lost and how it will affect the parties involved in the cold chain.

8.2.1 The calculated cost of a consignment

The research indicated that for LSP that transport fruit and vegetables cross border and locally the consignment in general consist of a mixture of these perishables. In order to couple a value to such a consignment a sample of items has been taken to approximate the average cost thereof. This sample is listed in Table 56 below.

In this table the amount of packaging units for each perishable that can be loaded per pallet has been calculated. The value of a consignment consisting of 25 pallets of each perishable is then calculated based on the pricing for the goods as listed on the Johannesburg market exchange in January 2016 [62]. This is the maximum amount of pallets a 15,2m reefer has the ability to carry as previously discussed in this document.

Table 54: Perishable consignment values

Description	Length (m)	Width (m)	Height (m)	Total Units per pallet	Value per Unit	Value per consignment
0,5 Kg Strawberry Punnet	0.015	0.12	0.04	600	R 14.91	R 223,575.00
Apple Carton(10 bags*1Kg)	0.6	0.4	0.28	48	R 85.70	R 102,840.00
Tomatoe Carton(3kg)	0.27	0.27	0.25	126	R 39.99	R 125,968.50
Pineapples(10kg)	0.47	0.39	0.19	66	R 81.20	R 133,980.00
Banana Carton (18kg)	0.47	0.39	0.19	66	R 85.32	R 140, 778.00
Baby Marrows (4 Kg)	0.27	0.27	0.25	126	R 57.24	R 180,306.00
Mango Carton(4kg)	0.27	0.27	0.25	126	R 47.04	R 148,176.00
					Pallets per consign.	25
					Average value p. consign.	R 150,803.36

The average value for the type of perishable goods per consignment has been found to be R150,803.36 but is directly influenced by the type, quantity and broker used for the purchase of the goods. Using this information and estimated loss figures as presented in Chapter 3 the estimated average losses were calculated as displayed in Table 57 below. Using these loss percentages it is seen that 17% of a consignment is lost or irreparably damaged over the supply chain. Although the producer, LSP and vendor has the same loss percentages, the LSP is taken as the weakest point in the chain. This is because it offers the largest vulnerability to temperature fluctuation and potential for improvement between all the links in the supply chain.

Using the parameters that one consignment is moved from the producer through the chain to the vendor per week, such as the case may be for consignments from JHB to Zambia. Furthermore that each truck is only operational for 85% of the time due to maintenance and repair schedules. It is calculated from these set parameters that 3,6 consignments can be transported a month, for 12 months of the year, thus 37,2 consignments is moved in this manner annually.

8.2.2 The mean loss experienced in the cold chain

Using this information the value of the losses experienced in perishables being transported along the chain could be calculated. This calculation is included in this sub section and serves as a measure to determine which area in the cold chain is the most vulnerable and would receive the most benefit through the implementation of a CCM solution.

If an average consignment transported in a 15,2m reefer, conservatively calculated, is R150,803.36 this comes to R 280,171.10 lost only from the LSP link in the chain per year. The overall loss for the 48 consignments being moved from the producer to the vendor comes to R 952,581.74, this large amount indicates the importance of improvement to be made in CCM. In the research presented in Chapter 3 it was seen that on average a producer may experience a 5% loss, a DC 2% , a LSP 5% and the Vendor self an additional 5% loss due to temperature degradation. These values is now used to calculated the losses experienced by each link in the chain using the calculated average value per consignments as previously calculated. This loss possible loss is listed in Table 57 which follow.

Table 55: Cold Chain Losses for one truck over the supply chain

	Producer	**DC**	**LSP**	**Vendor**
Percentage of cargo lost per participant	5,0%	2,0%	5,0%	5,0%
Number of consignment per month	3,6	3,6	3,6	3,6
Number of consignment per annum	37,2	37,2	37,2	37,2
Value of typical cold consignment	R 150 803,36	R 150 803,36	R 150 803,36	R 150 803,36
Total value of cargo lost per consignment	R 7 540,17	R 3 016,07	R 7 540,17	R 7 540,17
Total value of cargo lost per annum	R 280 171,10	R 112 068,44	R 280 171,10	R 280 171,10
Total loss of cargo per month over chain	R 93 390,37			
Total loss of cargo per annum over chain	R 952 581,74			

The values calculated in Table 57 is now applied to two kinds of LSP that are typically found in the industry. The first is a small LSP with 40 trucks, one DC, a supplier and multiple customers.

The second is for a medium LSP with 300 trucks, one DC, multiple suppliers and multiple customers. The losses experienced by these two scenarios for a full operational load, on a per month and per year basis is listed in Table 58 below. LSP's larger than the medium LSP has been excluded from this evaluation to keep it as simple as possible and because the two included LSP's provide the necessary information to extrapolate the results for LSPs beyond this evaluation scope.

Table 56: Losses experienced over the cold chain per annum

Scenarios	Losses per month	Losses per annum
Small LSP(40 trucks)	R 1 098 710,19	R 11 206 843,98
Medium LSP (300 trucks)	R 8 240 326,46	R 84 051 329,86

The values indicated in Table 58 allocates a rand value to losses experienced over the supply chain that reflects on the quality and shelf life of goods that reaches the consumer and not only absolute loss of goods. As to whom carries the brunt of the losses in the supply chain: this would depend on a couple of factors. The first is if a quality of delivered goods service level agreement (SLA) exists between the LSP and Vendor.

If it is stipulated that the goods must be delivered at a specific temperature and quality and consignment does not meet this stipulation the LSP is responsible for the loss. In the case where no such agreement exist the vendor would carry this loss if it is not able to sell the goods during the acceptable quality period of the goods. In the case where the goods are sold within this period the consumer will carry the loss in terms of diminished quality and shortened shelf life. But if a consumer experiences poor quality of goods purchased from a vendor they would not return to it for future purchases.

This again places the loss back on the vendors' shoulders. When a vendor realises that the quality of goods delivered by a specific LSP results in it experiencing unacceptable losses it would not make further use of the LSP's services. This will cause loss of business to the LSP. The same is true for the LSP with respect to the producer of the perishable goods, this include farmers of produce and other perishable goods. It can therefore be seen that the LSP would effectively carry most of these losses either directly or indirectly. It is thus in the interest of the LSP to reduce these losses to the minimum to ensure continued business from retailers and thus ensuring its future income.

8.3 The cost to company

The possible improvement in losses as seen from Chapter 2 and Chapter 4 can be achieved by either one of two types of systems: passive sensors systems such as data loggers and BAP sensors or real-time sensors such as active RFID and GSM/GPRS sensors. In the case of the latter, it is important to include the operational data cost to relay the data sampled through the GSM/GPRS network.

8.3.1 Cellular communication costs

One of the most important costs that needs to be analysed is the data transmission costs. To accomplish this valuation, the data and SMS costs of Vodacom, MTN and Cell C were obtained from their websites. The effective prepaid cost using these networks in different countries adjacent to South Africa is listed in Table 59 below.

Table 57: Mobile Data Cost (Rand)

	Vodacom		MTN		Cell C	
Countries	1 MB of data	Per message cost	1 MB of data	Per message cost	1 MB of data	Per message cost
South Africa	2	0.8	1.2	0.8	0.15	0.3
Botswana	51.2	2.75	2.5	2	149.5	3.5
Mozambique	51.2	2.75	150	5	114.53	3.55
Namibia	17.5	2.75	30	2.5	71.25	1.15
Zambia	17.5	2.75	30	7.5	20.4	1.55
Zimbabwe	51.2	2.75	10	7.5	156.04	3.14

Using the data in Table 59 the average data cost for the route depicted in Figure 4 could be calculated using the following parameters. An average period of two days is taken as time spent in each country on the route. An additional period of 1 day for departure and return to South Africa is also included. This parameters indicate an average return trip duration of 7days for a route such as defined in Figure 4 and depends on the route conditions and time of year. Using these parameters the data cost has been calculated for a transmission rate of once every 30 min for a total of 48 transmissions a day. A 35% probability that messages could be send during unscheduled periods if a temperature fluctuation occurs has been added to the amount of transmissions. This percentage was determined using the data collected and analysed during the field research conducted for this study.

The result for calculation of the data transmission costs is listed in Table 60; this table indicates that Cell C is the cheapest network, followed by Vodacom and then MTN. As found from the testing done in the field and network coverage statistics it indicated that MTN has the most visibility for the listed African countries followed by Vodacom and then Cell C. Please note that the calculation exclude any communication with the driver from the LSP when a notification is received that the temperature is out of the set temperature range. The method of handling the occurrence of a persisting temperature fluctuation will depend upon the internal process in place for the specific LSP and is not included in the calculations performed in this section.

The cost indicated in table 60 has been calculated for the operation of systems with a GSM communication unit, this is more expensive than the use of the GPRS system. When a greater percentage of dependability is required it is necessary to use the GSM capability of the systems because GPRS coverage is not ensured in all areas of foreign countries and rural areas. Thus the above is the worst case scenario relative to the operational data costs of each GSM system.

Table 58: Operational Data Costs Using SMS

	Values		
Transmission period (min)	30		
Total Transmissions per day	48		
	Vodacom	MTN	Cell C
Botswana transmission cost for 2 day period	R 264.00	R 192.00	R 336.00
Zambia transmission cost for 2 day period	R 264.00	R 264.00	R 148.80
Zimbabwe transmission cost for 2 day period	R 264.00	R 720.00	R 301.44
South Africa transmission cost for 1 day period	R 38.40	R 57.60	R 38.40
Total SMS cost per trip	R 830.40	R 1,233.60	R 824.64
Total Cost with 35% emergency messages	R 1,121.04	R 1,665.36	R 1,113.26

The operation sampling cost for this manner of data transmission for the three networks is depicted in Figure 119 below. It shows how cost varies between a sample rate of between 5 min and 180 min. This graphs indicates that Vodacom offers the least expensive overall data cost whilst MTN is only slightly more expensive than Cell C.

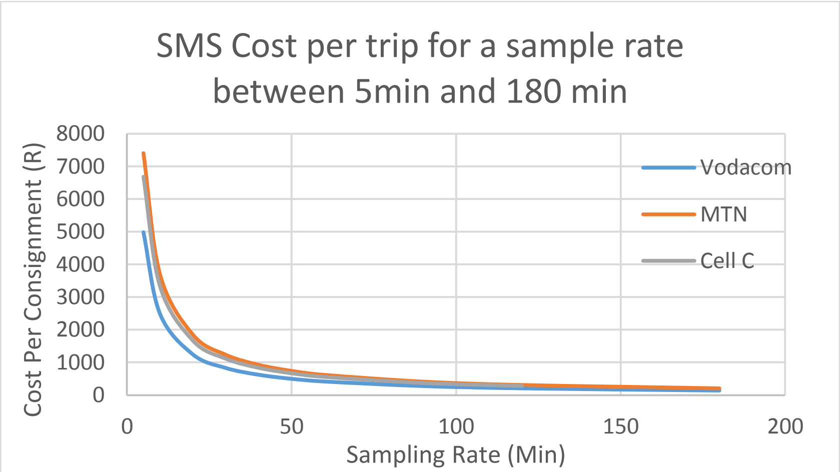

Figure 118: Relative transmission cost at different sampling rates

8.3.2 Net present value for RFID solution implementation.

It is important to compare the variation in sample rate to the net present value of the implementation of a system using the GSM network. This comparison is depicted in Figure 120, where the NPV is calculated over a 5 year implementation of the BAP (CAEN), active RFID (Piccolo) and long range active RFID (CTrack) systems using the Vodacom network during operation. Using the data collected during the field evaluations it was found that CAEN presented could provide a derived improvement of 10%, Piccolo 20% and CTrack 25% improvement in loss.

As indicated by these percentages only a fraction of improvement is accomplished by the implementation of the monitoring equipment. This fractional improvement is due to the fact that not all loss can be deterred by only reporting a persisting temperature fluctuation. Although by reporting the temperature issue action can be taken to minimise the risk of damage. External factor such as the reefer's cooling unit not functioning properly, breakdown occurring and the improper handling of the perishables in preceding links in the cold chain ext. is excluded from this analysis.

These aspects although important fall beyond the scope of this study and the main purpose of the CCM systems which is to provide a LSP or other party with the tools to have greater visibility over the cold chain for the purpose of management. By providing this visibility through real time data transmission when an error occur the user has the ability to rectify the issue before irreparable damage has been done. By providing this visibility the fractional improvement as mentioned before can be accomplished and all other factors not included in this analysis result in the fraction that could not be improved by the implementation of this system.

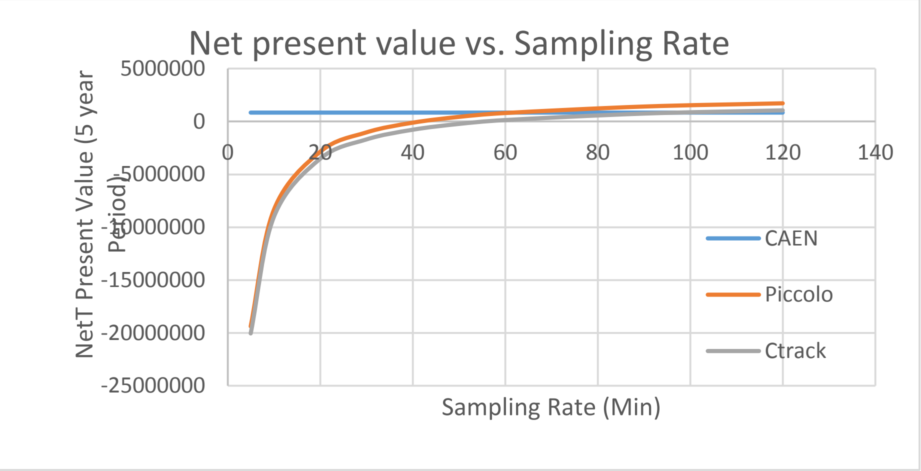

Figure 119: Net present value after 5 years at different sample rates

The graphs in Figure 120 indicate that a 40 min sampling rate for the active RFID system and a 50min sampling rate for the long range active RFID systems, using the before mentioned parameters, would result in a net present value of 0 after 5 years. It is clear from this that the proportional data cost in using active systems is an important aspect when comparing the system along with its installation costs and maintenance costs.

8.3.3 Operational cost analysis

The general attributes for further calculations for both the small and medium sized LSP's are listed in Table 61 that follows.

Table 59: Operational Attributes

	Values
Life expectancy of equipment (years)	2
Number of equipped depots	2
Trucks and trailers: Small	40
Trucks and trailers: Medium	300
Annual maintenance as % of capital outlay	20%

Using the parameters above the implementation cost for the Caen, Piccolo and Ctrack units are calculated as stipulated in the cost analyses in Chapter 4. The calculation of the capital investment required for each of the systems is indicated in Table 62. In the case of the Caen system no installation is made on the trucks themselves but a minimum of 2 readers is installed between the depots in the case of a 40 truck fleet and a minimum of 6 reader between the depots for a 300 truck fleet.

Table 60: Capital Cost of systems

	Systems		
	Caen (DC Reader)	Piccolo (On Truck Reader)	Ctrack (On Truck Reader)
Cost of computer per depot	R 10 000,00	R 10 000,00	R 10 000,00
Cost of total equipment per depot	R 19 360,00	R 10 000,00	R 10 000,00
Total cost of depot equipment	R 38 720,00	R 20 000,00	R 20 000,00
Cost to install reader equipment in truck	R 0,00	R 6 320,00	R 10 600,00
Cost per tag	R 750,00	R 765,00	R 1 700,00
Number of tags per truck	5	5	5
Total capital outlay for tags	R 150 000,00	R 153 000,00	R 340 000,00
Cost per truck	R 3 750,00	R 10 145,00	R 19 100,00
LSP:40 Vehicles			
Cost for fleet installation	R 150 000,00	R 405 800,00	R 764 000,00
Total capital outlay for equipment	R 188 720,00	R 425 800,00	R 784 000,00
Annual maintenance cost	R 37 744,00	R 85 160,00	R 156 800,00
Operational Data Cost per Month for fleet	R 0,00	R 98 010,93	R 98 010,93
Operational Data Cost per Annum for fleet	R 0,00	R 1 176 131,11	R 1 176 131,11
LSP:300 Vehicles			
Cost for fleet installation	R 1 125 000,00	R 3 043 500,00	R 5 730 000,00
Total capital outlay for equipment	R 1 241 160,00	R 3 103 500,00	R 5 790 000,00
Annual maintenance cost	R 248 232,00	R 620 700,00	R 1 158 000,00
Operational Data Cost per Month for fleet	R 0,00	R 735 081,94	R 735 081,94
Operational Data Cost per Annum for fleet	R 0,00	R 8 820 983,31	R 8 820 983,31

The calculation of the average income and losses for an LSP with 40 operating vehicles and 300 operating vehicles that are in operation for 85% of the year is listed in Table 63. With a consignment delivery that has an average duration of 7 days, a truck can complete 37.2 such trips per annum or 3.6 trips per month. If the average value of a consignment is still R 150,803.36 and taking into account that 5% is lost by the LSP, the total value of goods delivered to the consumer for the one vehicle is R 5,323,250,89 that results in R 280,171.10 of goods lost per year, this information is depicted in Table 47. This is clearly a lot of value to discard due to improper management of the cold chain.

Table 61: Income and loss calculation per vehicle

Attributes	Values
Average duration of trip (days)	7
Fraction of year truck active	0.85
Number of trips per month	3.64
Number of trips per annum	37.16
Typical Income for cross border transportation	R 52,500
Value of typical cold consignment with losses	R 150,803.36
Total turnaround per vehicle including losses per annum	R 5 323 250,89
Total losses per annum	R 280 171,10

Table 62: LSP Income and losses per annum

Per Annum	LSP Size	
Total number of trucks	40	300
Nett cash flow	R 525,583.26	R 3,992,210.41
Total annual value of goods with losses	R 5,323,250.79	R 5,323,250.79
Total loss per annum	R 11,206,843.98	R 84,051,329.86

Using the value of 5% loss experienced by the LSP as indicated in Table 57, gained from the research documented in chapter 3 the improvement can now be calculated. The application of mobile technologies according to the type of visibility it provide has a specific positive effect on the loss. Firstly the passive monitoring provides the LSP with visibility of the whole trip, but this data is only collected at the start and end point of a trip. This leads to reduction of loss because there is now accountability for the entire consignment. Thus leading to better practice being implemented on the exact area where the most loss is experienced. The probable improvement to loss that can be expected due to the passive implementation and its additional visibility provided is approximately 2%.

Secondly active systems which provides real time information from a consignment, allows immediate response to temperature fluctuation whilst still providing the same benefits of passive systems. The main defecate of this type of system is its dependence on network coverage with the acceptation of satellite enabled not included in this study. It has been seen that a mobile coverage of 65% of the time can be expected for a trip from SA to Zambia. This leaves a 35% duration, not necessarily a consecutive time period, during which the consignment is not monitored in real time and possible losses may occur.

Taking all of this factors into account and the functionality it provides as seen from Chapter 4, an approximate improvement of 5% to the loss can be expected.

In order to verify the above remarks on the expected improvement that can be obtained through the implementation of RFID equipment further comparison is required. It is required to determine at what approximate percentage the type of RFID equipment would provide a net positive improvement to cold chain into which it has been implemented. This comparison is depicted in Figure 121 below, in this graph the net improvement is calculated for various possible improvements to perishable goods of a consignment transported by the LSP.

In this comparison a LSP is used that experience a 5% loss of cargo per trip for each vehicle where 10% of the applied tags is lost per consignment. An annual equipment maintenance cost of 20% of the capital layout of the applied system is also included in the calculation of the possible net improvement. In order to obtain a positive net improvement by the implementation of the three types of RFID systems as represented by the CAEN, Piccolo and Ctrack systems improvements of more than 5.31% , 16.33% and 23.17% respectively are required for each solution. Thus the 10%, 20% and 25% improvement in losses of each system as found in the evaluation of the specification and their implementation will result in a positive net capital improvement in the loss experienced in implemented cold chain.

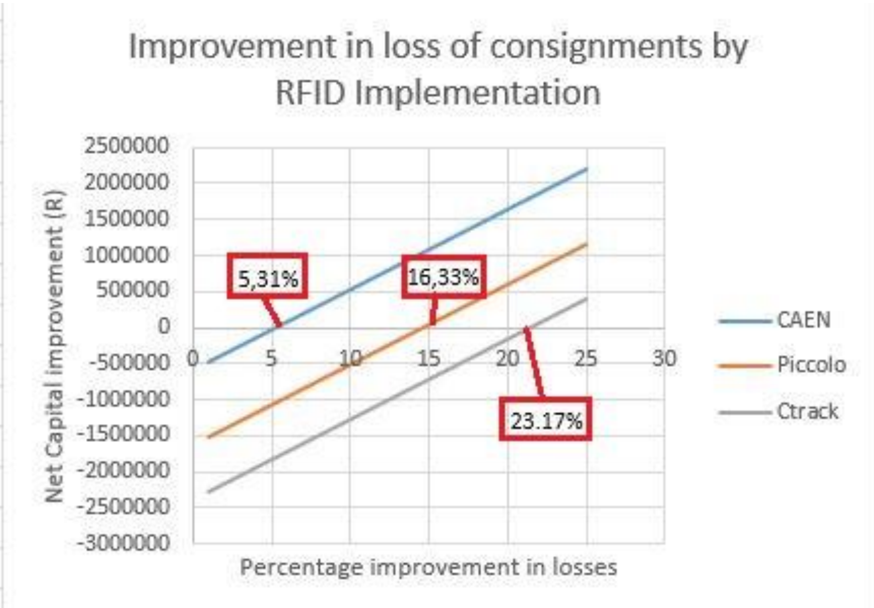

Figure 120: Net improvement in losses vs. percentile RFID implementation effect for LSP

This improvement percentages where thus determined by analysing the physical implementation and correlating it with the data collected on the evaluation of the equipment in both the controlled and field application. The value of this decrease is listed in Table 64 for both scenarios: when all the sensors are retrieved and when 50% of the sensors were lost over the year. The average value of the goods delivered with the loss of 50% of sensors is also listed here.

The total turnover listed was further calculated by using the above percentages along with that listed in Table 65. Each column represents a system from the three selected suppliers that results in a possible amount of improvement delivered by type of technology represented.

This percentage improvement is an approximation from the results obtained during the evaluation. It indicates that using passive technologies would improve the loss by a 10% whilst real time monitoring could result in an improvement in 20% and 25% of the possible loss experienced, for the Piccolo and CTrack irrespectively.

Table 63: Improvement on losses

	Values		
LSP:40 Vehicles			
	Caen	Piccollo	Ctrack
Percentage of improvement in losses	10,00%	20,00%	25,00%
Reduction in losses per annum	R 1 120 684,40	R 2 241 368,80	R 2 801 711,00
Net improvement per annum	R 525 583,26	R 411 573,40	R 205 437,03
LSP: 300 Vehicles			
Percentage of improvement in losses	10,00%	20,00%	25,00%
Reduction in losses per annum	R 8 405 132,99	R 16 810 265,97	R 21 012 832,47
Net improvement per annum	R 3 976 722,41	R 3 104 800,52	R 1 558 777,72

The table above has been calculated for a single vehicle but it is important to calculate this values relative to the LSP implementations for the small and medium implementation discussed. This calculation is shown in Table 66 below.

Table 64: LSP implementation costs

LSP:40 Vehicles			
	Caen	Piccollo	Ctrack
	15,00%	25,00%	25,00%
Total return	R 6 199 706,39	R 4 731 367,37	R 4 373 167,37
Total return with 50% sensor	R 5 449 706,39	R 3 966 367,37	R 2 673 167,37
Total turnover with monitoring	R 184 759 210,10	R 183 275 871,08	R 181 982 671,08
LSP: 300 Vehicles			
	Caen	Piccollo	Ctrack
	15,00%	25,00%	25,00%
Total return	R 46 497 797,92	R 35 485 255,26	R 32 798 755,26
Total return with 50% sensor	R 40 872 797,92	R 29 747 755,26	R 20 048 755,26
Total turnover with monitoring	R 1 385 694 075,72	R 1 374 569 033,06	R 1 364 870 033,06

The cost-benefits analyses conducted in this section determined the overall losses experienced and indicated firstly that the LSP is the link that is the most vulnerable to high amounts of loss. The amount of loss in the chain estimated at R952,581.74 per annum per consignment where the LSP contributes to R280,171,10 of this amount. Three different types of RFID solutions for cold chain improvement were analysed; this included the BAP RFID from CAEN, the 2.4 GHZ active RFID solution from Wireless links and the 433MHz solution from Ctrack and IKaya. From a purely financial point of view, the Caen solution provided the best solution, with the Piccolo system just slightly better than the Ctrack unit. It is clear that in terms of cost versus benefit the RFID solution provides an effective improvement and financial gain to merit its deployment for the improvement of cold chain logistics.

8.4 Chapter Summary

The purpose of this chapter was to evaluate and discuss the financial implication of the implementation of cold chain monitoring equipment. The aspects discussed in this chapter validated the feasibility of RFID to have a positive influence on the quality of goods whilst decreasing the losses experienced by the LSP.

A cost benefit analysis was conducted on the operational environment; in the analysis the overall loss in perishable goods was calculated and it was seen that the LSP was the most vulnerable of all players in the value chain. The GSM data cost for different networks was also calculated indicating MTN as the overall best network from a communication reliability perspective but also the most expensive. In the evaluation Vodacom was used as the selected network because of its dependability and relatively competitive financial data cost for a CCM operation.

The improvement in loss and the effect on the LSP’s income was also discussed, it showed that the real-time system provides a greater improvement than the passive sensors. On the calculation of ROI, the rate of return on the investment, on the other hand, indicated that the BAP system would repay its value at a faster tempo than the real-time sensors as it avoids the capital cost of equipment installed on trucks as well as mobile data costs for operation.

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Chapter 9: Conclusion and recommendation

9.1 Chapter Overview

This chapter is the final chapter of this dissertation on the investigation into the use of RFID for the management of cold chain logistics. In this chapter we will discuss the objectives of this study and indicate to what extent the requirements set thereby have been met. An overview will be provided of the research conducted, the designs made, the implementations and the results obtained. Finally some recommendations will be presented given the results of the study and an answer will be given to the main question posed: can off the shelf RFID systems be used to improve cold chain logistics and if so how will it be able to combine systems from multiple vendors in an interoperable manner to aid in real-time temperature monitoring, consignment traceability and accountability for losses that are incurred.

9.2 The Research Objectives

9.2.1 Primary objectives

This study had multiple objectives that posed questions in order to model all aspects of CCM in logistic operations. By using this real model of the industry, it was possible to identify possible solutions that could aid improved management of temperature controlled environments. By acquiring a sample of equipment that represents the different types of RFID solutions and include some of the essential functionalities for CCM, improvement evaluations could be done to quantify the effectiveness of this type of system and how to integrate them into one operational platform.

The main problem confronted in the CCM industry today is a lack of control over the stability of the cold chain. This is not the case for all entities involved in the cold chain, but in many cases, the entity involved in the management of a specific link in the chain is not sufficiently concerned about correct implementation of cold chain regulations as the financial losses are carried by other parties. This is because the effect of the temperature environment on perishables such as fruit and vegetable is to a large extent experienced only when reaching the retailer or consumer. This lack of concern and communication between the links of the chain poses the greatest threat to the quality of perishables reaching the consumer. Companies such as Woolworths solves this problem by instituting a set of fixed rules trying to hold each entity accountable for the link in the chain that it is responsible for.

Unfortunately this is not the only issue the industry is faced with. Even if it can be ensured that the entities responsible for storage and transportation in the cold chain be held accountable to a fixed standard there are still areas such as the loading bays that are not temperature controlled that causes large amounts of degradation to occur in perishables. These losses depend on the duration that perishables are left in uncontrolled environments; research has shown that this varies within each company. Further, there are also thermal losses during transportation, with the doors of a reefer responsible for the greatest loss. There are also some losses on the sides of the reefer due to thermal radiation from the sun during the day; these temperature losses are however manageable in comparison to the impact of open doors. In order to improve the process through accountability and enhanced visibility that includes feedback on temperature fluctuation it is necessary to install a monitoring system with abilities beyond the driver taking manual readings from the reefer.

In the technology survey conducted during this study, we investigated four different types of monitoring devices suitable as a tool in CCM. The first was the data logger that provides passive monitoring capability but that relies on a contact based data retrieval method. The second was BAP RFID tags, similar to standard data loggers but providing wireless data retrieval capability over distances of approximately 10m. The third type of system was a GSM/GPRS enabled sensor that capture temperature values from a probe or internal sensor and then sends the data via the mobile network. The fourth type of system is a hybrid system that uses either BAP RFID or Active RFID tags; the data is then collected from the sensors by a GSM/GPRS base station. This units stores the data internally and then forward the data in predefined cycles using the mobile network.

When evaluating these systems it was seen that, when taking into account the relative cost of the systems as well as the level of temperature monitoring and visibility provided by the systems, the fourth solution would be the best choice. This system costs more at initial installation than the others but provides the benefit of scalability with real-time information transferal. For the scenario where the user does not need real time monitoring the BAP RFID solution would be the most suitable. This type of devices provides a faster over the air data retrieval method thus providing an ideal solution for accountability and historical temperature verification.

The devices investigated provides the user with the ability to provide an overview of the operational process using different mediums. This can enable the improvement of the cold chain by addressing the issues discussed above. The systems from the different companies provides individual proprietary software to their solutions to gain the necessary data. Interoperability can be obtained by either using SDK offered by some companies to integrate into custom software directly; by adding a forwarding rule to the proprietary software to allow data to be sent from the their database to the custom database or by integrating the systems via database connectivity where the systems stream data directly to the custom database.

Six technologies that represents passive, BAP and Active RFID were initially evaluated in a free space environment by varying reading angle, distance and the environment the test were conducted in. The tests were repeated in free space with and without the placement of water-based goods, measured in a metallic container and finally in a reefer container for practical testing. The evaluation indicated that in order to maintain a successful, dependable real-time temperature monitoring capability during a trip the best system would be the active RFID solution. Because these units have their own internal power source they can counter act the attenuation caused by the perishable goods. This confirmed the initial observation made after completion of the technology survey.

The analysis of the systems showed that in most cases the maximum read range of the devices as defined in the datasheets could not be reached in the specified reading configuration. On average the reading range was 35%- 40% shorter that specified. The accuracy of the temperature monitoring was compared by using the log tag trix8 sensor, which closely reflected the reefer measurement, as the relative temperature point. The equipment showed that they all provided the ability to provide the accuracy of 0.5 ºC required for the safe monitoring of perishables such as fruit and vegetables.

During the measurement it was found that the casing placed around the sensor had a large effect on the thermal reaction time of the sensors. The largest problem occurred when the sensor is placed inside the pallet in which case it took on average 2.5 minutes to accurately reflect the temperature, once at the set point temperature the reactivity improved to reflect the temperature within 30 seconds dependant on the scale of the fluctuation in temperature.

The research indicated that the main purpose of the implementation of any monitoring equipment would be to provide visibility of the cold chain to enable corrective action if required and to provide accountability of the cold chain to protect the agents of the corresponding link against unsupported damage claims. Using this as criteria, three solutions were selected providing different levels of visibility and accountability.

The CAEN RFID solution was selected for the scenario of passive monitoring and historic reports thus providing an evidence trail. The second selection was the Wireless links Piccolo Plus unit operating at 2.4GHz to address the scenario of real-time temperature monitoring in an 8m radius. The third selections were the Ctrack/Ikaya system operating at 443MHz also to address the scenario of real-time monitoring but in a larger 15m radius.

By using these selections of a device to serve the purpose of temperature monitoring in the above scenarios a user friendly software solution could be designed and developed. In the design of the software platform, it was important to design it in a manner that provides a generic solution that could be used by multiple LSPs' and their clients. The design was based on research conducted during the evaluation of the cold chain and its internal operational processes. The design was implemented to provide complex functions in a simplistic manner for users with limited computer literacy.

The development of a web-based application provides users with the ability to access data from any location where internet access would be available. The developed platform included four essential tools: aiding its user in the management of resources and data, planning the delivery of consignments to clients, guiding the configuration of monitoring equipment reflecting the needs of the trip plan and generating reports reflecting essential data about the trips.

Evaluating this solution and equipment indicated that it had a valid use in the improvement of the cold chain. The processes implemented reflected the requirements in the industry thus validating the use of the software. A company specific paradigm that needs to be implemented to provide each end-user with only the functionality needed and to allow the addition of options to provide more detailed reports on completed trips with active reporting on threshold breaches.

The analyses of the return a company can expect from the implementation indicated that the initial capital outlay for the three different types of equipment would be returned within a period of a year. There will be little further investment required other that the data costs of the real-time implementation and possible lost sensor due to negligence, making this a financially viable implementation. The ROI indicated further that the passive equipment would generate a bigger return for the same period of standard operation than the real-time systems. From this, it is evident that the implementation would benefit the end-user company and have a positive impact on the annual net profit that can be expected.

9.2.2 Secondary objectives

The investigation into the effective use of sensors in a reefer container showed that the internal fluctuations varied greatly from the set point of the container. The temperature deviates by the greatest amount near the doors of the container, decreasing with closer proximity to the cooling unit of the trailer. Evaluating the results from multiple trips indicated through the use of trendlines that the best fit for the data would be a 4th order polynomial. Analysing this formula indicated that the equation could be used to effectively calculate the temperature at any point along the 9m length from the doors to the refrigeration unit using only one reference sensor value in each section.

The results further indicated that by dividing the trailer into five tiers of equal width the temperature could be effectively monitored with a 90% accuracy. The field evaluation indicated that the 6m from the refrigeration unit towards the doors showed the smallest amount of deviation, between 0,1ºC to 0,5ºC. Using the equation above could allow the use of only three sensors to provide sufficient visibility of the entire contents of a reefer container for CCM purposes. Using a minimum of five sensors placed on the periphery rather than the minimum of three provides the necessary redundancy to provide the LSP and client with verification information on all variations experienced by the consignment being monitored.

9.3 Recommendations and conclusion

The purpose of this study was an investigation into the use of RFID as a management tool to improve the cold chain. During this study, a sample of the different types of RFID systems available for cold chain management was evaluated. The evaluation included passive, battery assisted passive and active RFID solutions. By performing position and direction testing, environmental testing and field testing in refrigerated trailers, data was collected that provided information on the usability of the devices in the operational environment.

The evaluation indicated that passive RFID would only be suitable for identification and document traceability of the consignment and other resources. Because this type of RFID does not provide any sensing functionality and is dependent on the reader power for operation it is limited in its applicability. The BAP or semi-passive RFID tags presented a relatively low cost, attractive solution for cold chain monitoring. The research has shown that this passive tag with a battery-driven sensor offers an effective improvement on general data loggers. It is however adversely affected by water based perishable goods. This indicated that the best use of these sensors to still enable real-time monitoring would be the placement on the periphery of the trailer, but more effectively as a passive monitoring solution. This would provide a simple data retrieval method when returning to the DC or delivery at the client.

The third type of RFID system, the so called active RFID solution, showed the best promise for implementation in CCM. This battery powered system does not rely on the reader to power its operation and send the collected data. The research on active RFID sensors operating at frequencies of 2.4GHz and 433MHz distinctively showed that its operation would best suit the real-time monitoring of the CCM application. The 433MHz system provided a longer reading range and with less attenuation caused by the perishable goods. When looking at the physical dimensions of the sensing devices the 2.4GHz devices, in general, are however smaller with a more compact antenna design than that of the 433MHz.

The question posed in this research document, if off the shelf RFID systems can be used to improve cold chain logistics indicated that by integration of these building blocks into a custom software package, interoperability between multiple vendor products was indeed possible. RFID is a unique mobile technology that has versatile use and benefits for the improvement of cold chain logistics in various applications.

9.4 Future Research

The research presented in this dissertation provided may answers on the use for RFID for the management of cold chain logistics. Based upon the answers gained from this investigation, further future research can be done that can include the following:

1 An investigation into the loss sensitivity between the different cold chain participants. Although the LSP contributes to a large amount of the loss experience in the cold chain it is not the only one affected. Research can be expanded on what effect the consequential parties of the cold chain experience due to the improper enforcement of temperature standards. These parties includes retailers and consumers, and the effect upon the shelf life of perishables they experience. The study can include how to maintain the quality of goods as they arrive from the chain and how to effectively optimise the shelf life.

2 A loss sensitivity model can be derived that can be used by retailers to calculated the shelf life of perishables received. This can be based on the temperature profile experience by the perishables over their lifecycle until arrival at the vendor. This model can be applied as a basis to penalise LSPs, vendors and producers for losses due to temperature deviations experienced in the cold chain.

3 The effect of service level agreements on the improvement of quality criteria and the adoption of preventative measures to improve the quality of perishable goods from vendor to consumer can be researched.

4 What effect the long term installation of RFID based CCM systems have on the improvement of the shelf life of perishables can be researched. This can be combined with a detail cost analysis between the permanent installations of hardware and contracted maintained hardware installations.

5 A cost effective design and development of a custom RF solution to monitor and aid in the management of the cold chain can be investigated. This can be based upon the operational flow and industrial requirements that this study yielded.

The topics for future research that can be based upon the results delivered in this study is not limited to that listed above. Many more avenues can be explored and the only limit being the imagination and innovation of you, the researcher.

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BIBLIOGRAPHY

[1] L. Kitinoja, “Use of cold chains for reducing food losses in developing countries,” *White Pap.*, no. 13, pp. 1–16, 2013.

[2] D. L. Anderson, F. F. Britt, and D. J. Favre, “The Seven Principles of Supply Chain Management,” vol. 185647, pp. 1–15, 2005.

[3] J. Aked, “Maintaining the post-harvest quality of fruits and vegetables,” *Fruit Veg. Process. Improv. Qual.*, pp. 120–149, 2002.

[4] J. Parfitt, M. Barthel, and S. Macnaughton, “Food waste within food supply chains: quantification and potential for change to 2050.,” *Philos. Trans. R. Soc. Lond. B. Biol. Sci.*, vol. 365, no. 1554, pp. 3065–81, Sep. 2010.

[5] N. Huber, K. Michael, and L. Mccathie, “Barriers to RFID Adoption in the Supply Chain Barriers to RFID Adoption in the Supply Chain,” no. September, pp. 1–6, 2007.

[6] Y. Yuan and J. J. Zhang, “Using agent technology to support supply chain management : potentials and challenges,” 2001.

[7] A. Gullen, “RFID and Cold Chain Management,” *Interational Pharm. Ind.*, vol. 4, no. 4, pp. 70–72, 2012.

[8] S. A. Weis, “RFID (Radio Frequency Identification): Principles and Applications.”

[9] S. Yoon, J. Lee, and S. Park, “Anti-Collision Protocol Tuning for the ISO / IEC 18000-3 Mode 2 RFID System,” pp. 1–5, 2008.

[10] L. Ruiz-Garcia, L. Lunadei, P. Barreiro, and J. I. Robla, “A review of wireless sensor technologies and applications in agriculture and food industry: state of the art and current trends.,” *Sensors (Basel).*, vol. 9, no. 6, pp. 4728–50, Jan. 2009.

[11] L. Ruiz-Garcia and L. Lunadei, “The role of RFID in agriculture: Applications, limitations and challenges,” *Comput. Electron. Agric.*, vol. 79, no. 1, pp. 42–50, Oct. 2011.

[12] E. Abad, F. Palacio, M. Nuin, a. G. De Zárate, a. Juarros, J. M. Gómez, and S. Marco, “RFID smart tag for traceability and cold chain monitoring of foods: Demonstration in an intercontinental fresh fish logistic chain,” *J. Food Eng.*, vol. 93, no. 4, pp. 394–399, Aug. 2009.

[13] A. Characterization, C. Test, and T. Parties, “Advanced RFID Measurements : Basic Theory to Protocol Conformance Test,” pp. 1–10, 2013.

[14] “Imt-2000 - a c,” 2000.

[15] M. M. Aung and Y. S. Chang, “Temperature management for the quality assurance of a perishable food supply chain,” *Food Control*, vol. 40, pp. 198–207, 2014.

[16] B. H. Eds, “RFID in operations and supply chain management.”

[17] L. Zhang and Z. Wang, “Integration of RFID into Wireless Sensor Networks: Architectures, Opportunities and Challenging Problems,” *2006 Fifth Int. Conf. Grid Coop. Comput. Work.*, pp. 463–469, 2006.

[18] A. Mitrokotsa and C. Douligeris, “Integrated RFID and Sensor Networks : Architectures and Applications,” pp. 511–536, 2009.

[19] A. Higgins, S. Reidy, F. Barrett, S. Klein, and N. Johanning, “Real-Time Cold Chain Mapping,” 1800.

[20] D. Karali, “Integration of RFID and Cellular Technologies 1,” no. September 2004, 2005.

[21] D. Economic, “African Mobile Observatory 2011,” 2011.

[22] M. Attaran, “Critical Success Factors and Challenges of Implementing RFID in Supply Chain Management,” vol. 10, no. 1, pp. 144–167, 2012.

[23] K. Crowley, J. Frisby, S. Murphy, M. Roantree, and D. Diamond, “Web-based real-time temperature monitoring of shellfish catches using a wireless sensor network,” *Sensors Actuators A Phys.*, vol. 122, no. 2, pp. 222–230, Aug. 2005.

[24] D. Rico, a. B. Martín-Diana, J. M. Barat, and C. Barry-Ryan, “Extending and measuring the quality of fresh-cut fruit and vegetables: a review,” *Trends Food Sci. Technol.*, vol. 18, no. 7, pp. 373–386, 2007.

[25] P. Baker, “THE ROLE , DESIGN AND OPERATION OF DISTRIBUTION CENTRES IN AGILE,” 2008.

[26] R. Montanari, “Cold chain tracking: a managerial perspective,” *Trends Food Sci. Technol.*, vol. 19, no. 8, pp. 425–431, Aug. 2008.

[27] C. Turcu, Ed., “Sustainable Radio Frequency Identification Solutions,” Feb. 2010.

[28] “TRIX-8 _ Temperature Data Logger _ LogTag Recorders,” *LogTag Recorders*, 2015. .

[29] Gemini Data Loggers, “Tinytag Transit 2 Temperature Data Logger (-40 to +70° C),” *E&CE*, no. 4, pp. 3–4, 2013.

[30] Elpro, “LIBERO Ti1,” 2014.

[31] Shockwatch, “TrekView,” 2014.

[32] GOA RFID Inc, “This UHF semi-passive temperature logger tag,” 2014.

[33] Caen RFID, “A927Z - A927ZET Temperature logger UHF,” 2014.

[34] Caen RFID, “RT0005 - RT0005ET,” 2014.

[35] Caen RFID, “R4300P The first UHF RFID portal reader with embedded GPRS,” 2014.

[36] Caen RFID, “R260I: RFID UHF Desktop Reader,” 2014.

[37] Sensmaster, "Celebes S:Reader for stationary," 2014.

[38] MicroDAQ, "RTR-501 Temperature Logger with Internal Sensor," 2014.

[39] Aptifirst, "AGT Series: GSM Temperature Monitor," 2014.

[40] HW group, "HWg-Ares 12: GSM/GPRS Thermometer with E-mail and SMS alerts," 2014.

[41] Wirelesslinks, "Piccolo Plus."

[42] Wirelesslinks, "Piccolo RF Link," 2014.

[43] CTrack, "Basestation Manual [Ikhaya Automation Systems Documentation System].pdf." pp. 1–2, 2015.

[44] CTrack, "Wireless Probe Guide [Ikhaya Automation Systems Documentation System].pdf." pp. 1–4, 2015.

[45] CTrack, "Basestation Utilities Software Manual [Ikhaya Automation Systems Documentation System].pdf." pp. 1–3, 2015.

[46] K. Sensors, W. Sensor, A. Sensor, and A. Knoppie, "Hoe werk die stelsel ? Meer oor die verskillende sensors," no. 018.

[47] GPS Gate, "GpsGate Server GPS Tracking Platform," pp. 1–5, 2015.

[48] Fleetboard, "Individual control of logistics processes – more efficiency for your use," pp. 1–12, 2015.

[49] Fleetboard, "FleetBoard Temperature Management . Complete and secure .," pp. 1–2, 2006.

[50] Pulstrac, "Fleet management," 2015. .

[51] R. H. Seevers, D. Ph, J. Hofer, P. Harber, E. Lilly, and D. A. Ulrich, "The Use of Mean Kinetic Temperature (MKT) in the Handling , Storage , and Distribution of Temperature Sensitive Pharmaceuticals," no. June, pp. 927–929, 2009.

[52] Caen RFID, "UHF Semi-Passive Logger Tag," pp. 1–13, 2013.

[53] "Technological Evaluation of Shelf Life of Foods," no. 1962, pp. 87–102.

[54] I. U. Bron, R. V. Ribeiro, F. C. Cavalini, A. Pedro, and M. J. Trevisan, "TEMPERATURE-RELATED CHANGES IN RESPIRATION AND Q 10 COEFFICIENT OF GUAVA," pp. 458–463, 2005.

[55] J. Moureh and D. Flick, "Airflow pattern and temperature distribution in a typical refrigerated truck configuration loaded with pallets," *Int. J. Refrig.*, vol. 27, no. 5, pp. 464–474, Aug. 2004.

[56] H. J. Seltman, "Chapter 9 Simple Linear Regression," in *Experimental Design and Analysis*, 2015, pp. 213–240.

[57] C. Brown and R. Nelson, “Fitting Experimental Data,” no. July 2010, pp. 1–19, 2011.

[58] A. C. Cameron, “EXCEL Multiple Regression,” *Dept. of Economics*, 2016. [Online]. Available: http://cameron.econ.ucdavis.edu/excel/ex61multipleregression.html. [Accessed: 27-Jun-2016].

[59] B. Etzkorn, “Data Normalization and Standardization,” *Wordpress*, 2016. [Online]. Available: http://www.benetzkorn.com/2011/11/data-normalization-and-standardization/. [Accessed: 07-May-2016].

[60] “Pearson Correlation Coefficient_ Formula, Example & Significance - Video & Lesson Transcript _ Study,” *Study.com*, 2016. [Online]. Available: http://study.com/academy/lesson/pearson-correlation-coefficient-formula-example-significance.html. [Accessed: 06-Aug-2016].

[61] “EXCEL Pearson Correlation Tutorial,” *Statistical Tutorials*, 2016. [Online]. Available: http://stattutorials.com/EXCEL/EXCEL-pearson-correlation.html.

[62] Johanessburg Market, “Daily Prices,” pp. 1–6, 2016.

Appendix A: Detail Software Breakdown

1. Software page widgets

1.1 Pre-trip Configuration

The purpose of the pre-trip configuration is to determine the appropriate sensors, temperature values and placement of sensors for a specific trip. A driver and a truck will here also be linked to a specific consignment; in order to assist with trip scheduling and profitability calculations. The section will guide the user to pre configure a trailer with the maximum ease.

Table 65: Pre-Trip Configuration Widgets

Inputs:	Driver selection	Dropdown List
	Truck selection	Dropdown List
	Consignment ID	Textbox
	Company Name	Textbox
	User ID	Textbox
	Consignment selection	Dropdown List
	New Consignment	Button
	Start destination	Text box
	End destination	Text box
	Route chosen	Dropdown List
	Start Date	Text box
	Estimated Delivery Date	Text box
	Hardware Configuration	Button
Outputs:	Trip Information	Rich Edit
	Total Sensors required	Rich Edit
	Placement of sensors in trailer	Rich Edit
	Type of sensors	Rich Edit
	Configuration Settings	Rich Edit

1.2 Consignment Definition

In this section the user will have the ability to define the requirements of a new consignment. The type of goods, high and low temperature limits and humidity must be included in this definition.

Table 66: Consignment Definition Widgets

Inputs:	Consignment Name	Text button
	Consignment Type	Dropdown List
	Temperature Scale	Radio Buttons
	Maximum Temperature	Textbox
	Minimum Temperature	Textbox
	Humidity	Textbox

1.3 Hardware Configuration

In this section the user will have the ability to configure the appropriate sensors for a consignment. This will include configuring the sample rate, start time and exception temperatures of the consignment.

Table 67: Hardware Configuration Widgets

Inputs:	Connect Reader	Button
	Reader Select	Dropdown List
	Connection Type	Dropdown List
	COM port/IP address	Text button
	Detect tags	Button
	Create tag groups	Button
	Insert Tags to group	Button
	Sampling Rate	Textbox
	Time scale	Radio buttons
	Temperature Unit	Radio buttons
	High Temp limit	Textbox
	Low Temp limit	Textbox
	Alert Type	Dropdown List
	Tag Group select	Dropdown List
	Program Tags	Button
Outputs:	Connection Status	Label
	Configuration Status	Status bar
	Sensor Information	Rich Edit

1.4 Trip Monitoring

The section will indicate the consignments currently in the field, if they are real time enabled, any alerts triggered and notes made on the trip.

Table 68: Trip Monitoring Widgets

Inputs:	Consignment ID	Textbox
	Client ID	Textbox
	Search Information	Button
	Add Note	Button
	Note	Rich Edit
Outputs:	Consignment ID	Rich Edit
	Client ID	Rich Edit
	Alerts trigger	Rich Edit
	Time Stamp of alert	Rich Edit
	Information on alert	Rich Edit
	Notes on Consignment	Rich Edit

1.5 Data retrieval

The section will assist the user with retrieving the information from the sensors once arrive at the DC. It will allow you to connect to a reader, select a consignment and retrieve the corresponding data once the tags are in range.

Table 69: Data retrieval widgets

Inputs:	Connect Reader	Button
	Reader Select	Dropdown List
	Connection Type	Dropdown List
	COM port/IP address	Text button
	Detect tags	Button
	Select Tag Group	Dropdown List
	Retrieve Data	Button
	Storage Method	Dropdown List
	Storage format	Dropdown List
	Storage Path	Textbox
	Store Data	Button
Outputs:	Connection Status	Label
	Read Status	Status bar
	Data Integrity	Label

1.6 Reporting of information

This section will allow the user to retrieve stored data of consignments. The purpose of this page will be to format and present the user with logical results in report from of a selected consignment. The sections will include temperature vs. time graphs, shelf life, alerts logged on trip and all notes on consignment.

Table 70: Reporting of information widgets

Inputs:	Consignment ID	Textbox
	Client ID	Textbox
	Search Information	Button
	Add Note	Button
	Note	Rich Edit
	Generate Report	Rich Edit
Outputs:	Consignment ID	Rich Edit
	Client ID	Rich Edit
	Alerts trigger	Rich Edit
	Time Stamp of alert	Rich Edit
	Information on alert	Rich Edit
	Notes on Consignment	Rich Edit
	Calculated Shelf life of goods	Rich Edit
	Temperature vs. Time graph	Scatter Plot

2 Data Structures

2.1 Data Types

In this section the data types required for the cold chain management section is defined. In Table 1 the data that must be retrieved form real-time operation is defined. This data must be stored in the database for data analysis purposes.

Table 71: Real-time data Types

Type	**Information**
String	GSM/GPRS Unit Identifier
String	Tag Identifier
Double	Temperature value
Double	Humidity value
Date/Time	Timestamp
String	Alert information

In Table 73, the data stored for historical reporting and evaluation purposes are indicated.

Table 72: Storage Data Types

Type	**Information**
String	Company Identifier
String	Consignment Identifier
Integer	Alerts on consignment
Integer	Type of consignment
Integer	Monitoring period
Double	Quality Measure- At Arrival
Double	Average Temperature History
Double	Quality Measure -Delivery
Double	Shelf life of goods
Double	Data of consignment
Boolean	Temperature correction
Text	Consignment Summary

In Table 74, data types of the results of the calculation and analysis preformed for evaluation purposes.

Table 73: Calculation and Analysis data types

Type	**Information**

Double, Double	Consignment temperature range calculations
Double	Average temperature of goods analysis
Integer	Critical temperature area in consignment
String	Alert Calculation
Double	Trip Duration
Double	Shelf life Calculation

3. Data analysis and configuration

Real-Time data analysis must be confronted in accordance to two system scenarios:

- The system can be pre-configured to send data to a central company server for a specific equipment type. In this scenario the software platform would have to poll periodically to retrieve the data stored on the database. The data must then be extracted from the company software and populated to appropriate place in logistic database.
- The hardware can be configured to send data directly to the logistic platform, this would require the software to identify the hardware and use the corresponding protocol to retrieve the data from the periodical data packages received. The data extracted from data packages must then be populated to the appropriate place in logistic database.

Both the above mentioned scenario provides a high level of difficulty in the retrieval process. For the purpose of real-time alerting the latest temperature value must then be evaluated according to the cargo type and the temperature requirements for the goods in the consignment. A comparison test must be done between the current temperature and the required, if the data is outside the specification an alert must be generated and send. The alert can be passive, added to the database and only viewed by the user when logged in, or active alerting where the alert is send to a list of email addresses / phone numbers for immediate notification. This function must be configured by the user of the platform and will depend on the sensitivity of the consignment.

3.1 Data Reporting

- The goal of the retrieval of data is to present the user with concise and valuable results. The following data reports must be generated. Temperature variation over time.
- Humidity variation over time.
- Section display of temperature exception inside container
- Duration of temperature exceptions.
- Consignment quality
  - Quality measures
  - Predictive shelf life of goods

- Alerts on goods

Communication and data retrieval error

4 Database field breakdown

Table 74: Driver information table

DriverInformationtbl			
Field	**Data Type**	**Initial value**	**Key Type**
DriverId	Int	Not Null	PK
Name	Nvarchar(100)	Null	
Surname	Nvarchar(100)	Null	
Sex	Boolean	Null	
Age	Int	Null	
Nationality	Nvarchar(50)	Null	
ID Number	Nvarchar(20)	Null	
Passport Number	Nvarchar(20)	Null	
PassExpiryDate	Date	Null	
PassIssueLocation	Nvarchar(50)	Null	
DriverLicNumber	Nvarchar(20)	Null	
LicExpiryDate	Date	Null	
LicIssueLocation	Nvarchar(50)	Null	
VehicleClass	Nvarchar(2)	Null	
TotalYearsDriving	Int	0	
TotalAccidents	Int	0	
Physical Address	Nvarchar(50)	Null	
HomeNumber	Nvarchar(10)	Null	
CellNumber	Nvarchar(10)	Null	
EmailAddress	Nvarchar(50)	Null	
CompanyId	Int	Null	FK

Table 75: Driver employment information

DriverEmploymentInformationtbl			
Field	**Data Type**	**Initial value**	**Key Type**
EmploymentId	Int	Not Null	PK
DriverId	Int	Null	FK
EmplomentDate	Date/Time	Today	
Position	Nvarchar(50)	Null	
HourlyRate	Decimal	0	
CriminalRecord	Boolean	False	
CreditBureaRec	Boolean	False	
Blacklisted	Boolean	False	
PsycEvalHR	Boolean	True	
PsycEvalMR	Boolean	True	
PsycEvalLR	Boolean	True	
Supervisor	Nvarchar(100)	Null	

Table 76: Driver Contact Information

DriverContactInformationtbl			
Field	**Data Type**	**Initial value**	**Key Type**
ContactId	Int	Not Null	PK
DriverId	Int	Null	FK
CellNumber	Nvarchar(12)	Null	
Country	Nvarchar(50)	Null	

ContactId =ContactId++

Table 77: Horse information table

HorseInformationtbl			
Field	**Data Type**	**Initial value**	**Key Type**
HorseId	Int	Not Null	PK
Make	Nvarchar(50)	Null	
Model	Smallint	Null	
VIN	Nvarchar(17)	Null	
Chassis Number	Nvarchar(20)	Null	
Registration	Nvarchar(12)	Null	
FleetnumberH	Nvarchar(20)	Null	
EngineCap	Decimal	0.0	
MaxHaulWeight	Decimal	0.0	
FuelCap	Decimal	0.0	
AxleConfig	Int	1	
HorseRFIDEPC	Nvarchar(50)	Null	
CompanyId	Int	Null	FK

VehicleId=VehicleId++

Table 78: Trailer information table

TrailerInformationtbl			
Field	**Data Type**	**Initial value**	**Key Type**
TrailerId	Int	Not Null	PK
Make	Nvarchar(50)	Null	
Model	Smallint	Null	
VIN	Nvarchar(17)	Null	
ChasisNumber	Nvarchar(20)	Null	
Registration	Nvarchar(12)	Null	
FleetNumberT	Nvarchar(20)	Null	
TrailerType	Nvarchar(20)	Null	
FuelCapCooler	Decimal	0.0	
FuelCap	Decimal	0.0	
TrailerSize	Decimal	0.0	
MaxLoadWeight	Decimal	0.0	
AxleConfigT	Int	1	
TrailerRFIDEPC	Nvarchar(50)	Null	
CompanyId	Int	Null	FK

TrailerId = TrailerId ++

Table 79: Vehicle Allocation table

VehicleAllocationtbl			
Field	**Data Type**	**Initial value**	**Key Type**
VAllocationId	Int	Not Null	PK
DriverId	Int	Not Null	FK
HorseId	Int	Not Null	FK
TrailerId	Int	Not Null	FK
TraceId	Int	Not Null	FK
ConsignmentId	Int	Not Null	FK

AllocationId= Allocation++

Table 80: Company information table

CompanyInformationtbl			
Field	**Data Type**	**Initial value**	**Key Type**
CompanyID	Int	Not Null	PK
CompanyName	Nvarchar(50)	Null	
CityLocated	Nvarchar(50)	Null	
CountryLocated	Nvarchar(50)	Null	
UserId	Int	Not Null	FK
TelephoneNumber	Nvarchar(13)	Null	
CellNumber	Nvarchar(13)	Null	
EmailAddress	Nvarchar(50)	Null	
MailingList	Boolean	True	
ServiceAllowed	Bit	1	

CompanyID= CompanyID++

Table 81: User Information table

UserInformation			
Field	**Data Type**	**Initial value**	**Key Type**
UserId	Int	Not Null	PK
Username	Nvarchar(50)	Null	
Name	Nvarchar(50)	Null	
Surname	Nvarchar(50)	Null	
EmailAddress	Nvarchar(50)	Null	
CellNumber	Nvarchar(13)	Null	
Password	Nvarchar(50)	Null	
Designation	Nvarchar(50)	Null	
AccessLevel	TinyInt	0	
CompanyId	Int	Null	FK

UserId= UserId++

Table 82: Client Information table

ClientInformation			
Field	**Data Type**	**Initial value**	**Key Type**
ClientID	Int	Not Null	PK
CompanyName	Nvarchar(50)	Null	
StreetAddress	Nvarchar(50)	Null	
CityLocated	Nvarchar(50)	Null	

Country	Nvarchar(50)	Null	
GPSCoordinates	Nvarchar(40)	Null	
ContactName	Nvarchar(50)	Null	
ContactSurname	Nvarchar(50)	Null	
WorkNumber	Nvarchar(12)	Null	
CellNumber	Nvarchar(12)	Null	
EmailAddress	Nvarchar(50)	Null	
CompanyID	Int	Not Null	FK

Table 83: Consignment information table

ConsignmentInformation			
Field	**Data Type**	**Initial value**	**Key Type**
ConsignmentId	Int	Not Null	PK
TempStandardId	Int	Null	FK
TempSetpoint	Decimal	0	
MaxTemperature	Decimal	0	
MinTemperature	Decimal	0	
TemperatureDev	Decimal	0	
Humidity	Decimal	0	
ClientId	Int		FK
CompanyId	Int	0	FK

ConsignmentId=ConsignmentId++

Table 84: Temperature standard table

TempStandardtbl			
Field	**Data Type**	**Initial value**	**Key Type**
TempStandardId	Int	Not Null	PK
PerishableName	Nvarchar(50)	Null	
TempSetpoint	Decimal	0	
MaxTemperature	Decimal	0	
MinTemperature	Decimal	0	
TemperatureDev	Decimal	0	
Humidity	Decimal	0	
DegradationPeriod	SmallInt	0	

Table 85: Trip information table

TripInformationtbl			
Field	**Data Type**	**Initial value**	**Key Type**
TripId	Int	Null	PK
LoadingDestination	Nvarchar(50)	Null	
DispatchDate/Time	Date/Time	Today	
DispatchAgentName	Nvarchar(50)	Null	
DispatchAgentSurname	Nvarchar(50)	Null	
DispatchAgentNumber	Nvarchar(12)	Null	
DeliveryDestination	Nvarchar(50)	Null	
DeliveryDate	Date/Time	Today	
ReceivingAgentName	Nvarchar(50)	Null	
ReceivingAgentSurname	Nvarchar(50)	Null	
ReceivingAgentNumber	Nvarchar(12)	Null	

CompanyId	Int	Null	FK
VAllocationId	Int	Null	FK

RouteId=Int

Table 86: Agent Table

Agenttbl			
Field	**Data Type**	**Initial value**	**Key Type**
AgentId	Int	Not Null	PK
Name	Nvarchar(50)	Null	
Surname	Nvarchar(50)	Null	
WorkNumber	Nvarchar(13)	Null	
Cell Number	Nvarchar(13)	Null	
CompanyName	Nvarchar(50)	Null	
CompanyId	Int	Null	FK

Table 87: Location Table

Locationtbl			
Field	**Data Type**	**Initial value**	**Key Type**
LocationId	Int	Not Null	PK
Adress	Nvarchar(150)	Null	
City	Nvarchar(50)	Null	
Country	Nvarchar(50)	Null	
GPSPosition	Nvarchar(13)	Null	
CompanyId	Int	Null	FK

Table 88: Equipment Table

Equipmenttbl			
Field	**Data Type**	**Initial value**	**Key Type**
EquipmentId	Int	Not Null	PK
Name	Nvarchar(50)	Null	
Manufacturer	Nvarchar(50)	Today	
Functionality	Nvarchar(50)	Null	
Quantity	Int	Null	
CompanyId	Int	Null	FK

Table 89: Equipment Allocation Table

EquipmentAllocationtbl			
Field	**Data Type**	**Initial value**	**Key Type**
EAllocationId	Int	Not Null	PK
EquipmentId	Int	Null	FK
QuantityUsed	Int	0	
VAllocationId	Int	0	FK

Table 90: Sensor Configuration Table

SensorConfigtbl			
Field	**Data Type**	**Initial value**	**Key Type**
SensorConfigId	Int	NotNull	PK
EPC	Nvarchar(50)	Null	
SampleRate	SmallInt	0	
MinTemperature	Decimal	0.0	
MaxTemperatue	Decimal	0.0	
ConsignmentId	Int	Not Null	FK
ConfigDate	Date/Time	0.0	

Table 91: Read Data Table

ReadData			
Field	**Data Type**	**Initial value**	**Key Type**
DataID	Int	Not Null	PK
EPC	Nvarchar(50)	Null	FK
Temperature	Decimal	0.0	
SampleDate	Date	Null	
SampleTime	Time(7)	Null	

DataID = DataID++

Table 92: Analysed Data Table

AnalysedData			
Field	**Data Type**	**Initial value**	**Key Type**
IrregularityID	Int	Not Null	PK
ConsignmentID	Int	Null	FK
DataID	Int	Null	FK
TempDeviation	Decimal	Null	

IrregularityID= IrregularityID++

Table 93: Report Data Table

ReportData			
Field	**Data Type**	**Initial value**	**Key Type**
ReportEntryID	Int	Not Null	PK
ConsignmentID	Nvarchar(50)	Null	FK
CompanyId	Nvarchar(50)	Null	FK
TotalTempDeviations	SmallInt	0	
AverageTemp	Decimal	0.0	
DeliveryTemp	Decimal	0.0	
ReportDate	Date/Time	Null	

***

Appendix B: Consignment data analysis graphs.

4.3.2.4 Data analysis of consignment Johannesburg to Zambia with approximate trendlines

The graphs shown in this section depicts the result of the detail analysis conducted on a consignment accompanied. The transported consignment was of a perishable nature consisting mainly of fruits and vegetables. The goods was transported between Zambia and Johannesburg and over a turnaround period of 8 days.

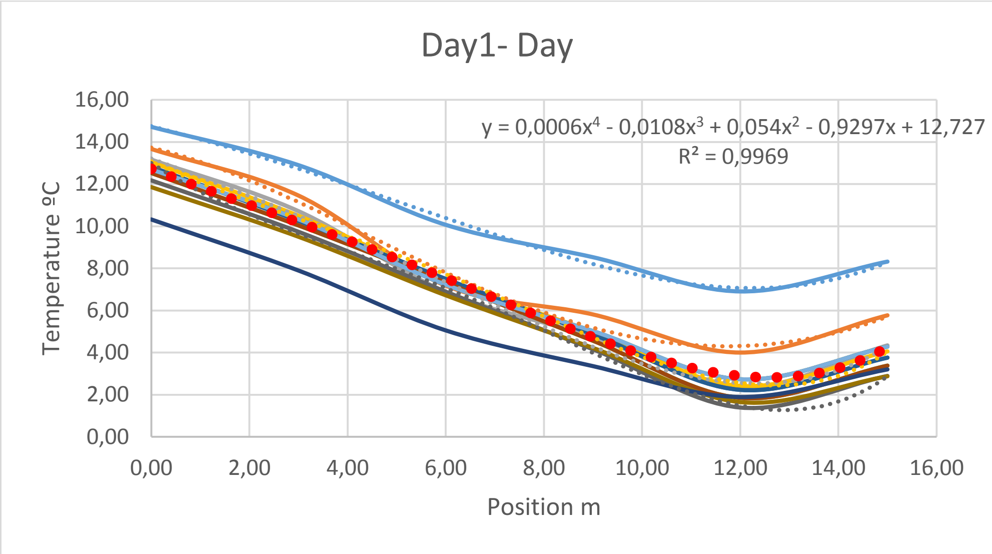

Figure 121: Temperature sample data Day 1- Day

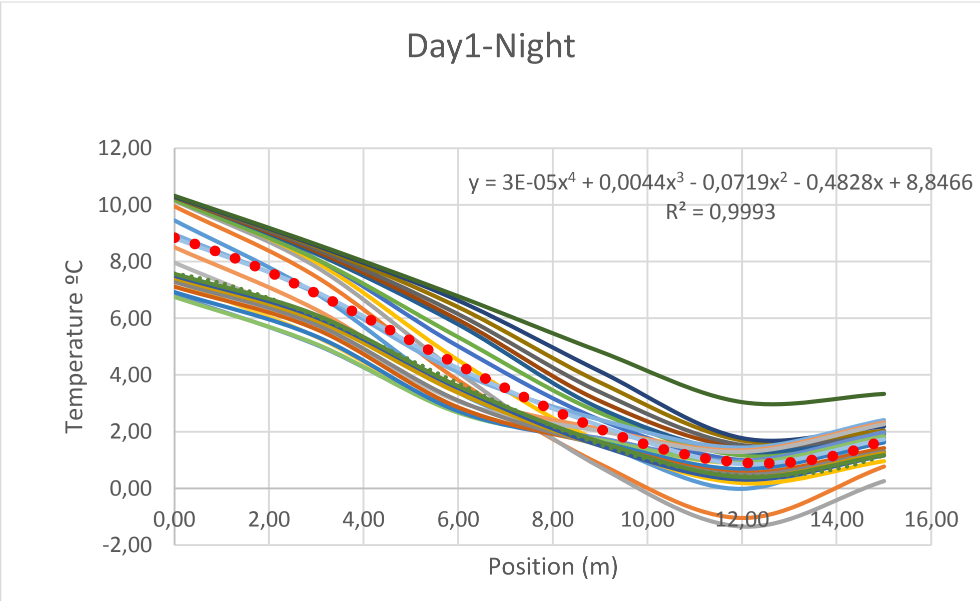

Figure 122: Temperature sample data Day 1- Night

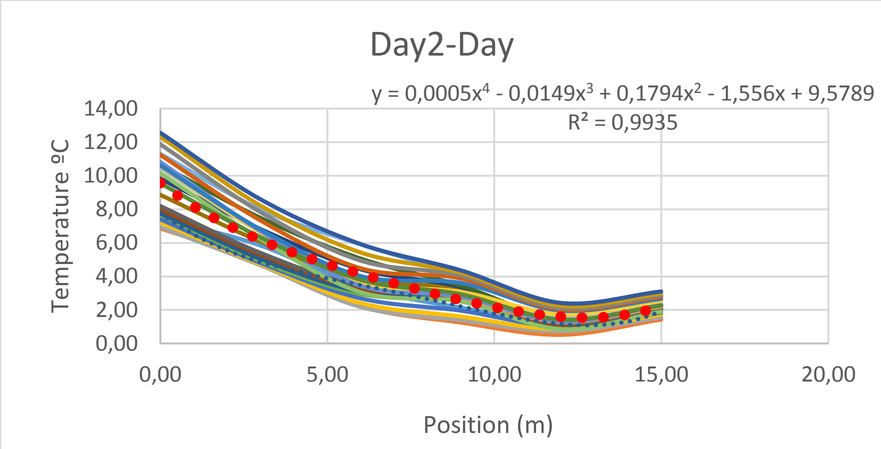

Figure 123: Temperature sample data Day 2-Day

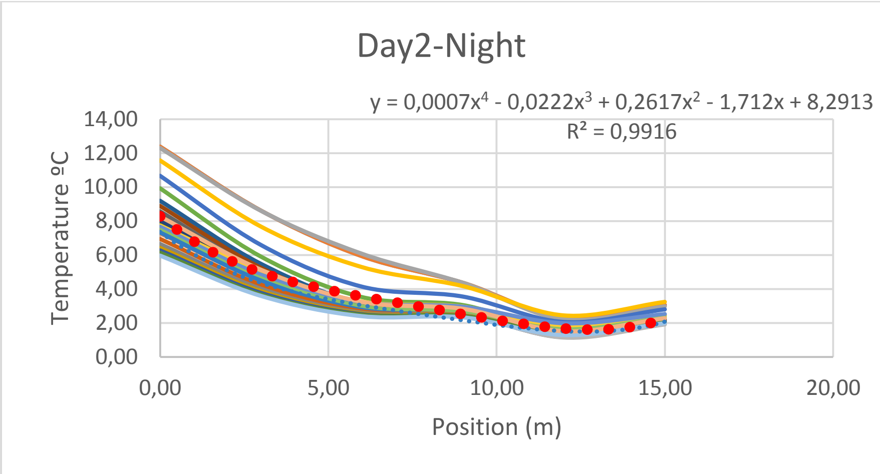

Figure 124: Temperature sample data Day 2- Night

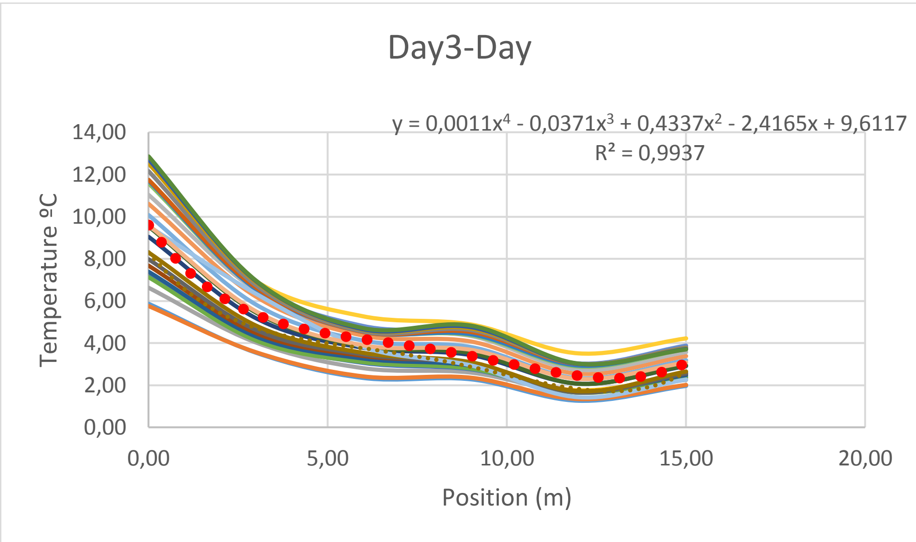

Figure 125: Temperature sample data Day 3 - Day

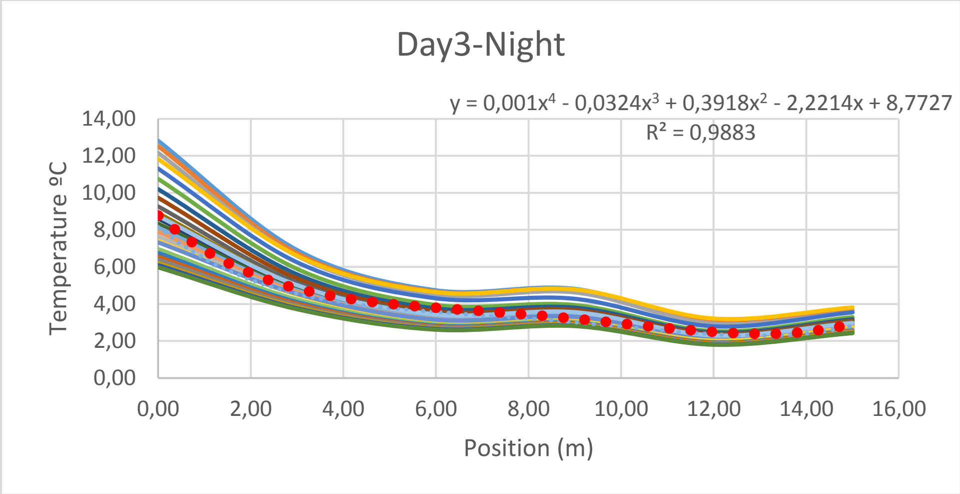

Figure 126: Temperature sample data Day 3 -Night

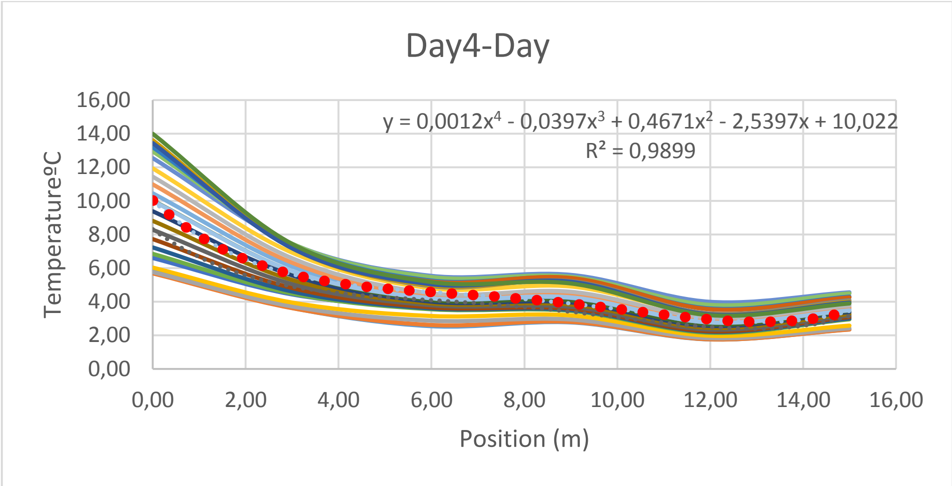

Figure 127: Temperature sample data Day 4 - Day

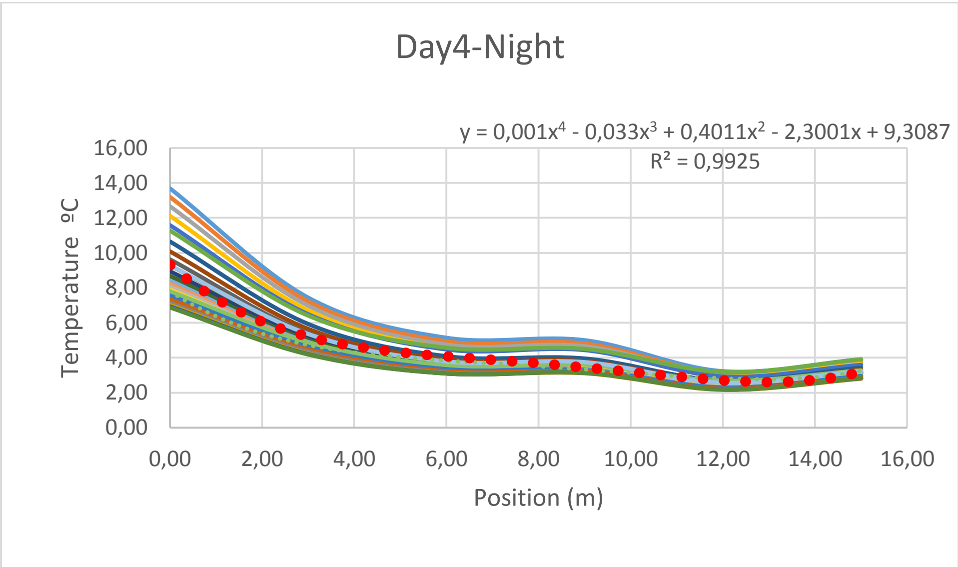

Figure 128: Temperature sample data Day 4 - Night

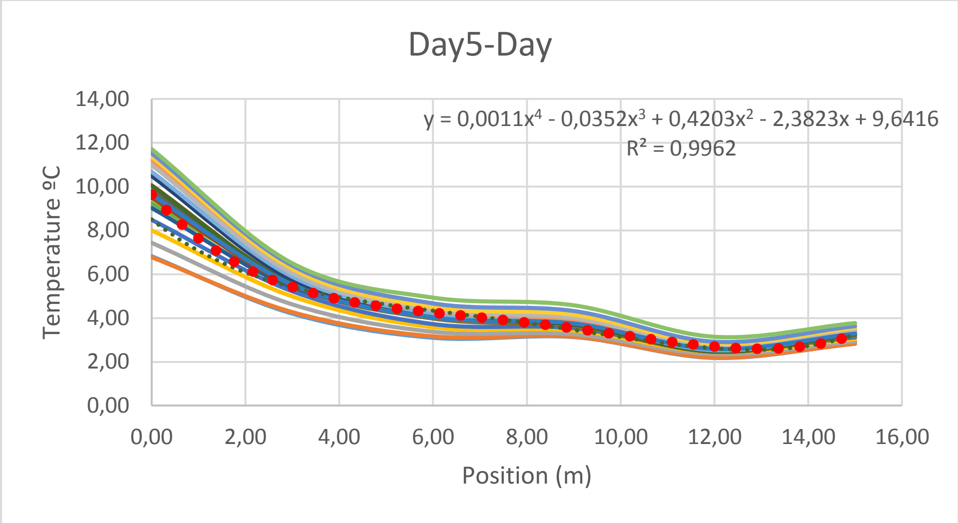

Figure 129: Temperature sample data Day 5 - Day

Appendix C: Data Sources

1 Articles

SATNAC: Using mobile networks for effective cold chain management:

https://drive.google.com/open?id=0B0gCwW2KLnA-Q045T2cwN01YTlU

2 Data Analysis and Results

https://drive.google.com/open?id=0B0gCwW2KLnA-VWxXaVBhTFdnd3M

3 Designed Software Solution

https://drive.google.com/open?id=0B0gCwW2KLnA-azVsTTd1ZjdFaWc

4 Experimental Data

https://drive.google.com/open?id=0B0gCwW2KLnA-YTNRV1JQU3dmY3c

5 Cold Chain Systems and datasheets

https://drive.google.com/open?id=0B0gCwW2KLnA-VWxXaVBhTFdnd3M

6 Literature Study Documents

https://drive.google.com/open?id=0B0gCwW2KLnA-U3FXQjU1Z055OWs

7 Master Study Documents

https://drive.google.com/open?id=0B0gCwW2KLnA-ZHdib2FjQURUSFU

8 Questionnaires

https://drive.google.com/open?id=0B0gCwW2KLnA-ZHdib2FjQURUSFU