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# **Real-Time Solution for Automated Inventory Monitoring of Antiretroviral Medicines:**

**Case of Nairobi County**

**Raymond Stephen Alick**

**078374**

**Submitted In Partial Fulfilment of the Requirements for Degree of  
Master of Science in Information Technology at Strathmore  
University**



**Faculty of Information Technology**

**Strathmore University**

**Nairobi, Kenya**

**June, 2016**

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## Abstract

Cases of stockouts and expiry of Antiretroviral Therapy medicines are occurring and this is due the fact that the current inventory monitoring systems for Antiretroviral Therapy Medicines and commodities are manual despite the use of electronic systems for the ordering and issuing of the same. This research proposed a real-time inventory control and monitoring model to address the challenges. The model uses fuzzy logic through a fuzzy inference engine to predict the appropriate quantity level on when to place an order so as to reduce the probability of a stockout occurring. The model uses a continuous review technique to monitor the quantity of the medicines in real-time as they are being issued or received. The model gives immediate notification when a reorder point for a particular inventory item is reached. The model is also able to monitor product lifetime of the medicines to ensure those concerned are informed when medicines in inventory have expired and need to be replaced. The model is validated through the implementation of a web-based system which is then tested against the propositions of model to confirm it works as expected. The tests on the system yielded a positive validation of the model. The fuzzy inference engine's accuracy of predictions was tested using the Random Mean Square Error method and it yielded a standard deviation error result of 4.3% from a set of actual test data sets. The model was then compared against other existing models and it was proven that the model developed in this research is the most appropriate for the monitoring of Antiretroviral Therapy medicines and commodities.

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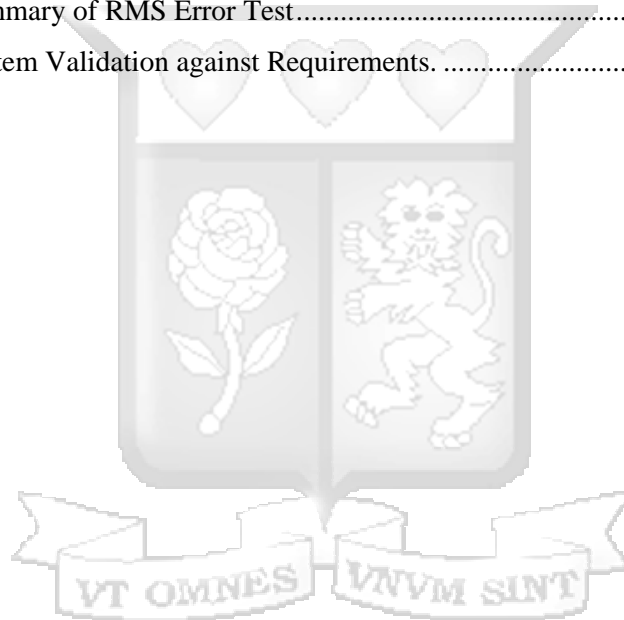
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## **Abbreviations/Acronyms**

<b>AIDS</b>	- Acquired Immune Deficiency Syndrome
<b>ANN</b>	- Artificial Neural Networks
<b>AVERT</b>	- AVERTing AIDS & HIV (AIDS Education & Research Trust)
<b>ART</b>	Antiretroviral Therapy
<b>ARV</b>	- Antiretroviral
<b>CD4</b>	- Cluster of Differentiation 4
<b>DFD</b>	- Data Flow Diagram
<b>EOQ</b>	- Economic Order Quantity
<b>EPQ</b>	- Economic Production Quantity
<b>E-SCM</b>	- Electronic Supply Chain Management
<b>GA</b>	- Genetic Algorithms
<b>HIV</b>	- Human Immunodeficiency Virus
<b>IMS</b>	- Inventory Monitoring System
<b>KEMSA</b>	- Kenya Medical Supplies Authority
<b>MSF</b>	Médecins Sans Frontières (alias Doctors Without Borders)
<b>NACC</b>	- National AIDS Control Council (Kenya)
<b>NASCOP</b>	- National AIDS & STIs Control Programme (Kenya)
<b>OS</b>	- Operating System
<b>PLWHA</b>	- People living with HIV/AIDS
<b>UN Cares</b>	- United Nations Cares
<b>UNAIDS</b>	- United Nations Program on HIV/AIDS
<b>UNGASS</b>	- United Nations General Assembly Special Session
<b>UNICEF</b>	- United Nations Children's Fund
<b>USAID</b>	- United States Agency for International Development
<b>WHO</b>	- World Health Organization
<b>RAM</b>	- Random Access Memory
<b>RMSE</b>	- Random Mean Square Error
<b>ROL</b>	- Reorder Level
<b>ROP</b>	- Reorder Point
<b>ROQ</b>	- Reorder Quantity

## Definition of Terms

**Antiretroviral Medicines (ARV):** Medicines that inhibit the replication of HIV. When antiretroviral medicines are given in combination, HIV replication and immune deterioration can be delayed, and survival and quality of life improved (WHO, 2015).

**Antiretroviral Therapy (ART):** Refers to a range of treatments that includes antiretroviral (ARV) medicines. The medicines that are used in the treatment of HIV, a retrovirus, are designed to interfere with the virus' ability to replicate itself and, therefore, slow the progression of the disease. ART consists of the use of at least three antiretroviral medicines to maximally suppress HIV, the virus, and stop or slow the progression of HIV disease (WHO, 2015).

**ART Medicines and Commodities** Refers to the ART medicines and accompanying commodities such as HIV test kits (WHO, 2015).

**Inventory Monitoring** Involves reviewing the level inventory at regular levels to ensure that the levels being maintained are optimal so as not to have too much, too little or obsolete in the inventory (Bragg, 2014).

**Inventory Control** Inventory Control or Stock control can be broadly defined as "the activity of checking a shop's stock" (Merriam-webster Dictionary, 2016).

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## **Chapter 1 : Introduction**

### **1.1 Background of Study**

According to the World Health Organization (2015), most People Living with HIV/AIDS (PLWHA) do not have access to Antiretroviral Therapy (ART) medicines and commodities and that most of those most at risk of contracting it do not have adequate preventive measures at their disposal. All this is happening even though there has been significant progress by the global medical community in conjunction with many governments together with several non-governmental organizations making strides towards better worldwide access to treatment and care to those in need. Knowledge on HIV/AIDS has greatly increased championed by scientific research but still there is no known cure, although the proper use of ART medicines can ensure longer lives for those infected and greatly delay the eventual progression from HIV to AIDS.

Friedman (2012), notes that the previous decade witnessed a remarkable increase in the distribution of ART medicines in sub-Saharan Africa. Friedman (2012), also notes that the progression from HIV to fully blown AIDS has been tremendously reduced by the availability of ART medicines treatment which also helps in reducing the rate of transmission between those currently infected and those not infected. As at 2013, Global access to ART medicines has improved from 64% to 80% due to significant improvements in the delivery services for the medicines. In Kenya for instance, in 2013 656,000 PLWHA were receiving ART medicines compared to just 6,000 in 2003 (United Nations General Assembly Special Session [UNGASS], 2014).

According to a 2015 report by the United Nations Program on HIV/AIDS (UNAIDS), Antiretroviral Medicine procurement and supply is one of the problems that should be looked at and addressed in order to fast-track its fight against this pandemic. The goal of successful distribution of ART medicines and commodities is achieved when there is a continual uninterrupted delivery of the medicines to the patients. (AVERT, 2014).

In a 2009 survey report by the World Health Organization, 38% (36 out of 94) of the countries that had taken part had at least gone through one stock out of antiretroviral therapy medicines (ART) in their distribution centres (WHO, UNAIDS & United Nations Children's Fund [UNICEF], 2010). Unhindered and continual access to ART medicines is required in order to ensure suppression of the viral load and slow progression from HIV to AIDS, otherwise individual patients are put at increased risk

due to such medicine stockouts which indicate to an inefficient supply chain for delivering the medicines. The successful realization of delivery of the medicines is usually hindered by problems due to inefficiency of the delivery system and the supply chain in general. Factors that contribute to the challenges of effective delivery include over-purchasing of the medicines and under-estimating of the demand. Financial strain and Storage space problem occur when over-purchasing occurs while under-estimating leads to stockouts and usually necessitates expensive purchase of emergency supplies.

Lack of appropriate inventory control and monitoring systems for ART medicines and commodities is one the problems that contributes to inefficiencies of the delivery system and the supply chain (Kagashe and Massawe, 2012; Mahoro, 2013; Muthoni & Okibo, 2014). Clark and Barraclough (2010), indicate that inadequate monitoring of medicines and other medical equipment as they move through the supply chain may lead to health facilities suffering wastages, such as stockouts, expiries and underutilization of the medicines and medical equipment, which in turn leads to the inability to meet the treatment goals of the patients due to inability to obtain adequate medicines. Inventory control is one of the elements underpinning inventory management, a failure to monitor stock levels regularly could have fatal consequences, disruption of or delay in course of treatment may worsen a patient's condition and lead to death if a lifesaving medicine is out of stock (Clark & Barraclough, 2010).

Securing a dependable, regular supply of ART medicines and commodities at service delivery points is critical to the success of ART programs and laboratory diagnosis. Any interruption in the supply chain will prevent diagnosis of new patients or endanger the lives of those patients already on therapy due to risk of discontinuation of treatment or development of medicine resistance. Frequent interruptions could lead to failure of the program. Making timely entries and recording issues on logistics tools are recommended to keep up to date inventory records and management information system. Frequent monitoring of stock status is suggested to avoid discrepancies and to keep it to adequate levels which will minimize multiple ordering (Mahoro, 2013).

In Kenya particularly, one the vision 2030 goal is to accomplish zero new HIV infections by the year 2030 and for this to be realized efficiency of delivery of ART medicines and commodities has to be improved upon. For this to be achieved, there is need to have efficient supply chain systems which have proper inventory control and monitoring.

## **1.2 Problem Statement**

A report by UNAIDS (2015), concluded that Antiretroviral Therapy medication procurement and supply is one of the problems that should be looked at and addressed in order to fast-track its fight against this pandemic. Lack of appropriate inventory control and monitoring systems for ART medicines and commodities is one the problems that contributes to inefficiencies of their delivery system and the supply chain (Kagashe and Massawe, 2012; Mahoro, 2013; Muthoni & Okibo, 2014).

Despite many improvements, the limited availability of ART medicines still continues in Kenya. This is partly because the inventory control and monitoring of antiretroviral medicines is faced by a number of challenges. The cycle of providing antiretroviral medicines is information based, therefore poor coordination of the necessary information such as when to place to place an order is the major cause of the unavailability of these medicines to people who need them (Muthoni & Okibo, 2014). The lack of coordination causes confusion and stockouts at many antiretroviral treatment clinics, often forcing patients to switch to other regimens not for medical reasons, but because of supply-chain failures. In addition to interrupting treatment, medicine stockouts increase the risk that the virus will become resistant to treatment (Muthoni & Okibo, 2014).

To address this problem, this research will look into the inventory control and monitoring schemes of the ART medicines and commodities and then develop a prototype real-time solution that monitors inventory in real-time as well as assist in decision making by predicting when to order using a fuzzy inference engine.

## **1.3 Research Objectives**

- i. To identify the challenges of the current systems used for inventory control and monitoring of ART medicines and commodities.
- ii. To review models used in inventory control and monitoring.
- iii. To develop a model to support better inventory control and monitoring of ART medicines and commodities.
- iv. To develop a prototype based on the model developed.
- v. To test the developed prototype.

#### **1.4 Research Questions**

- i. What are the challenges of the current systems used for inventory control and monitoring of ART medicines and commodities?
- ii. What are the models used in inventory control and monitoring?
- iii. How to develop a model to support better inventory control and monitoring of ART medicines and commodities?
- iv. How to develop a prototype based on the model developed?
- v. How to test the developed prototype?

#### **1.5 Significance of the Study**

This research will address the issue of automating monitoring of the inventory for ART medications issuing centres. This study is justified by the fact that inventory control and monitoring are still complex problems even in the age of computerised inventory systems for many public institutions dealing with disbursement of ART medicines and commodities. This research is justified because it offers a prototype solution to address the key issues of determining when and how much to order as well as real-time monitoring of inventory and notification of when stock levels are running low, something that is currently not quite well solved.

#### **1.6 Scope and Limitations**

This research deals with developing a web based system for inventory control and monitoring for ART medicines and commodities. Inventory control and monitoring are a subset of inventory management which is a subset of supply chain management. This research addresses the challenges of Inventory control and monitoring only, and not the whole subject of supply chain management. The fact that the solution is a prototype means that the developed system will function only to the point of “proof of concept” of the conceptual design, it will not be a fully functioning system.

## Chapter 2 : Literature Review

This literature review presents descriptions for inventory management and inventory control and monitoring. It then presents a review of inventory control and monitoring for ART medicines and commodities and thereafter looks at inventory control and monitoring models and architectures. It then review the concept of fuzzy logic which will be used to determine when to order (Reorder point). It finally presents the conceptual model developed.

### 2.1 Inventory Control and Monitoring

Inventory control or stock control can be broadly defined as "the activity of checking a store's stock" (Macmillan Dictionary, 2016). It can also be defined as the Coordination and supervision of the supply, storage, distribution, and recording of materials to maintain quantities adequate for current needs without excessive oversupply or loss (Merriam-webster Dictionary, 2016).

Inventory control regulates the inventory that is already in a distributor's warehouse. This includes knowing what products are being stocked and how much of a particular item a distributor has available. It is also about knowing exactly where each product is located in the warehouse, ensuring that all inventory remains in great condition, and laying out the warehouse in a way that minimizes the cost of filling customer orders (Bragg, 2014).

Inventory management, on the other hand, includes the activities of forecasting and product replenishment. It determines when to order products, how much to order and the most effective source of supply for each item in the warehouse. This ensures that distributors have the right quantity of the right item in the right location at the right time. In order to achieve better inventory management, distributors first need to improve their inventory control (Bragg, 2014).

Inventory Monitoring involves reviewing the level inventory at regular levels to ensure that the levels being maintained are optimal so as not to have too much, too little or obsolete in the inventory. The three words may actually been seen as synonymous to each other, that is they technically refer to the same thing. The crossover of definitions is almost interchangeable and the use is usually within reference to the author's context in which the words are used (Van Bodegraven & Ackerman, 2012).

### ***2.1.1 The Need for Inventory Control***

Inventory is a major source of cost in a supply chain and has huge impact on responsiveness, so inventory control becomes significant entity of supply chain management (Priya & Iyakutti, 2011). Inventory control is a fundamental requisite to supply chain optimization. The processes and controls of effective inventory control are critical to any successful business. Since it is rarely the case that any business has the luxury of unlimited capital, inventory control involves important decisions about what to buy or produce, how much to buy or produce and when to buy or produce within the capital limits (Narmadha, Selladurai, & Sathish, 2010). Even though there are literally millions of different types of products manufactured in our society, there are only two fundamental decisions that one has to make when controlling inventory which are when should an inventory replenishment order be placed and how large should the inventory replenishment order be.

### ***2.1.2 Inventory Control Systems***

Inventory control is a complex problem area owing to the diversity of real life situations. Successful inventory control requires sophisticated methods to cope with the continuously changing environment (Anigbogu, Oladipo, & Usman, 2011). Therefore due to its complex and repetitive nature, most inventory control is usually done using computerised systems. Inventory control system (software) is a computer-based system for tracking inventory levels, orders, sales and deliveries. It can also be used in the manufacturing industry to create a work order, bill of materials and other production-related documents. The main goal of inventory control system is to ensure consistent availability of supplies for consumers. Thus, inventory control System is directed toward owners of small to large stores and stock managers who are responsible of maintaining sufficient goods on hand in a retail or manufacturing business. It can scale from a single computer running both client and server software up to multiple stores and warehouses (Lu, 2013).

### ***2.1.3 Reorder Point***

Inventory monitoring is usually done with the aim of ensuring that optimum stock is available at all time so as to ensure that cases of overstocking, understocking and obsolete stock do not occur. In order to ensure that optimum stock level are in place, inventory monitoring usually seeks to address the issue of when to order which is known as the reorder point and how much to order which is known as the reorder

quantity. Usually the following formulas are used to determine the reorder point (i.e. equation 2.1) and reorder quantity (i.e. equation 2.2) with variable demand.

$$R = \bar{d}L + z\sigma_d\sqrt{L}$$

where

$\bar{d}$  = average daily demand

$L$  = lead time

$\sigma_d$  = the standard deviation of daily demand

$z$  = number of standard deviations corresponding to the service level probability

$z\sigma_d\sqrt{L}$  = safety stock

*Equation 2.1: Reorder Point Formula: (Russell & Taylor, 2000)*



$$Q = \bar{d}(t_b + L) + z\sigma_d\sqrt{t_b + L} - I$$

*Equation 2.2: Reorder Quantity Formula (Russell & Taylor, 2000)*

$\bar{d}$  = average demand rate

$t_b$  = the fixed time between orders

$L$  = lead time

$\sigma_d$  = the standard deviation of daily demand

$z\sigma_d\sqrt{t_b + L}$  = safety stock

$I$  = inventory in stock

Demand refers to the consumption of a commodity from the inventory. It is usually expressed a rate (such as 10 units per day) and usually it is the average demand of a certain period. Lead time is the time between when an order for replenishment of inventory is placed and when that order is received. Safety stock is the buffer stock kept in inventory as a countermeasure to guide against uncertain demand patterns. It is used in the case where lead time may vary to act as a cushion against stockout in the event an order delivery is late. There are several ways to determine the amount of the safety stock, one popular method is to establish a safety stock that will meet a specified service level. Service Level: The service level is the probability that the amount of inventory on hand during the lead time is sufficient to meet expected demand, that is, the probability that a stockouts will not occur.

## **2.2 ART Medicines Inventory Control and Monitoring**

Currently ART medicines and commodities are inadequately monitored. Despite the wide use of electronic systems from ordering and issuing medicines, the systems do not usually incorporate inventory control and monitoring capabilities in most countries. Mahoro (2013), states that the absence of a standardized inventory control system with procedures for monitoring and managing stock levels of ART medicines and commodities is a challenge to the logistics management systems in place. Making timely entries and recording issues on logistics tools are recommended to keep up to date inventory records and management information system. Frequent monitoring of stock status is suggested, to avoid discrepancies and to keep it to adequate levels which will minimize multiple ordering.

Kagashe and Massawe (2012), found out that over 65% of medical facilities in Dar es Salaam, Tanzania were not employing systematic ways for control and monitoring of medicines. This was later linked to lack of knowledge of inventory control and monitoring techniques among the employees of this facilities. They also determined that availability of medicines is directly affected by the lack thereof or use of inadequate inventory control and monitoring systems. Another example of problems with inadequate monitoring of medicines is a study conducted in Darbhanga district in India found that no inventory control techniques were used for the maintenance of the stock in public hospitals, resulting in frequent stockouts (Roy, et al., 2009), as was as was the case in Lesotho where stock levels were not monitored, resulting in improper stocking of certain medicines (Mahoro, 2013).

According to the United States Agency for International Development (USAID) (2008), selection, design, and proper implementation of proper inventory control and monitoring systems needs to be implemented in order to achieve the goal uninterrupted quality supply of ART medicines and commodities. Inventory control and monitoring of ART medicines and commodities is an important aspect that directly affects their adequate availability and quality of ART medicines and commodities. Failure to monitor stock levels regularly could have fatal consequences, disruption of or delay in a course of treatment may worsen a patient's condition and lead to death if a lifesaving medicine is out of stock (Clark & Barraclough, 2010).

AVERT (2014), indicate that Inventory monitoring is required in order to avoid the over-purchasing of the medicines and as well as under-estimating of demand.

Financial strain and storage space problem occur when over-purchasing occurs while under-estimating leads to stock-outs and usually necessitates expensive purchase of emergency supplies. Appropriate demand forecasting technologies need to be applied to prevent such situations from occurring. Traceability of the medicines as they move through the supply chain is also necessary and is currently a problem. Some medicines tend to expire when shelved too long.

### ***2.2.1 ART Medicines Inventory Control and Monitoring Challenges in Kenya***

In attempting to prolong the lifespan of the people infected, the Government of Kenya partnered with donors for the supply on the antiretroviral medicines. The inventory control of these antiretroviral medicines has faced a number of challenges such as improper record keeping, poor stock levels, obsolescence, irregular access of antiretroviral medicines by patients and rollout of antiretroviral therapy (Vawda & Variawa, 2012). In addressing these challenges, the Government of Kenya has adopted the use of e-health systems (Muthoni & Okibo, 2014).

In Kenya, the use of a web-based system to control inventory of antiretroviral medicines through the computerized Logistics Management Information System (LMIS) was originally solely used for resupply decisions at Kenya Medical Supplies Authority (KEMSA) and did not consider the information needs of different centers. Generally, the LMIS should monitor inventory levels throughout the supply chain, calculate reorder quantities for individual facilities, and provide data for estimating future demand (USAID, 2008).

According to the Kenya health sector strategic plan for health information system for 2009-2014 (Ministry of Medical Services; Ministry of Public Health and Sanitation, 2009), web-based systems are being implemented in health institutions in the country. A study by Zhou (2011) focused on mobile personal health care systems for patients with diabetes showed that web-based systems were being adopted for monitoring patients' medical records. However, the adoption of web-based systems in monitoring the stock of antiretroviral medicines in Kenya remains untapped (Muthoni & Okibo, 2014).

In the study by Muthoni and Okibo (2014), their results indicated that there is poor inventory control and monitoring of antiretroviral medicines in level 4 hospitals in Kisii County. The report however indicated that hospitals that had adopted use of web-based systems fared better in terms of experiencing less stockouts than those that did not adopt use of the web-based systems. They concluded that the web-based systems

are a very crucial part in inventory control of antiretroviral medicines, and as a result they can help to control and monitor stock levels, obsolescence and record keeping of these medicines.

### ***2.2.2 Proposed Solutions to ART Medicines Inventory Management***

USAID (2008), indicates that the key aspects of inventory monitoring and control systems is to assist the personnel in charge of inventory on when to order or issue, how much to order or issue, and how to maintain an appropriate stock level of all products to avoid shortages and oversupply. USAID (2008), also states that Inventory control system requirements for ART medicines and commodities include shortest possible pipeline, lower buffer stocks than other health commodities, as well as more frequent reporting period and order interval.

USAID (2008), recommends the use of maximum-minimum Inventory Control Systems. A maximum-minimum system allows objective resupply decisions based on need and takes into account established levels of safety stock, with the ultimate goal of having product available each and every time it is needed. Given the life-saving nature of ART and the public health risks associated with the emergence of ARV medicine resistance, uninterrupted product availability must be of primary concern. When developing a logistics system, one of the first decisions that will have to be made is the type of maximum-minimum inventory control system to use. There are several types of max-min inventory control systems, two such systems recommended for ART medicines and commodities distribution are the full-supply and fixed ordering systems. Implementation of a maximum-minimum (max-min) inventory control system is most effective in a full-supply situation, where sufficient quantities of all commodities are available to meet all needs, as should be the case for an ART program and some programs that use HIV tests (e.g., voluntary counseling and testing, preventing mother-to-child transmission).

In forced ordering systems, orders are placed at regular intervals; all products are ordered/resupplied to the maximum stock level. Use the forced ordering version of the maximum-minimum inventory control system is currently preferred In light of the special requirements for ARV medicines and HIV tests, and to take advantage of some of the common characteristics of ART and HIV testing programs.

Some of the Special characteristics of ARV medicines and commodities include short shelf life, which can range from six to 24 months as well the special requirement

for refrigerated storage needed for some products. Other special characteristics include their high price, treatment and testing protocols that require multiple products from multiple sources to be available simultaneously to provide a service and lastly the limited possibility for substitution in the case of stockouts (USAID, 2008).

### 2.3 Classification Inventory Control Models

The problem of inventory control is one of the most important in organizational management. As a rule, there is no standard solution, the conditions at each company or firm are unique and include many different features and limitations. Classically inventory control models are many and can be classified in summary as shown in the table 2.1 below:

Table 2.1: Models of Inventory Control Classification (Ziukov, 2015)

By purpose	By period
<ul style="list-style-type: none"> <li>• Economic order quantity model</li> <li>• Economic production quantity model</li> <li>• Joint economic lot sizing model</li> </ul>	<ul style="list-style-type: none"> <li>• Single-period model</li> <li>• Multi-period model</li> </ul>
By type of inventory monitoring	By quantity of items
<ul style="list-style-type: none"> <li>• Continuous review system model</li> <li>• Periodic review system model</li> </ul>	<ul style="list-style-type: none"> <li>• Single-item model</li> <li>• Multi-item model</li> </ul>

#### 2.3.1 Classification Based On Purpose

Models can be classified based on purpose into numerous groups. Below three such models based on purpose are presented.

##### a. The Economic Order Quantity Model

The Economic order quantity (EOQ) Model is most used inventory control model. It is a very old technique that has been in use for a very long time. It assumes that inventory and holding cost are fixed. The model also assumes that lead time is zero. It is used to determine the optimum ordering quantity which lowers the ordering and carrying costs (Ziukov, 2015). Figure 2.1 below shows how inventory levels vary over time based on EOQ assumptions, as can be the model assumes zero lead time and

hence the reorder point is when inventory runs out and as such the order quantity is the same as the maximum quantity level.

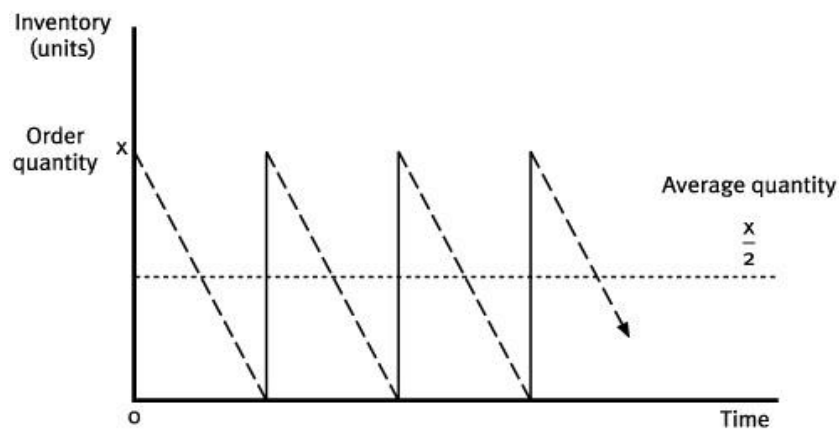


Figure 2.1: Inventory Levels over Time Based on EOQ Assumptions (Kaplan Financial, 2012)

Paul and Azeem (2011), in their study indicated that the simplicity of the EOQ model is the main reason that it is still widely used to determine when and how much to order. This simplicity is due to the assumption that key values such as lead time and demand are fixed as well using zero lead time. This makes the model simple but also unrealistic for use in real world scenarios where the values vary over time. The EOQ model is of limited usefulness if deployed with its original assumption because values such as lead time and demand vary over time (Paul & Azeem, 2011). The EOQ model is rarely employed in its classical straight forward manner. Nowadays it is usually coupled with technologies such Fuzzy Logic, Artificial Neural Networks, and usually several assumptions of the original model are changed and new assumptions incorporated so as to overcome its limitations .

### ***b. Economic Production Quantity Model***

The Economic Production Quantity (EPQ) is another classic model which is basically an extension of EOQ. It is used to determine the optimal order quantity that minimizes the total inventory cost by manipulating the holding and ordering costs for the company (Ziukov, 2015). The difference between these two methods is that the EPQ model assumes the company will produce its own quantity. But just like its counterpart the EOQ model, the classical EPQ model has unrealistic assumptions and efforts have been made over the years to improve the model using techniques such as Fuzzy Logic while employing new improved assumptions (Ziukov, 2015).

### ***c. Joint Economic Lot Sizing Models***

Joint Economic Lot Sizing models (JELS) is class of inventory control models that address the issues of inventory coordination between a buyer and a seller. Classically the buyer and seller would each have to manage their respective economic lot sizing independently. The objective of these models is the development of a jointly coordinated buyer-seller inventory strategy that is more beneficial to each member's individual non-coordinated inventory strategy (Ziukov, 2015).

#### ***2.3.2 Classification Based On Period***

Classification based on periods can be grouped into one being single-period models and the other being multi-period models. Single-period models address the special situation where a commodity or product is useful for only a single period, such as newspapers that are not needed the day after their intended sale date. The newsvendor model is a single-period, probabilistic inventory model, whose objective is to determine the order quantity that minimizes expected underage costs (i.e. costs due to shortage) and overage costs (i.e. costs due to holding inventory) (Ziukov, 2015).

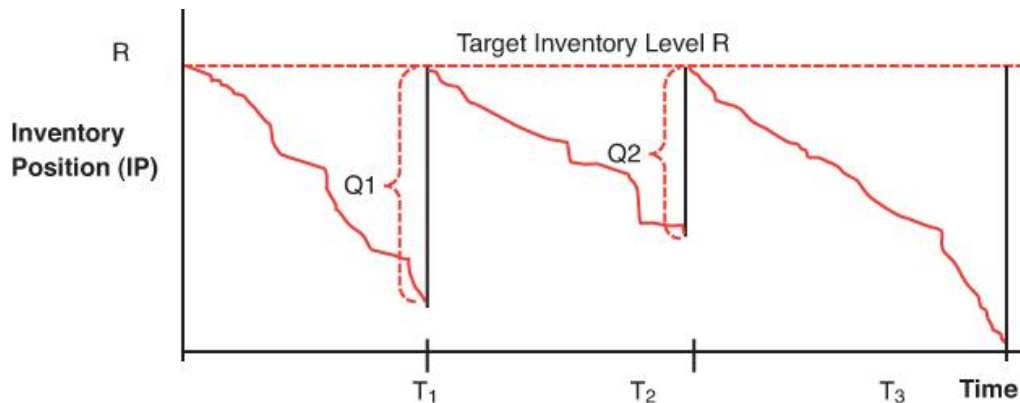
The main difference between the single-period models and the multi-period models is that the multi-period models may involve stock leftovers from previous periods, which makes the optimal choice of order quantities more complicated. In real-world applications, inventory and production decisions are interdependent and temporal in nature (Ziukov, 2015).

#### ***2.3.3 Classification Based On the Type of Inventory Monitoring***

Tracking inventory is an essential part of business operations for any company that sells tangible goods. Periodic and continuous reviews are the two common methods used to track inventory for accounting and ordering purposes. The type of inventory review policy appropriate for a business depends on several factors, including the sales volume of the business and the number of employees handling inventory. A sole proprietorship with limited sales may not need to adopt a continuous review policy to maintain a level of accuracy necessary to continue business operations. Conversely, a large retailer with numerous employees handling merchandise may have difficulty maintaining accurate inventory counts under a periodic inventory review policy.

### **a. Periodic Review System Models**

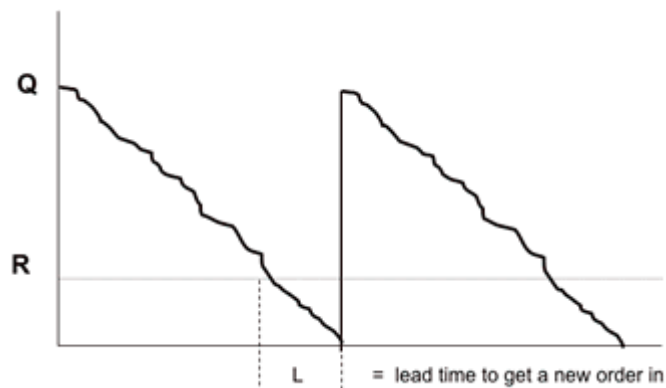
Periodic inventory review involves counting and documenting inventory at specified times. Periodic inventory review reduces the time a business owner or manager spends analyzing inventory counts, which allows more time for other aspects of running the business. However, it may not provide accurate inventory counts for businesses with high-volume sales. The owner or manager must make assumptions between inventory review periods regarding inventory counts. This can make it difficult to ascertain when reordering items is necessary. It also can make accounting less accurate (Pearson, n.d.). Figure 2.2 below shows how inventory levels fluctuate over time in a periodic review system.



*Figure 2.2: Periodic Review System (Council of Supply Chain Management Professionals [CSCMP] & Sanders, 2014)*

### **b. Continuous Review Systems Models**

Continuous inventory review, also known as perpetual review, involves a system that tracks each item and updates inventory counts each time an item is removed from inventory. Inventory level is constantly monitored and a new order place when a pre-established reorder point(R) is met, as shown in the figure 2.3 below



*Figure 2.3: Perpetual Review System Concept Showing ROL (Bozarth, 2011)*

Perpetual inventory review permits real-time updates of inventory counts, which can make it easier to know when to reorder items to replenish inventory. This method of inventory review also facilitates accurate accounting, since the inventory system can generate real-time costs of goods sold (Pearson, n.d.). The main disadvantage of this type of inventory review is the cost of implementation, bar code scanners, inventory software and computer systems are all necessary to maintain perpetual inventory review.

#### ***2.3.4 Classification based on the quantity of items***

Classification based on quantity of items can be grouped into two, one being single-item models and the other being multi-item models. Many of the inventory control models are single item models or assume that multiple items are ordered independently of each other, resulting in a large number of small orders. But in real-life situations coordination of orders and joint replenishments often take place in order to achieve economies of scale. Therefore as the names suggest single-item models inventory items are ordered individually while in multi-item models many items are considered at once before an order is made as batch of different items.

### **2.4 Inventory Control Models**

Given the various shortfalls of the classical inventory monitoring models such as EOQ and EPQ which make them unrealistic in real world environments, several innovative inventory control and monitoring models have been developed to address different problem areas with regard to this subject. Most recent models tend to focus on the use of Artificial intelligence techniques such as Genetic Algorithms (GA) and Artificial Neural Networks (ANN), while some use fuzzy logic. Below are some of the reviewed models.

#### ***2.4.1 Fuzzy-Based Models***

Anigbogu et al. (2011), developed an intelligent model for sales and inventory management using Fuzzy Logic. The model was developed with the purpose of predicting when to reorder stock in situations where demand is uncertain. The model uses a single antecedent and single consequent fuzzy logic model whereby Lead Time was the only antecedent and reorder point (ROP) was the only consequent output. The

model used five fuzzy rules to predict the ROP. Below are the rules used for their model.

*R1: IF (Lead\_Time is "very short") THEN (ROP is "very small");*

*R2: IF (Lead\_Time is "short") THEN (ROP is "small");*

*R3: IF (Lead\_Time is "average") THEN (ROP is "average");*

*R4: IF (Lead\_Time is "long") THEN (ROP is "big");*

*R5: IF (Lead\_Time is "very long") THEN (ROP is "very big")*

Anigbogu et al. (2011), designed their model with the aim of reducing the gap between theoretical and practical models of inventory monitoring, most of which seem to be based on complicated mathematical theories that in reality are almost impractical outside of the academic arena. The system implemented from their model was able to learn demand and lead time automatically based on the sales from a Point of Sale system. The model also served as point-of-sale in itself and was deployed and tested at a local supermarket chain and they claimed that the results were good. The model also had inbuilt notification in real time of inventory levels to the inventory managers.

Dutta and Kumar (2013), developed a fuzzy inventory model for deteriorating items with shortages under fully backlogged condition. The model assumed demand and deterioration rate to be constant. The model's main objective was to minimize the final cost function brought about by deteriorating items using fuzzy logic. Unlike the model by Anigbogu et al. (2011), which did not consider deteriorating items, this model did.

#### ***2.4.2 Models Using Artificial Intelligence***

Artificial intelligence techniques have been used in inventory control and monitoring. In most cases it takes the form of inventory optimisation of the output function, usually the total inventory cost function. Paul and Azeem (2011), developed an artificial neural network (ANN) model for optimization of finished goods inventory. The model seeks to address inventory control from a point of how much inventory to stock as a function of holding, material and setup costs and product demand. The model employs the use of feed-forward back-propagation ANN with four inputs, ten hidden neurons and one output as the optimum network. The model was used in a live test on a manufacturing plant and it was used to forecast the optimum level of finished goods to have in inventory. The model utilises historical data and uses knowledge from

supply chain experts to determine the inputs variables for the ANN. The ANN model proved successful and it could capture and model complex relationships between input and output variables without complex mathematical model. Figure 2.4 below shows the basic outline of the model.

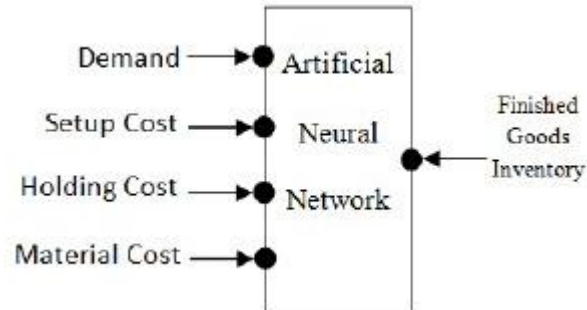


Figure 2.4: ANN Model for Inventory of Finished Goods (Paul & Azeem, 2011)

Priya and Iyakutti (2011), developed a model to optimize the re-order point in a manufacturing plant with regard to the distribution centres where finished good are taken. The model uses Genetic algorithms to optimise the production quantity so as deliver an optimum number of stock to the various distribution centres served in the supply chain from the factory. The optimization focused on minimizing the holding cost for inventory at the distribution centres. The genetic algorithm model allows for prediction of an optimum re-order level so as to ensure that overstocking and understocking do not take place in the whole supply chain. The re-order level is optimized from the factory but sales are monitored throughout the whole supply chain in individual distribution centres. Below is figure 2.5 showing outline of the model.

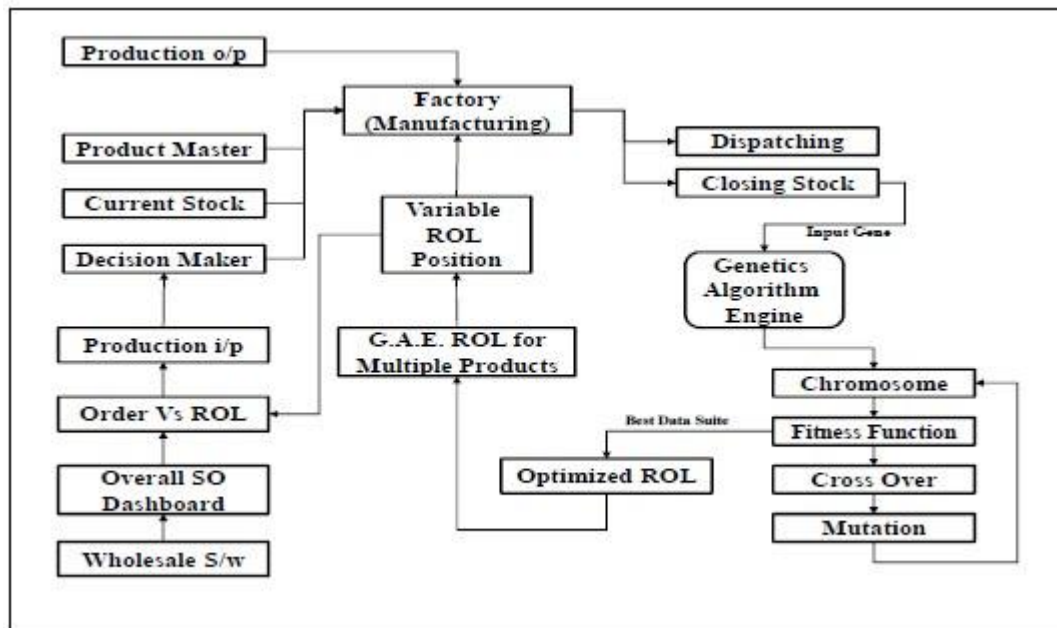


Figure 2.5: Web based Multi Product Inventory Optimization System using GA (Priya & Iyakutti, 2011)

### 2.4.3 Summary of Reviewed Inventory Control Models

Below is table 2.2 showing the summary of the reviewed models.

Table 2.2: Summary of Reviewed Inventory Control Models

Name of Model	Area of Focus	Merits	Demerits/ Limitations
An intelligent model for sales and inventory management (Anigbogu et al. , 2011)	Automatic demand and lead time pattern identification for inventory management. The intelligent inventory model was formulated using of fuzzy logic.	Has Learning for the reorder point, Lead-Time, and Quantity Order.	Does not consider deteriorating items i.e. Expiration  Single Antecedent fuzzy model
Web based Multi Product Inventory Optimization using Genetic Algorithm (Priya & Iyakutti, 2011)	Optimization of the reorder level (ROL) in the manufacturing unit taking consideration of the stock levels at the factory and the distribution centres of the supply chain. Genetic algorithm is used for the optimization in a multi-product, multi-level supply chain in a web enabled environment.	Prediction of optimal ROL enables the manufacturing unit to overcome the excess/ shortage of stock levels in the upcoming period.  Considers deteriorating items	Does not consider other Metrics such as Lead Time.
An artificial neural network model for optimization of finished goods inventory (Paul & Azeem, 2011)	An ANN model is developed to determine the optimum quantity of finished goods inventory in a fuzzy environment.	Implements Learning by the system and adapts as the inputs vary.	Does not consider deteriorating items i.e. Expiration  And does not consider lead time
Dutta and Kumar (2013)	Fuzzy inventory model for deteriorating items with shortages under fully backlogged condition.	Considers deteriorating items and their effect on the total inventory cost	Considers key Inventory factors such as Demand to be constant and Lead time to be zero

## **2.5 Inventory Control Software Architectures**

Several Inventory control and monitoring software architecture exist. Most recent architectures are web based systems. Web based architectures take the shape of Client-Server architecture systems. This has great benefits mainly due to the ubiquity of web based systems. Other benefits offered by web based systems include centralised setup which allows for easy upgrade of the overall system and this creates a no-install deployment model on the client machines as they only need a web browser to access the system. Also a benefit of web based systems is the inherent ability to serve several clients at once something that most client based applications do not achieve. Other architectures use the classic desktop application architecture for inventory management. But even these standalone applications still use a client server architecture where by the database is usually in a remote server.

### ***2.5.1 Web-Based Architecture***

Arsan, Baskan, Ar and Bozkus (2013), developed an inventory management system (IMS). They used a web-based architecture that uses Asynchronous JavaScript and XML (AJAX), HTML/CSS on the clients' side and PHP on the server side as well MySQL for the database engine. The system architecture encompassed six key modules namely definitions/setup, inventory management, maintenance management, service management, debit management and deposit management. The software has the ability keep record of inventory as it flows and also to give detailed reporting. Below is figure 2.6 showing the general inventory management system architecture used.

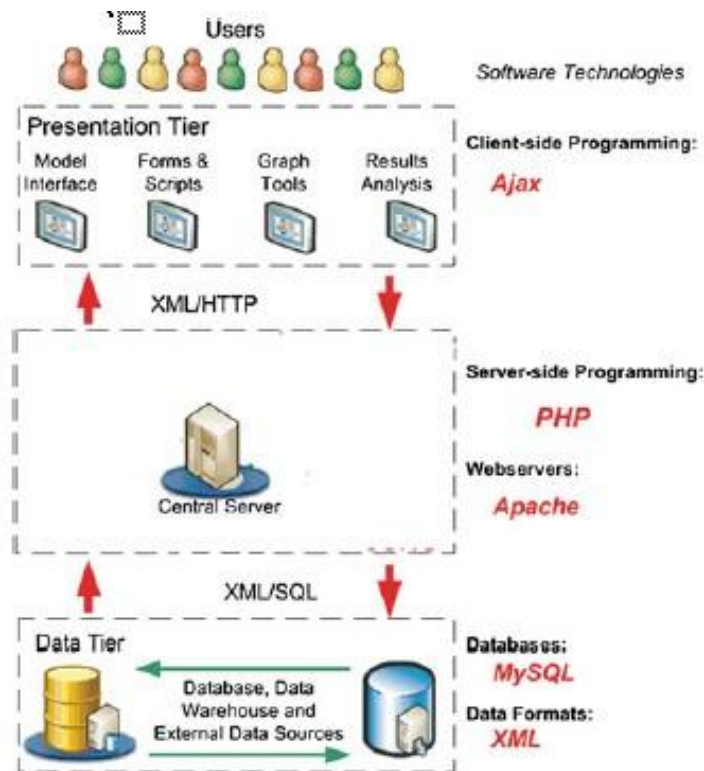


Figure 2.6: Inventory Management System Architecture (Arsan et al., 2013)

### 2.5.2 Desktop Application System Architecture

Inedo (n.d.), developed an Inventory Management System for Kramerica Industries using C# (C-sharp) and Microsoft SQL server. The C# application runs on a windows desktop client machine but the SQL server database runs on a remote cluster server. The software was responsible for inventory reporting and ordering. The architecture is still client server but requires the C# frontend to be installed on each individual client machine separately. This is not a problem for them since all client machine are in located in single work site as well as the developers being internal employees, but it is not a suitable scenario for institutions that cannot afford to have developers onsite on a full time basis. Below is figure 2.7 showing the system architecture used :

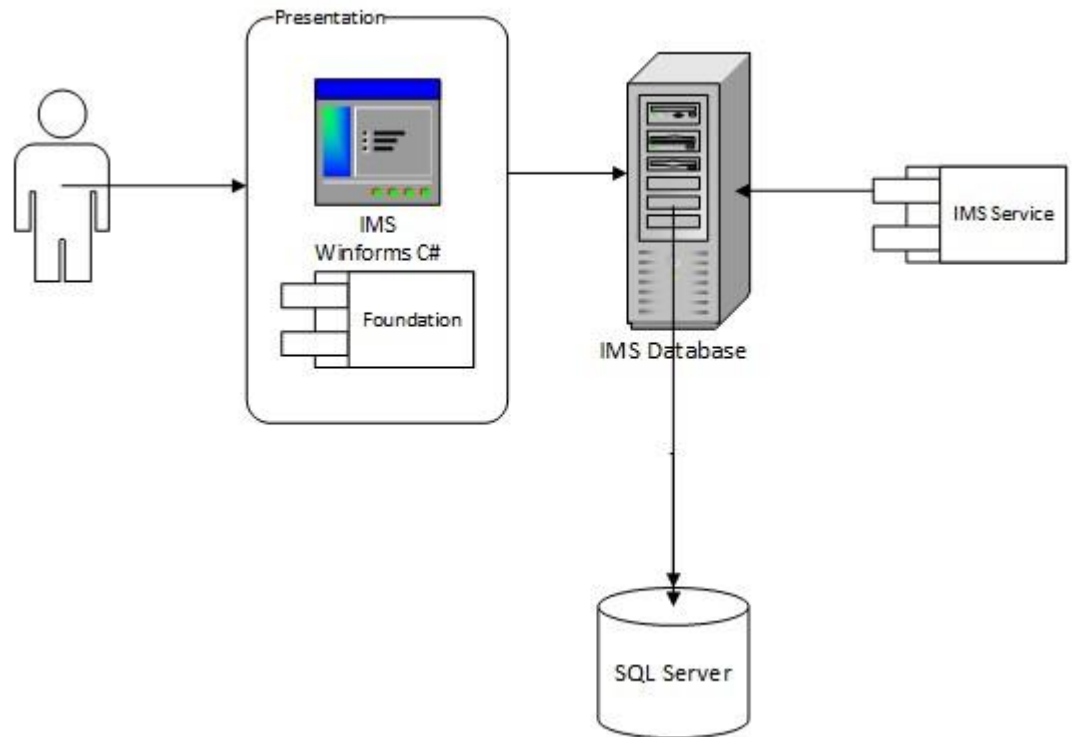


Figure 2.7: Kramerica IMS Architecture (Inedo, n.d.)

## 2.6 Fuzzy Logic

Fuzzy logic has been chosen to be the method used to determine when to order (i.e. reorder point) in this research. The main motivation for this choice is that fuzzy logic deals with uncertainty much better than do mathematical formulars. The demand and lead time of ART medicines and commodities tends to be somehow constant in one period but then tends to vary in certain situations that are not very well explained. As such attempting to develop a mathematical model might yield a model that works works well for a specific period and then is unapplicable on another period. With fuzzy logic only the inputs(antecedents) and outputs (consequents) need to be known, their relationship is not really necessary as fuzzy inference engines use simple rules to map the input space to an appropriate output space by simply using rules in the rules base. This eliminates the need for use of complex mathematical functions to describe how to map an input space to an output space. Such mathematical models usually end up being really good academic literature but usually never capable solving real world problems (Anigbogu et al. , 2011).

It must be noted that it is common (as it will be the case in this research) to use mathematical formulas to generate the initial training datasets that are used to generate

fuzzy rules. But usually after a fuzzy inference system is up and running real world scenarios are then used to generate more precise fuzzy rules.

### **2.6.1 Fuzzy Logic Description**

Fuzzy Logic is a method of reasoning that resembles human reasoning. In fuzzy logic, unlike standard conditional logic, the truth of any statement is a matter of degree. A fuzzy subset  $A$  of a (crisp) set  $X$  is characterized by assigning to each element  $x$  of  $X$  the degree of membership of  $x$  in  $A$  (Cavallaro, 2015). An element can belong to more than one set because of overlapping membership functions of the two sets. Membership functions make it possible to quantify a linguistic term (fuzzy variable) and represent it in a fuzzy set graphically. There can be multiple membership functions applicable to fuzzify a numerical value. Simple membership functions are used because the use of complex functions does not add more precision in the output.

Fuzzy logic overcomes the disadvantages of both table-based and formula-based control systems. Fuzzy logic can handle problems with imprecise and incomplete data, and it can model nonlinear functions of arbitrary complexity. Additional benefits of fuzzy logic include its simplicity and its flexibility (Aliev, 2013).

Fuzzy logic starts with and builds on a set of user-supplied human language rules. The fuzzy systems convert these rules to their mathematical equivalents. This simplifies the job of the system designer and the computer, and results in much more accurate representations of the way systems behave in the real world (Anigbogu et al., 2011).

While computers are more comfortable working with numbers, human are more much more comfortable linguistic variables hence the fact that fuzzy logic is easier to humans than numerical based systems. Fuzzy logic is very flexible and can easily be improved upon by simply changing the rules the fuzzy rule base .Fuzzy logic's flexibility allows for it to be applicable in various fields such as medicine, engineering, logistics, control systems, data mining and several others (Eyoh & Umoh, 2013).

Designing a fuzzy controller requires general knowledge of the process and also knowledge of the effect of the membership functions on the performance of the Fuzzy controller. During the initial design, membership functions are most likely to be chosen in a trial and error basis. This means that membership functions will have to be returned to achieve more desirable behavior. An unwritten rule of determining the number of membership is that there must be at least twice as much plus one number of membership functions for either the inputs (antecedents) or the outputs

(consequents). i.e.  $2N+1$  membership functions, where  $N$  is the number of inputs or outputs. It also noted the more membership functions used the better, but they must always be odd-numbered so as to have proper median membership function.

### 2.6.2 Fuzzy Inference System

Fuzzy inference engines are used to map a set of fuzzified crisp input(s) onto an appropriate crisp output(s). They achieve this by assigning a linguistic variable (fuzzy variable) to a crisp input and then passing it to the fuzzy inference engine which uses a set of rules (rule Base containing fuzzy rules) to determine the fuzzy output that matches closely and then it transforms the fuzzy output to a crisp output. Below is figure 2.8 showing the general structure of most fuzzy inference systems.

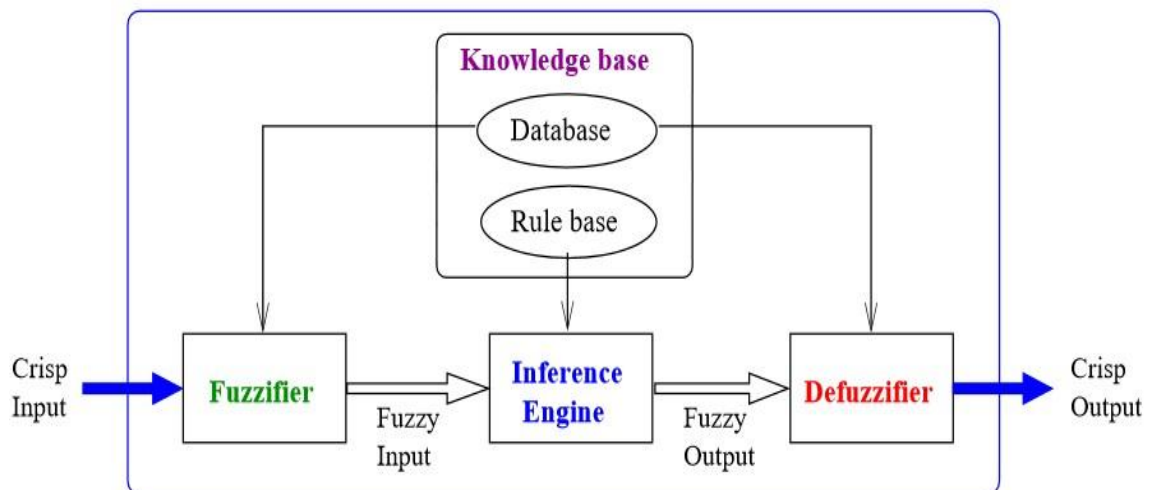


Figure 2.8: Fuzzy Inference System (Adopted from: Cavallaro, 2015)

Below is a brief description of the major components of a fuzzy inference system:

- i. Fuzzification Module - Also known as the fuzzifier, it is used to transform crisp inputs into fuzzy inputs (fuzzy linguistic variables). A crisp input is closely matched to the most appropriate linguistic variable (Fuzzy set), as is usually the case in fuzzy logic when a crisp input exist in more than one set, then the it is assigned to set where it has a larger degree of membership.
- ii. Knowledge Base - The knowledge base also known as the rule base. It is used to store the fuzzy rules which are usually in the form of “IF-THEN” rules. The rules are usually set either from capturing knowledge an actual human expert or by generating them from sample data which is usually referred to as training

data set. A feature of most fuzzy inference engines is the ability to automatically modify rules so as to improve the accuracy of the process.

- iii. Inference Engine - It simulates the human reasoning process by making fuzzy inferences on the inputs and IF-THEN rules, and then assigns a set of fuzzy inputs to the corresponding set of fuzzy output (Cavallaro, 2015). Fuzzy inference engines are usually able to also map fuzzy inputs to a fuzzy output that is not in the rule base.
- iv. Defuzzification Module - Also called the Defuzzifier. It is used to transform fuzzy output into a crisp value. This is achieved used several methods such as the Centroid Method or the Weighted fuzzy mean method.

## 2.7 Conceptual Model

The conceptual model developed for use in this research can be classified a continuous (Perpetual) review model with regard to the type of inventory monitoring implemented. The term Real-Time inventory monitoring will be used for the rest of this document to mean continuous (Perpetual) review. This model can also be classified as single-item model, it will monitor the levels of several items in the inventory database at once but it will technically consider each item individually.

The model will employ fuzzy logic to predict when to order (i.e. Reorder point). The main motivation for the choice is that fuzzy logic deals with uncertainty much better than do mathematical formulars (i.e. statistical methods). With fuzzy logic the relationship between the antecedents (Inputs Demand and Lead Time) and consequents (output Reorder Point) does not really have to be known. All that is needed are training datasets used to generate initial fuzzy rules which closely map any inputs to an appropriate output space. If statistical methods had been used to predict the ROP then an explicit understanding of the relationship between the antecedents and the consequents would have to be developed in terms of mathematical formula. The relationship changes over time as such the model would only be applicable as long as the relationship between the antecedents and consequents stays the same. With Fuzzy logic transactional data(from real transactions) in the inventory database would be used to generate new training data sets which should they contain sets with higher rule weight among the Fuzzy rules' membership functions, then they would replace the respective rule in the fuzzy rule base. This takes care any unknown factors that may affect the relationship between the antecedents and the consequents without any

explicit knowledge, with statistical methods one would have to go back to the drawing board to write another mathematical formula to map the antecedents to the consequents more appropriately. Below is figure 2.9 showing the conceptual model.

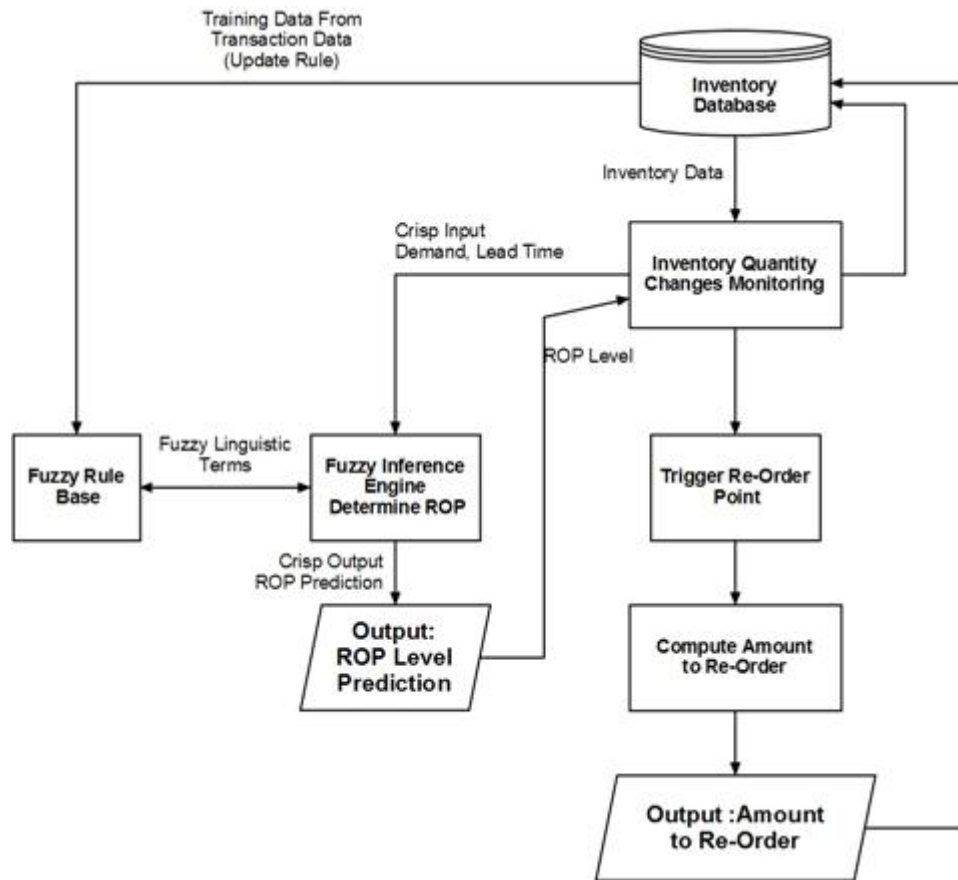


Figure 2.9: Conceptual Model

As can be seen from table 2.3 below, the model's independent variables will also act as the inputs and this will be demand, lead time and maximum stock capacity. The model's dependent variables will be reorder point level (i.e. ROP prediction) and reorder quantity. Below is a description of the variables.

Table 2.3: Summary Model Variables

Independent Variables	Dependent Variables
Demand	Re-Order Point
Lead Time	Re-Order Quantity
Maximum Stock Capacity	

- i. Demand - The model will partially be fuzzy-based and it will use the demand to maximum stock capacity ratio (Demand ratio) and the lead time as crisp inputs for the model; s fuzzy inference engine. The reason for using the demand-to-maximum stock capacity ratio derives from two reasons first being the recommendation by USAID (2008), that the recommend inventory control model for ART medicines and commodities is the maximum-minimum level. This model uses maximum stock capacity as the maximum and uses the fuzzy inference engine to predict the most appropriate ROP level which will be used as the minimum level. Secondly, in order to reuse the same Fuzzy inference engine to predict the appropriate ROP level for all the products in the inventory database, a standard variable has to be used so that it can be mapped on to one or more of fuzzy membership functions of the Demand function, hence the use of the demand ratio.
- ii. Lead time - Lead time values will be in days.
- iii. Maximum Stock Capacity - Will be the maximum stock level for a particular inventory item.
- iv. ROP Level - ROP will also be a ratio of the maximum stock capacity and will be the level (in Percentage) when a reorder should be placed in order to avoid a stockout.
- v. Reorder Quantity (ROQ) - Reorder Quantity will be computed outside the fuzzy inference engine but will use the ROP as a reference. The reason for computing the ROQ outside the fuzzy inference engine is that from the study by Anigbogu et al. (2011), it was noticed that the ROQ seems to belong to a single output membership fuction in all test data sets, which is uppermost in a five-membership function output, this indicated that the ROQ has little fluctuations and and as such using fuzzy logic to predict it is not very useful. Also other factors may be at play beyond the control of the system and the management and as such it is better to compute the ROQ using mathematical formualars (i.e equation 2.3 and equation 2.4) shown below:

Equation 2.3 below, will be used when the reorder is due to the trigger of the ROP level.

$$ROQ = \left( \begin{array}{c} \text{Max} \\ \text{Stock} \\ \text{Capacity} \end{array} \right) - \left( \begin{array}{c} \text{Average} \\ \text{Demand} \end{array} * \begin{array}{c} \text{Lead} \\ \text{Time} \end{array} \right) - \left( \begin{array}{c} \text{Stock on} \\ \text{Hand at} \\ \text{ROP} \\ \text{level} \end{array} \right)$$

*Equation 2.3: Reorder Quantity Formula after ROP Trigger*

Equation 2.4 below, will be used if an order is placed at any other time apart from the ROP level trigger point.

$$ROQ = \left( \begin{array}{c} \text{Max} \\ \text{Stock} \\ \text{Capacity} \end{array} \right) - \left( \begin{array}{c} \text{Average} \\ \text{Demand} \end{array} * \begin{array}{c} \text{Lead} \\ \text{Time} \end{array} \right) - \left( \begin{array}{c} \text{Stock on} \\ \text{Hand at} \\ \text{time of} \\ \text{order} \end{array} \right)$$

*Equation 2.4: Reorder Quantity Formula at Any Time*



## **Chapter 3 : Research Methodology**

This chapter outlines the methodology used in this research and more specifically the research design chosen, the target population and sampling method. It also includes the data collection techniques to be used and methods that will be employed to analyse the data after it has been collected. This chapter also looks at the issue of research quality.

### **3.1 Research Design**

The research design can be described as the general plan on how various aspects of the research will be organized together in a manner that is both orderly and meaningful, so as to ensure the research problem will be properly addressed. It establishes how the data collection, measurement and analysis will be conducted. The research design's main purpose is to make sure that the gathered evidence allows for the research problem to be effectively addressed in the most precise and logical manner. The research problem usually dictates the research design to be used, not the other way around.

This is an applied research whereby investigations through interviews and structured questionnaires are used to study the bottlenecks of the monitoring of inventory of ART medicines and commodities, and thereafter an immediate solution in terms of a software application will be offered. The Applied research design fundamentally goes through a distinctive cycle that at first involves an exploratory stance whereby an in-depth grasp of the problem at hand is established and an intervention strategy plan is produced. During the execution of the intervention appropriate observations are made in different ways (University of Southern California [USC], 2015).

Applied research usually involves the immediate intervention to try and solve a problem being investigated while in contrast basic research involves research usually simply to gain more knowledge on a certain problem. Basic research is usually a precursor to applied research and they tend to complement each other in the long run (Coghlan & Brannic, 2014).

## 3.2 Population and sampling

### 3.2.1 Research Location

The research location of concern is Nairobi County, which also happen to be the capital of Kenya. HIV counselling and testing and linkage to care and treatment are important steps in reducing the sexual transmission of HIV. Despite the huge importance of HIV testing as a way to increase prevention and treatment, about 73 per cent of people in Nairobi County had never tested for HIV by 2009 (National AIDS Control Council [NACC], 2014). According to the NACC ( 2014) Nairobi has the highest number of PLWHA as can be seen from the figure 3.1 below;

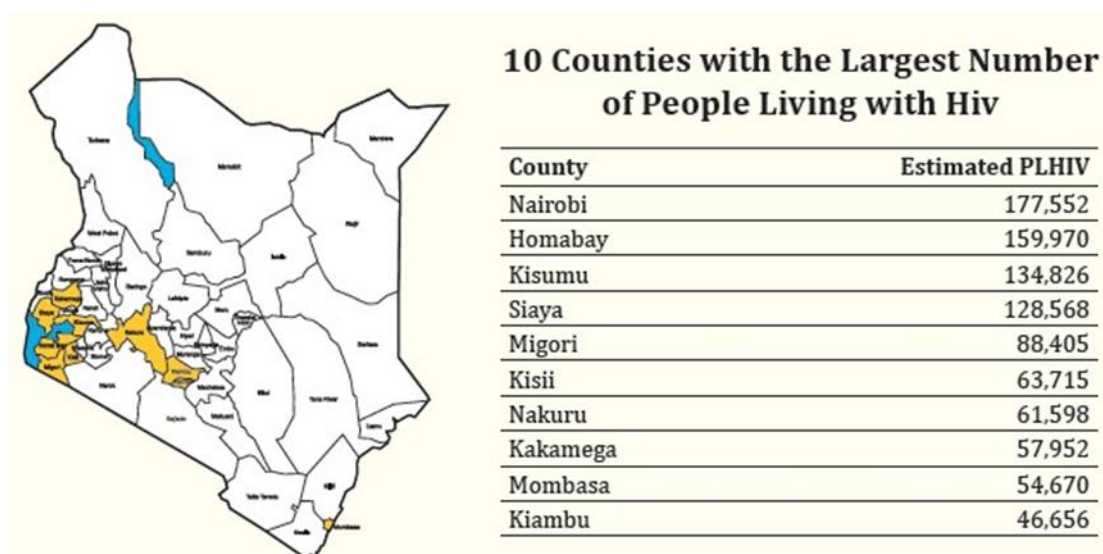


Figure 3.1: Ten Counties with Largest PLWHA (NACC, 2014)

The population 177,552 PLWHA includes 164,658 adults and 12,894 children. Despite the total number of PLWHA in Nairobi being the highest in the Nation, it only has the thirteenth (13<sup>th</sup>) highest coverage of ART medicines for adults in need, as can be seen in table 3.1 below, and the second (2<sup>nd</sup>) highest coverage among children in need as seen in table 3.2 below.

*Table 3.1: Adults ART Coverage in Nairobi (NACC, 2014)*

<b>Indicator</b>	
Adults in need of ART	102,103
Adults receiving ART	93,714
County ART adult coverage	92%
National ART adult coverage	79%
County ranking of ART coverage among adults*	13

*Table 3.2: Children ART Coverage in Nairobi (NACC, 2014)*

<b>Indicator</b>	
Children in need of ART	9,398
Children receiving ART	6,988
County ART children coverage	74%
National ART children coverage	42%
County ranking of ART coverage among children	2

*\*In this ART coverage ranking, the county with the highest coverage is 1, while the county with the lowest coverage is 47.*

Currently ART medicines are given to those who are considered to be the sickest in terms of disease progression. This determination of who is the sickest is done through the CD4 count with those with a lower count considered to be the sickest and most in need of ART medicines. A higher CD4 count usually indicates a stronger immune system in an infected patient. Those in need of ART medicines are considered to be those with a CD4 count of 350.

Most of the distribution of the ART medicines and commodities was until recently (i.e. September 2015) handled by Kenya Pharma, a donor funded project under the umbrella of USAID. But as of September 2015 Kenya Pharma has handed over its operations to Kenyan agencies namely KEMSA (Kenya Medical Supplies Authority) and NASCOP (National AIDS and STI Control Programme) (KEMSA,

2015). The use of an electronic supply chain management system (E-SCM) was one of the factors that allowed Kenya Pharma to deliver ART medicines well. This electronic system has also been transferred to KEMSA (KEMSA, 2015).

Disbursement of ART medicines and commodities in Nairobi is done through the existing health facilities, both public and private. Treatment is provided for free for all those in need through a combination of donor funding and the government's budget through the Ministry of Health (Friedman, 2012). NASCOP currently has over 14 Voluntary Counselling and Testing Centres (VCT) in Nairobi (United Nations Cares [UN Cares], 2010). Other VCT centres in Nairobi are run by Médecins Sans Frontières (MSF – alias Doctors Without Borders) which has 4 VCT centres, all public hospitals and as well as several private hospitals (UN Cares, 2010). All these centres offer testing, counselling and treatment with ART medicines free of charge to PLWHA (UN Cares, 2010).

### **3.2.2 Target Population**

The target population includes those who are involved in the logistics, distribution, storage and disbursement of the ART medicines and commodities, this includes the decision making manager in-charge at ART medicines issuing centres/dispensaries (usually doctors) and logistics personnel at KEMSA and National AIDS and STIs Control Programme (NASCOP). The exact target population will be the centres run by NASCOP (14) and the centres run by MSF (4) and therefore a population of 18 ART disbursement centres. In addition to the personnel at NASCOP and KEMSA the personnel in charge of these 18 centres the total of population under consideration becomes 20.

### **3.2.3 Sampling**

Convenience sampling is employed to reach the target population in their respective places of work and it comprises of those people easiest to reach. As a non-probability sampling technique convenience sampling tends to take a sample of those whose are easily available, as such no sampling formula is usually necessary (Laerd Dissertation, 2012a).

Purposive sampling is also employed to target specifically those knowledgeable about the logistics, storage, distribution and disbursement of ART medicines and commodities. Purposive sampling also referred to as subjective, judgemental or

selective sampling, is a type of non-probability sampling that depends on the judgment of the researcher in selecting the sample size based on some desired merit they have identified, the target population can be people, events, cases/organization or even some data (Laerd Dissertation, 2012b).

For this research a sample size of ten respondents is chosen. The sample of ten is half of the total population under consideration of twenty, this is because the total population is quite small and ideally all in the population should be targeted, but this may not be possible due the geographical distribution of this centres within Nairobi, as well as due to time and financial limitations of the research. A fifty percent sample size is considered ideal in this case and is chosen arbitrarily without the use of any sampling formula (as is common with non-probabilistic sampling techniques) due to the population under consideration being small. It is also worth noting that convenience and purposeful sampling being non-probabilistic sampling techniques tend to lead to small sample sizes when used in comparison to probability sampling techniques.

The sample size of respondents will have to be knowledgeable about the storage, distribution and disbursement of ART medicines and commodities. The target population is not quite known and may be hard to reach, as a result the researcher will interview only those among the target population whom are readily available.

### **3.3 Data Collection Methods**

Below are the tool that will be used for data collection:

#### **i. Interviews**

Since the intended sample size is potentially small structured Interviews will be conducted in conjunction with a structured interview questionnaire to establish the nature of the current ART medicines storage and distribution system as well as how inventory is monitored. The choice of interviews is ideally the best option in this research since it will provide immediate feedback. Prior planning of the questions to be asked is a key aspect structured interviews which enables for almost identical reproduction of the interview with other interviewees. This makes it possible during analysis to discern and categorize the responses from interview and to come up with some summary conclusion about the respondents' answers. This type of interviews are of great preference due to the fact they provide more comprehensive information in comparison to other data gathering techniques, such as surveys (Woods, 2011).

## **ii. Structured Interview Questionnaires**

Structured interview questionnaire containing similar questions to those used in the interview will be used for those individuals for who a face to face interview will not be possible.

### **3.4 Data analysis**

Interview data is a form of qualitative data. This research will use an interpretive technique which is the observer's impression. It will be used to summarize the results collected from the structured interviews. Observers' impression means using expert or bystander observers to examine the data, interpret it via forming an impression and report their impression in a structured way and sometimes includes quantitative information about the frequency of occurrences (Simpson, n.d.). Use of observers' impression is justified in this research because the interview questions will direct and will be asked on a specific target individual. Description of critical themes will be used, all determined by the observer.

### **3.5 Research Quality**

Research quality usually describes the scientific process which includes all facets of the research design and more specifically relates to the judgment criteria used with regard to the methods employed in relation to the research question, target sample selection, evaluation of the outcomes and protection against biases that might result in random, systematic and inferential errors (Lohr, 2004). According to Litman (2012), honesty and good judgment are needed to ensure the overall quality of a research study. Good quality research notifies the audience about potential errors, limitations and conflicting evidence in the research process. Sources of information are to be carefully chosen and any neglected factors that may be of importance are to be pointed out. The choice of analysis techniques employed and why they were chosen should also be explained.

To ensure the quality, validity, reliability and objectivity of the research, judgement and honesty will be the central principle that guide this research. Transparency of the procedures, methods and design of the research will ensure an objective, independent and balanced approach to this research. Methods that are most appropriately suited to address the research questions of this research have been chosen and are backed up by reviewed literature. This being an applied research the researcher

will provide sufficient description of the intervention to be applied in terms of a web based solution.

Another way of ensuring research quality is during the analysis of data gathered. To ensure the quality of the data collected during interview it will be checked for outliers and for explanations why they are so. Also the researcher will look for contradictions and gain feedback from participant to gain clarity on the respective issue. The researcher's analytical capabilities greatly influence the applicability and accuracy of the data collected, and as such they have to ensure that data analysis yields proper results (Woods, 2011).



## Chapter 4 : System Design and Architecture

This chapter presents the brief summary of the data collected as well a summary of the data. The chapter then presents the system requirements and then presents the system design. The chapter finally presents the system architecture used.

### 4.1 Presentation of Findings

Data collection was conducted to gain insight into how the monitoring of ART medicines and commodities is conducted and the challenges experienced. Structured interviews and questionnaires were used as primary sources. Structured interviews were conducted with seven successful responses, this being 70% percent of the selected sample size of ten. Three of the responses were face to face interviews conducted in conjunction with a printed copy of a structured interview questionnaire and the other responses were collected through an online equivalent of the structured interview questionnaire using Google forms. Some of the responses had to be obtained online due to the respondents being unavailable due to busy schedules and travel, therefore a face to face interview could not be conducted.

The respondents included a logistics personnel from KEMSA headquarters in Embakasi, Nairobi, five doctors in-charge of ART medicines dispensing centres located in Nairobi and a doctor who is a HIV/AIDS researcher who deals with research concerning ARV medicines storage and distribution (and supply chain in general) at NASCOP located at Kenyatta National Hospital. As stated before, convenience and purposeful sampling techniques were employed which tend to lead to lower number of respondents, but this is sufficient for this research.

Observer impression is used to summarize the collected data. It is important to state that according to the conventional view, qualitative methods produce information only on the particular cases studied, and any more general conclusions are only propositions (informed assertions). Below is a summary of the key questions responses' from structured interview questionnaires.

#### 4.1.1 *Current limitations/Problems/Bottlenecks of the system*

The questing asked was: “*What current limitations/Problems/Bottlenecks are clearly evident in the system?*” The summary of the four responses are shown in table 4.1 below.

Table 4.1: Current Problems That Are Clearly Evident In the System

Response number	Response
1	The system do not perform to full expectation, there are a lot of missing functionalities.
2	The system is electronic but it simply gets used as record keeping system.
3	People are not educated enough on how to use the system
4	The problem is it's an offline system that makes it 40% automatic and 60% manually .according to some of our geographical locations an offline system leads us to the delay of submitting the reports and the delay of getting support/help/solutions at the right time when needed.

#### 4.1.2 Cases of Stockouts, Excess Stock and Obsolete Stock Occur

The question was: “Do cases of stockouts, excess stock and obsolete stock occur?” All the respondents answered with yes to the stock-outs and five of the respondents said yes to the obsolete stock. It can be concluded that cases of stockouts were indeed present in the distribution and issuing of ARV medicines. A summary of the responses can be seen in figure 4.1 below.

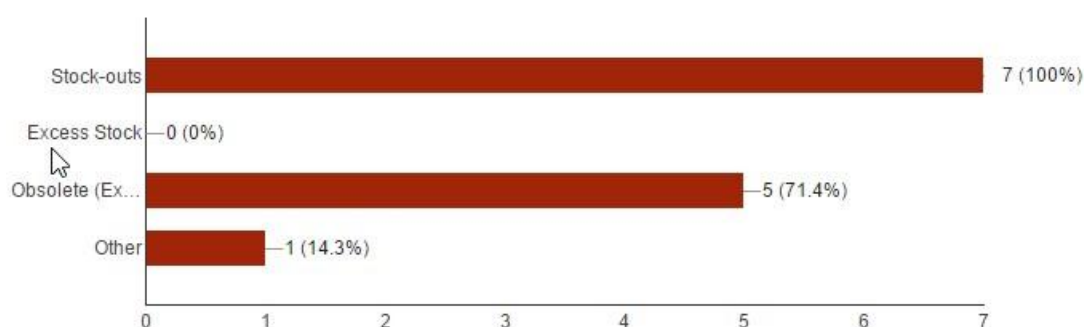


Figure 4.1: Stockouts, Excess Stock and Obsolete Stock

#### 4.1.3 Use of Electronic System for Decision Support

The question was: “. To what extent does the electronic system get used for decision support with regard to inventory monitoring and control?” Six respondents indicated that the systems are used passively and one stated that it is not used for that at all. It can be concluded, as one of the respondents told me a follow up question,

“The electronic systems despite being in use for issuing of the medicines, they are not really there for decision support issues but rather for record keeping purpose?” A summary of the responses can be seen in figure 4.2 below.

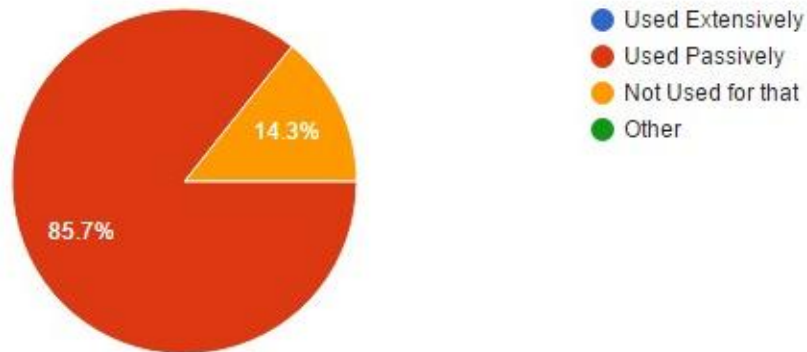


Figure 4.2: Use of Electronic System for Decision Support

#### 4.1.4 Reorder of ART Medicines

The question was: “With regard to re-ordering ART medicines, when are orders placed?” One respondent said after a fixed order period, two said when inventory runs out and the rest said when the inventory runs out. A follow-up question on two of the respondents asked them about the predetermined fixed order level and one stated that it is actually very close to zero in the actual sense and the other stated that it is determined arbitrary when someone manually notices inventory is running low. A summary of the responses can be seen in figure 4.3 below.

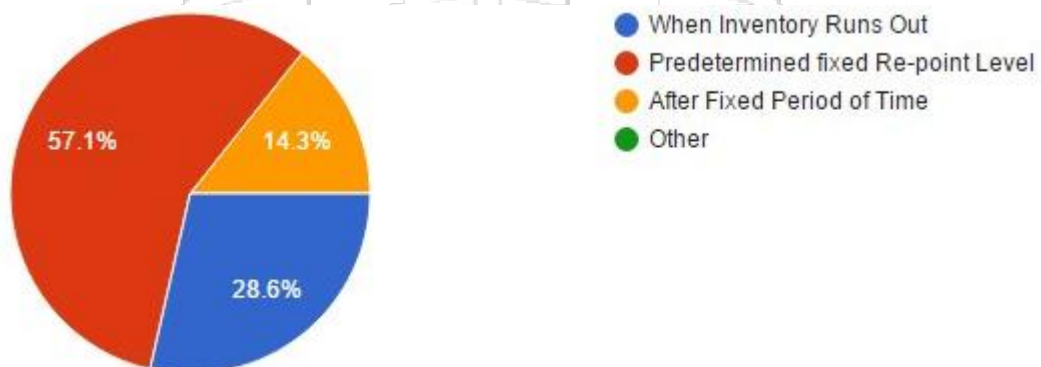


Figure 4.3: Reorder of ARV Medicines

#### 4.1.5 Demand Variation for ART Medicines

The question was: “Does the demand of the ART Medicines vary over time or is it constant always?” Five of the respondents indicated that varied slightly ,one said it was somehow unpredictable due to patients from other centres coming to a centre

not designated for them when their designated centre runs out of medicine. A summary of the responses can be seen in figure 4.4 below.

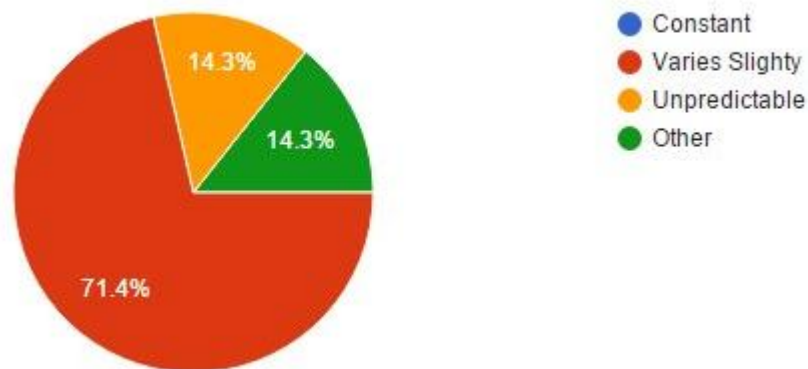


Figure 4.4: Demand Variation for ART Medicines

#### 4.1.6 Monitoring of ART Medicines

The question was: “How is the inventory quantity level of various ART medicines and commodities tracked?” Five respondents stated that the inventory monitoring is hybrid while two said that it is completely manual. A summary of the responses can be seen in figure 4.5 below.

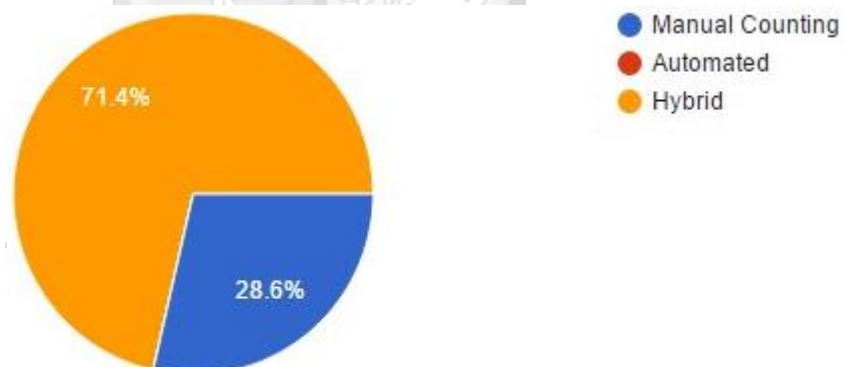


Figure 4.5: Monitoring of ART Medicines

#### 4.1.7 Factors Considered During Reorder of Medicines

The question was asked in order to know which factors are considered when determining ordering quantity and five respondents replied stating that all they consider the quantity and the demand. 2 stated that they consider lead time as well. One follow-up question the respondent said that the lead time usually not considered as it is out of their control.

#### **4.1.8 Summary of all Interview Questions**

The summary of the interview question and that of the structured interview questions can be concluded to indicate that current inventory monitoring systems for the ART medicines are manual despite the most of the centres in Nairobi using electronic systems for the issuing of medicines. Stock control and monitoring capabilities are present to a degree in the electronic systems but the systems get used passively for decision support with regard to when to reorder. It can also be deduced that when to order and how much to order are determined as fixed points. It is also stated that cases of stockouts are prevalent all over, as well as cases of obsolete medicines.

The problem of stockouts and obsolete stock cannot be purely ascribed to the use of inadequate inventory control and monitoring systems, but from the findings it can be concluded that the systems in use are not optimized nor are they systematic (i.e. do not use a specific systematic procedure). It can be concluded that the deployment of an inventory control and monitoring system will help ease the situation in better predicting when to order and how much to order while keeping track of the inventory in real time as it is issued through the electronic systems.

## **4.2 Requirements Analysis**

To address the issues identified in the summary of data collection, a web-based system based on the model developed in this research will be developed. The system will be used to monitor the level of inventory in real time as ART medicines and commodities are issued out. The system's main functionality will be to predict when a reorder for the inventory should be placed to avoid a stockout of an item in the inventory.

### **4.2.1 Functional Requirements**

- i. The system should be able to monitor inventory quantity changes in the database in real-time.
- ii. The system should be able to monitor inventory of multiple items collectively.
- iii. System should be able to notify the users and management when inventory of an item is learning low.
- iv. The systems should be able to learn and change average periodic demand and lead time automatically.

- v. The system should be able to predict the Re-order point using the fuzzy inference engine.
- vi. The System should be able to track the Product lifetime (Item's Shelf Life).

#### **4.2.2 Non-Functional requirements**

- i. Performance: The system should be able to monitor a large amount of inventory data at once and it should be able to have high throughput and a short as possible response time.
- ii. Speed: The system will be an addition to an existing inventory management system and as such it should be able perform fast enough without causing a time lag in the current system. It should at least perform as fast as the current system or faster. The speed that matters the most in ensuring the system runs fast enough is the speed of reading/writing to the database.
- iii. Scalability: It should be possible to make the system capable of monitoring much more inventory data simultaneously by simply upgrading the underlying hardware only and not necessarily the system itself.

### **4.3 System Design**

This systems design defines the components, modules, interfaces and data for the inventory monitoring system based on the requirements set. The system design here is shown through description of the modules in the system and then several modelling diagrams are used to visualize the system design further.

#### **4.3.1 Outline of the prototype**

The system consists of several modules and interfaces as indicated below:

- i. Module to track Inventory in real time and issue messages on inventory levels, such when Inventory is running low. This module will also trigger the reorder point when it is reached and also informed those concerned that ROP level has been reached.
- ii. Module to predict the reorder point using a fuzzy inference engine.
- iii. Module to track the product lifetime (Expiry Dates) of items in the inventory.

The scope of this research as mentioned will not develop the rest of the inventory management system as it already exists. The prototype involves developing the

inventory monitoring subsystem and the rest of the inventory management will be simulated in order to validate the model.

### 4.3.2 Data Flow Diagrams

Data flow diagrams (DFDs) are used to show a brief overview of the system and also to graphically show the flow of data through the inventory monitoring system. The DFDs show what kind of information will be input to and output from the system, where the data will come from and go to, and where the data will be stored. The DFDs developed show that the inventory monitoring system will have data flowing to and from three main external interfaces namely the management interface, transactional processing interface and the inventory database. Below are the two data flow diagrams, figure 4.6 the context level DFD and figure 4.7 the Level 0 DFD.

#### a. Context Level Data Flow Diagram

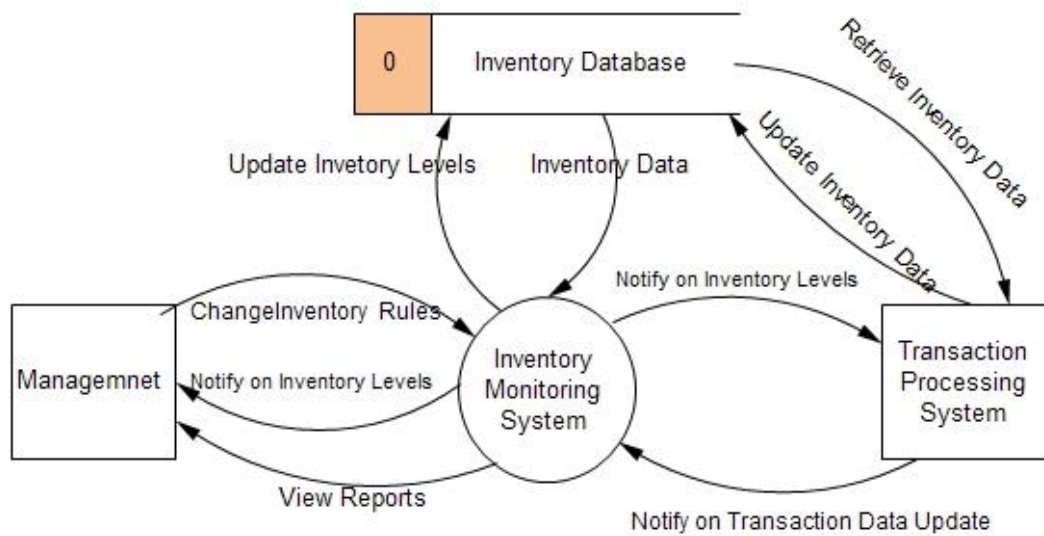


Figure 4.6: Data Flow Diagram: Context Level

**b. Data Flow Diagram Level 0**

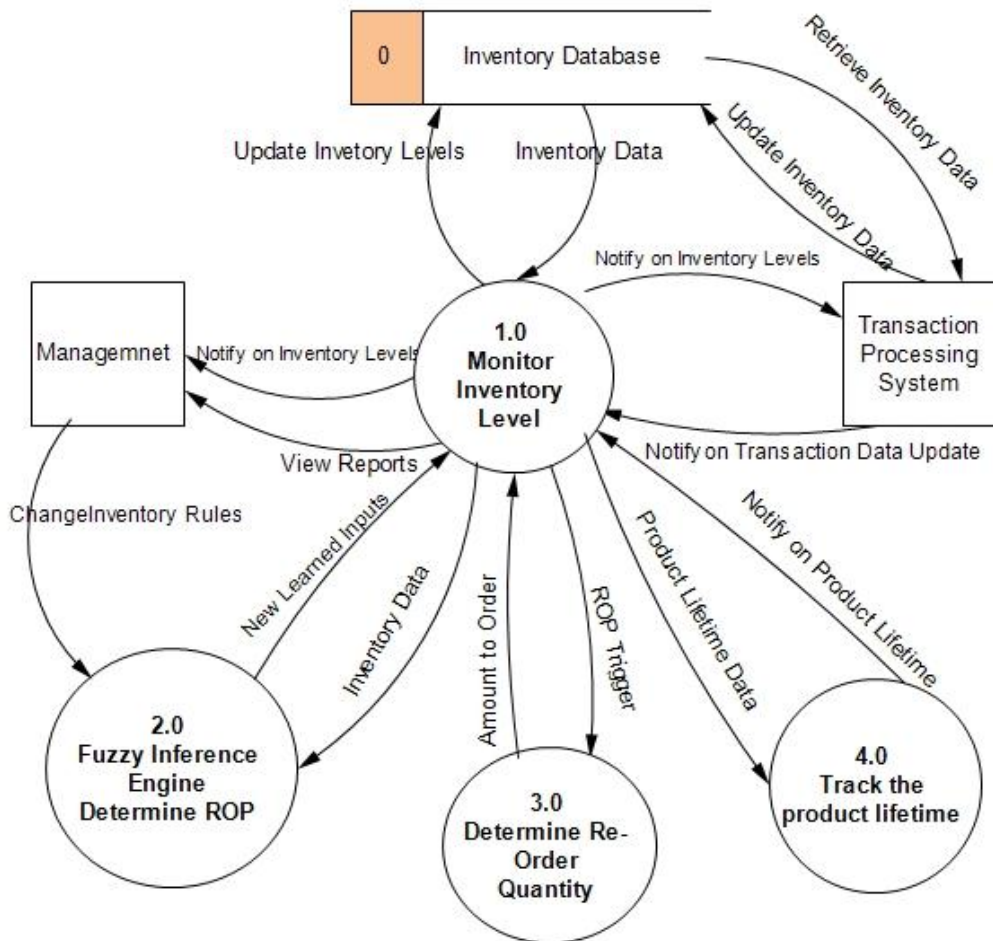


Figure 4.7: Data Flow Diagram Level 0

**4.3.3 Sequence Diagrams**

The interaction between processes in the system are shown using sequence diagrams. The sequence diagrams show how processes operate with one another and in what order. Two sequence diagrams are shown below.

**a. Sequence Diagram for Real Time Monitoring**

This sequence diagram below (figure 4.8) shows the interaction between processes and modules during real-time monitoring of inventory during transaction processing which are either the issuing or receiving of inventory items.

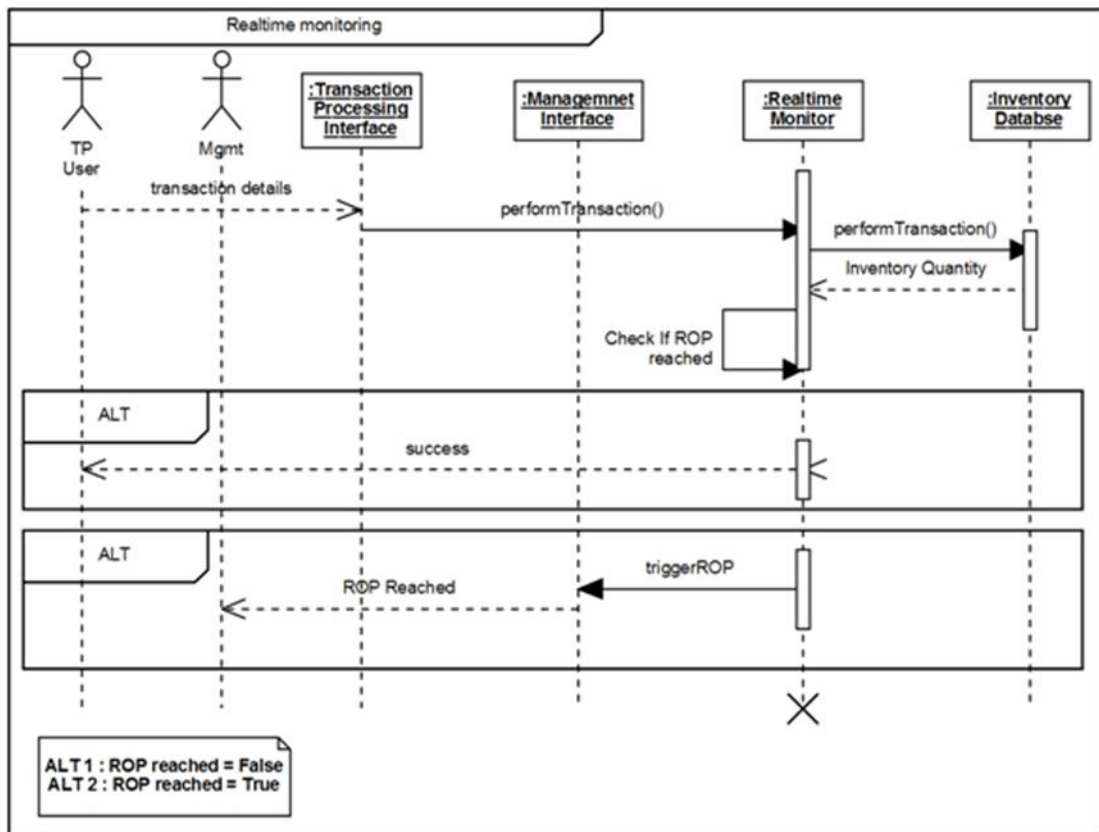
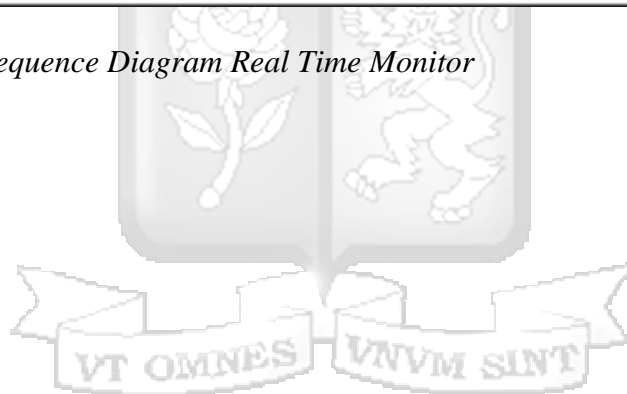


Figure 4.8: Sequence Diagram Real Time Monitor



**b. Sequence Diagram Periodic Reconciliation of Demand, Lead Time, ROP AND Product Life Time**

The sequence diagram below (figure 4.9) shows interactions between processes during the automated periodic review of inventory quantity, reorder point and product lifetime of each respective item in the inventory database.

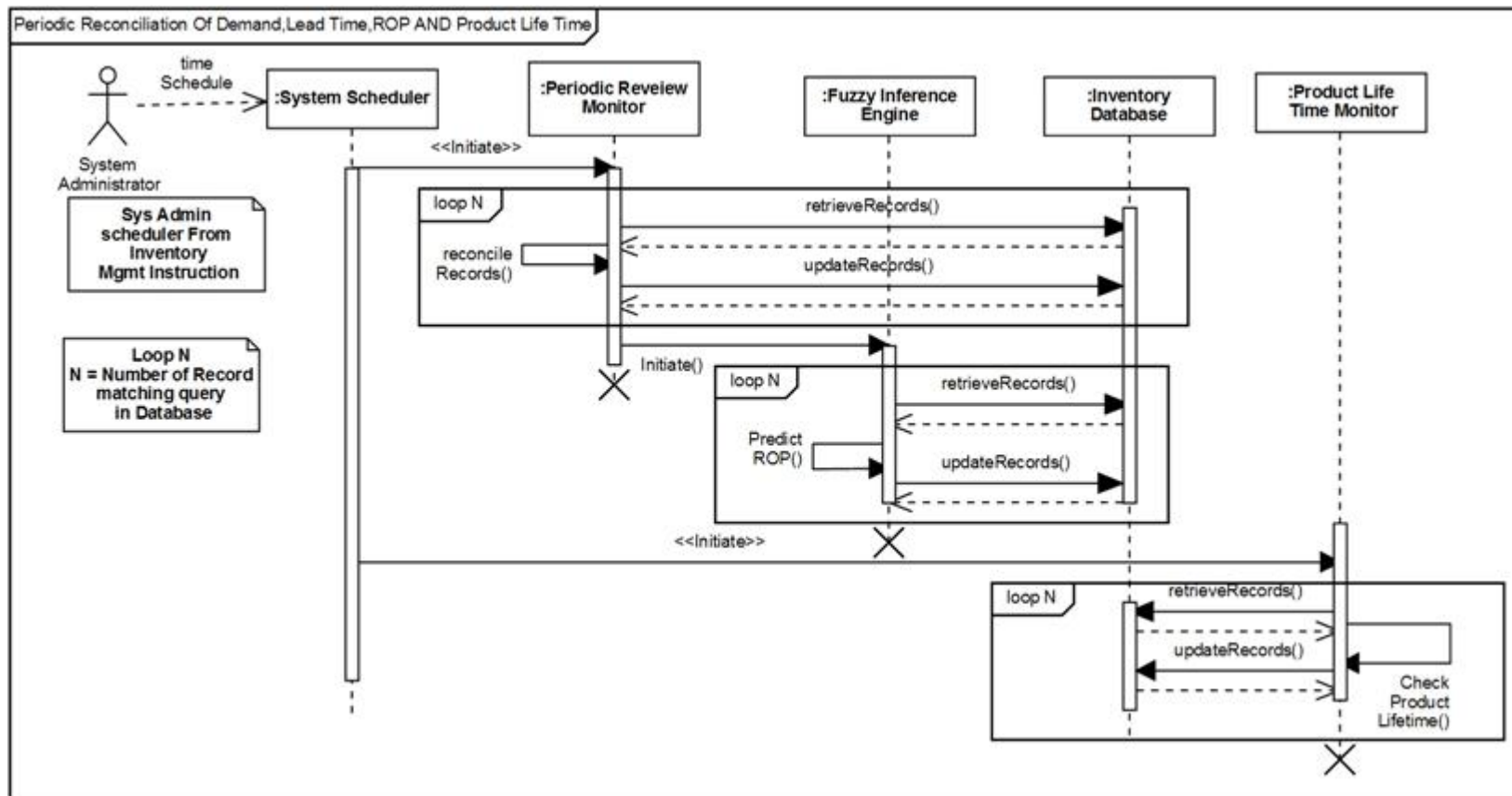


Figure 4.9: Sequence Diagram- Periodic Reconciliation

### 4.3.4 Entity Relationship diagram

Modelling of the Entity Relationship Diagram (ERD) was done in MySQL Workbench. Below is the ERD (figure 4.10) that was generated which shows the tables used and their relationships.

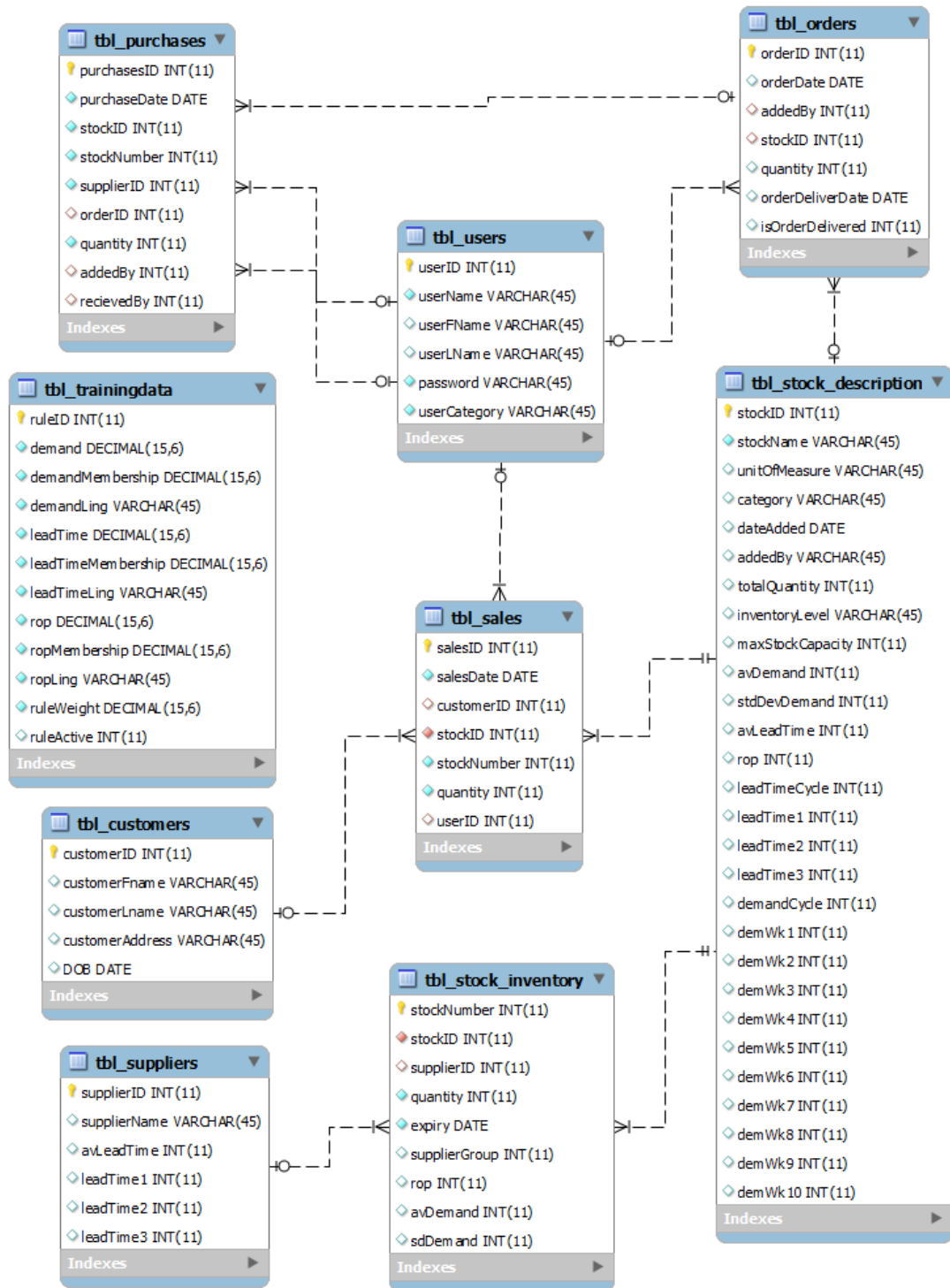


Figure 4.10: Entity Relationship Diagram

#### 4.4 System Architecture

The system architecture is web-based and utilises a client-server architecture. The choice of a web-based architecture is generally due to its ubiquity as well as the inherent centralized setup environment which allows for easy deployment and maintenance. The system architecture is shown in figure 4.11 below and it defines the structure of the system to be developed.

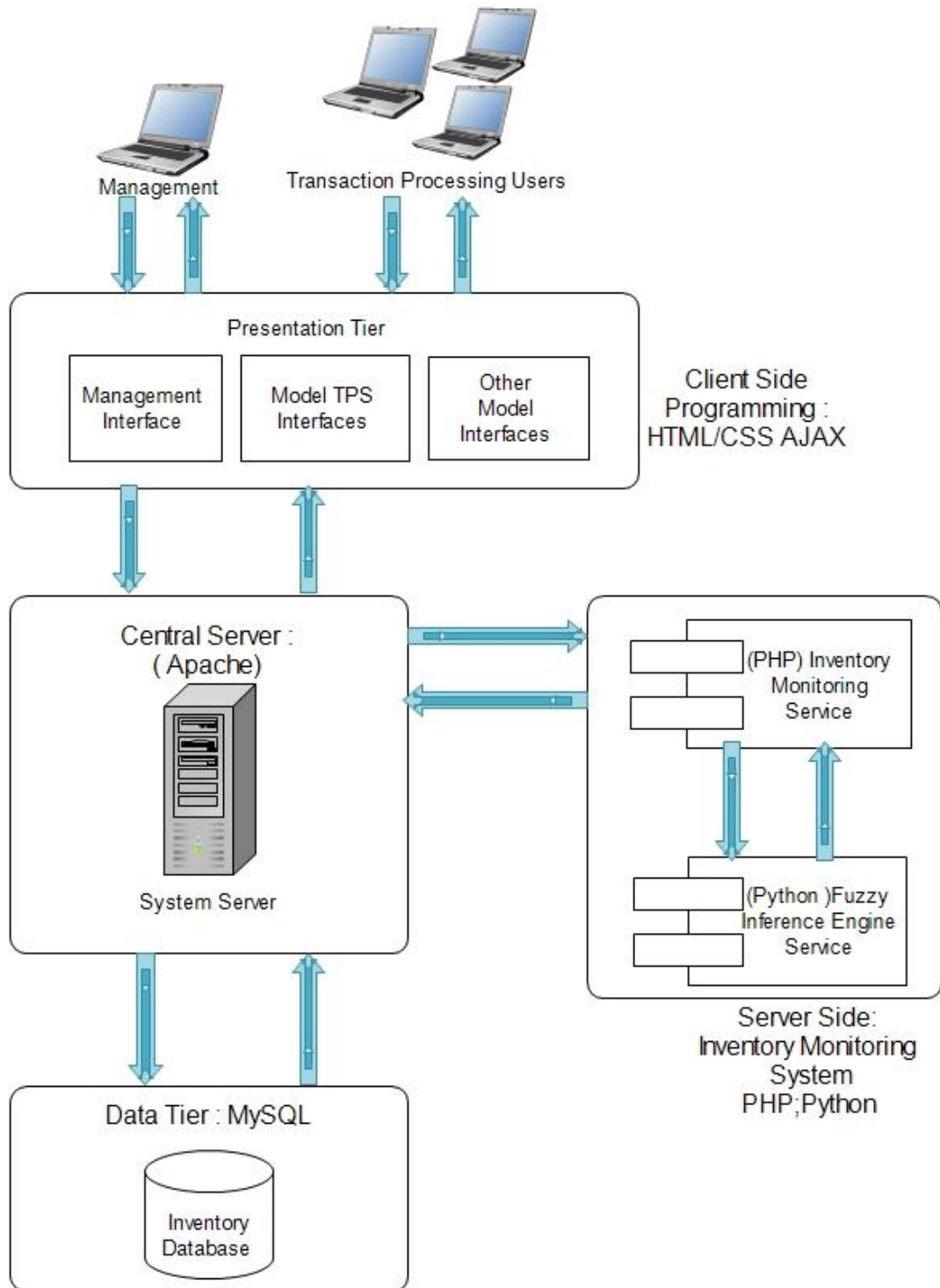


Figure 4.11: System Architecture

## Chapter 5 : Implementation and Testing

This chapter presents the details implementation of the inventory monitoring model developed with regard to tools used and procedures followed. Finally the chapter then presents details on how the tests were conducted and the results of the tests.

### 5.1 Implementation

The System is developed to be an add-on module to the already existing larger Inventory monitoring system that is web based system that runs over a network in a client-server architecture. The system is developed using PHP and AJAX on the server-side scripting language and HTML/CSS on Client-end. AJAX and JavaScript are used as the client-side scripting languages. MySQL was used as the database management system. Apache is used as the web server application. Python 3.4 is used to implement the fuzzy inference engine which is employed to determine the reorder point. FISpro 3.5 is used to generate the fuzzy rules based on an input training data sets of 120 scenarios. Sublime Text 2 is used as the text editor for coding in both PHP and Python.

It must be noted that the choice of languages of PHP and Python is because they are scripting languages. Scripting languages unlike compiled programming languages do not need to be compiled, this makes the development faster and easier because adding/removing features is just a matter of changing lines of code and executing the script, no need to recompile again, and this allows for complex tasks to be performed in relatively few steps (Scottish Qualifications Authority [SQA], 2007). The choice of languages and architecture is appropriate as this also allows for the system to be platform independent as all the above mentioned are platform independent and also open source. Below is summary of the setup used to develop the system.

- i. Server: OS 64-Bit Ubuntu 14.04 (Debian Linux) ;8GB RAM ; Intel Core i3 Processor 2.1GHz (x4) ;
- ii. Apache 2.4.9 (64-Bit)
- iii. PHP 5.5.12
- iv. MySQL 5.6.17 (64-Bit)
- v. Python 3.4 (winPython SciPy Bundle + scikit-fuzzy)
- vi. FISpro 3.5 (Fuzzy Inference System Professional)

- vii. AJAX (Asynchronous JavaScript and XML)
- viii. Sublime Text 2 (Text Editor)

### 5.1.1 Interface

The inventory monitoring system will use a web based interface for the graphical user interface (GUI). HTML/CSS, JavaScript and AJAX are used for the front end web interface and PHP and AJAX are used for the back end and database connection in the web interface (note: AJAX works in both the front end and Back end). The fuzzy inference engine and fuzzy rule base will be implemented by Python 3.4 which will run in a command line interface (terminal), and will not have a GUI during normal runtime. Python scripts will be executed from PHP using the “*exec( )*” function to call on the fuzzy inference engine, results will either be sent to the MySQL database straight from python or back to PHP as per the instructions. Below figure 5.1 showing a sample screen shot of a web interface used for performing issuing of ART medicines simulations. More sample screenshots can be found in the appendices (Appendix I).

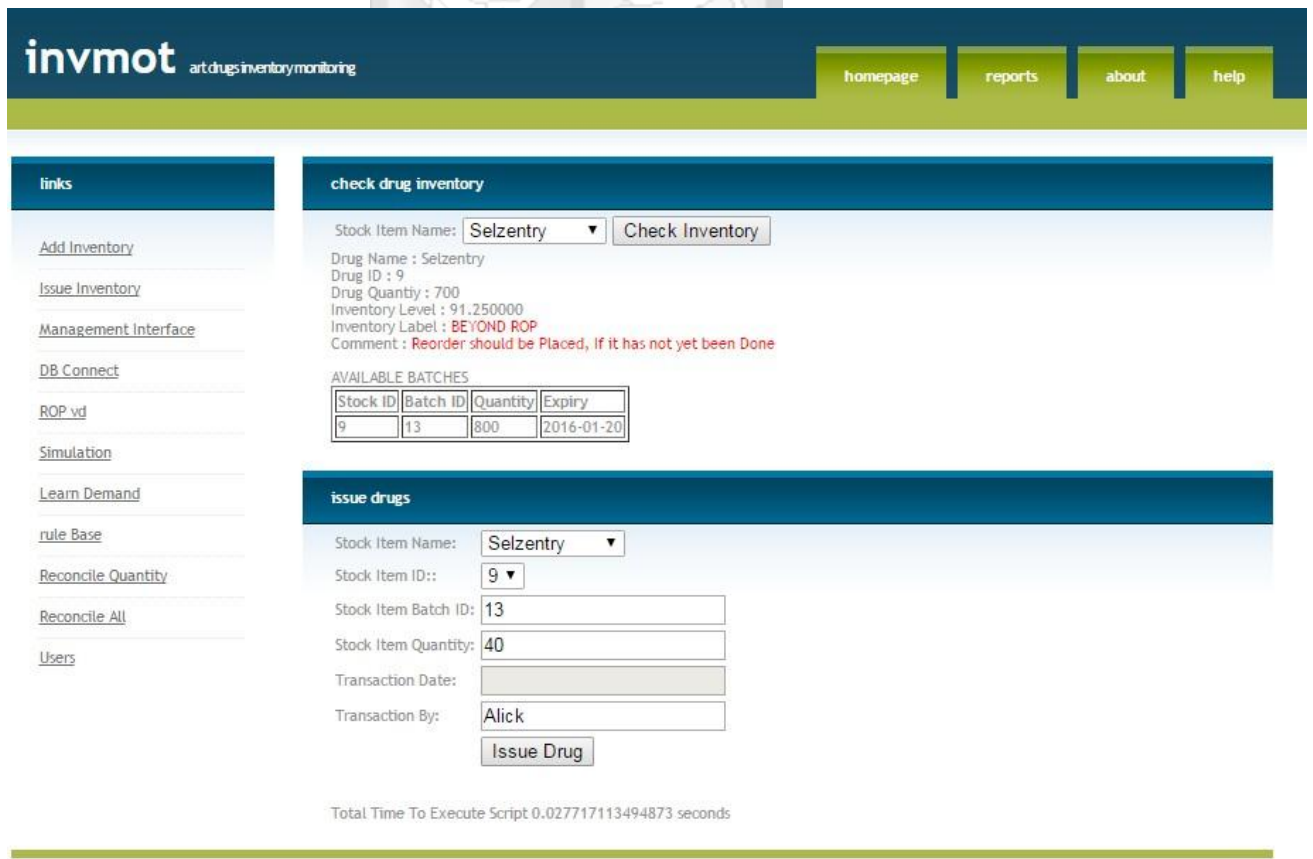


Figure 5.1 : Screenshot of ART Medicine Issuing Interface

### **5.1.2 Database**

The inventory database is implemented using MySQL relational database management system (RDBMS). The actual database storage engine within MySQL is InnoDB. The implemented database contains all the necessary tables for the inventory monitoring system to work as well as tables to help simulate the sales, orders and purchases. The actual database is created by forward-engineering an Entity Relationship Diagram that was modelled using MySQL workbench.

### **5.1.3 Inventory Monitoring**

The main Inventory monitoring module will be implemented in PHP. It will consist of two following sub-modules, the first being the real-time inventory monitor and the second being the periodic reconciliation script.

#### **a. Real-Time Inventory Monitor**

Real time inventory monitoring will be implemented in PHP and will be embedded in all transactional processes. This is done so as to implement a continuous (perpetual) review system. It will check the inventory quantity and see if it approaching ROP level. If ROP level is reached then a message preferable an email will be sent to management to inform them that ROP level is reached and that a reorder is recommended.

#### **b. Periodic Reconciliation Script**

The periodic reconciliation script's main characteristic is that it will be automatically invoked periodically. The set periodic value currently is on a weekly basis. This PHP script will run in the command line (PHP CLI) and not with a GUI (PHP CGI). The automated periodic execution of the script is achieved by scheduling the script to be executed by the UNIX scheduling service Cron (The environment being Ubuntu 14.04). If the system were to be run in a Microsoft Windows platform then the scheduling would have to be done by the windows service called "Scheduled Tasks". Therefore every week at when Sunday begins at Midnight Cron will execute the script automatically. Below is what the script will achieve after it is executed.

- i. It will check the Sales, Orders and Purchases tables in the database and will compute new Average demands from the sales tables for each respective Inventory Item. It will also check the orders and purchases tables to

determine the time between orders being placed and being received to use compute lead time for each respective inventory. The new values are averaged and saved in the stock inventory table.

- ii. The script then calls on the execution of the python script that implements the Fuzzy inference engine, at which point it terminates.

The Python script is called from PHP rather than from a Cron Job directly, this is because the Python script needs the PHP script to first compute the demand and lead time values which it uses as inputs.

#### ***5.1.4 Fuzzy Inference Engine***

The fuzzy inference will be used to predict the ROP level. Python 3.4 is used to implement the fuzzy inference engine. Python on its own does not come with capabilities to either perform scientific computing or fuzzy logic, as such SciPy (Scientific Python) for scientific computing is required with all common extensions and their dependencies. The process is simplified by using a scientific python distribution called WinPython which comes with all but one of the scientific extensions required to build the fuzzy inference engine. Sci-Kit Fuzzy which is also from SciPy but is never included in the standard distribution is also required. Sci-Kit fuzzy also known as SK-fuzzy, is used to perform fuzzy operations with aid of two other SciPy extensions called NumPy and Matplotlib (For Visually plotting the Membership Functions – Used In design mode only). Below is a description of each membership function, followed by the fuzzy rules used and then the procedure followed to use the fuzzy inference engine to determine the reorder point level.

##### ***a. Demand Membership Functions***

Five equidistant membership functions are used due to their being two antecedents in order to respect the  $2N+1$  rule. Demand as a percentage of maximum stock capacity for the respective Inventory Item. The graphical representation of the five demand membership functions is shown in figure 5.1 below and a detailed description of the membership functions is shown in table 5.1 below.

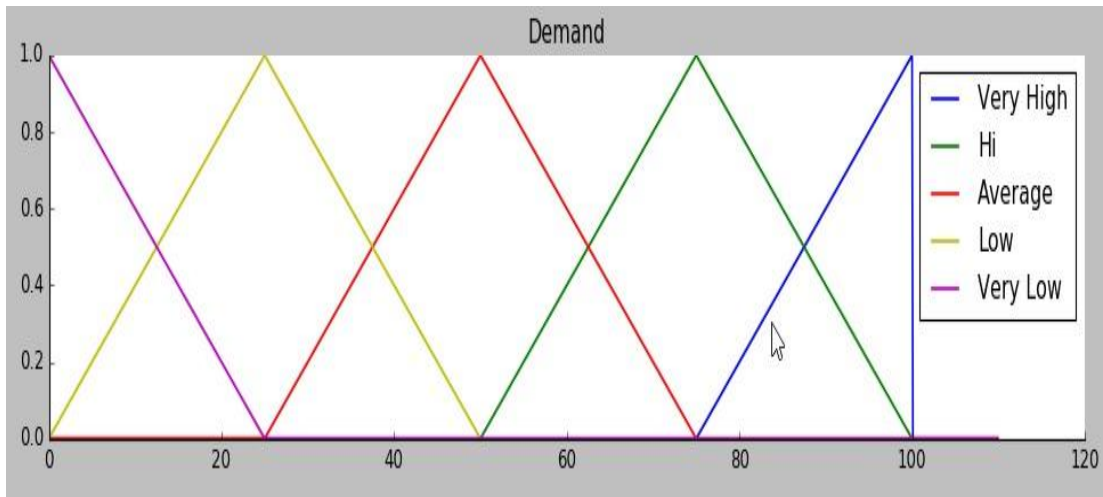


Figure 5.2: Demand Membership Functions

Table 5.1: Demand Membership Functions

Fuzzy Membership Function	Range	Equation of the Line
Very Low	$0 \leq x \leq 25$	$y = 1 - (0.04)x$
Low	$0 \leq x \leq 25$	$y = (0.04)x$
Low	$25 \leq x \leq 50$	$y = 2 - (0.04)x$
Average	$25 \leq x \leq 50$	$y = -1 + (0.04)x$
Average	$50 \leq x \leq 75$	$y = 3 - (0.04)x$
High	$50 \leq x \leq 75$	$y = -2 + (0.04)x$
High	$75 \leq x \leq 100$	$y = 4 - (0.04)x$
Very High	$75 \leq x \leq 100$	$y = -3 + (0.04)x$

**b. Lead Time Membership Functions**

Five equidistant Membership are used due to their being two antecedent in order to respect the  $2N+1$  rule. The graphical representation of the five lead time membership functions is shown in figure 5.2 below and a detailed description of the membership functions is shown in table 5.2 below.

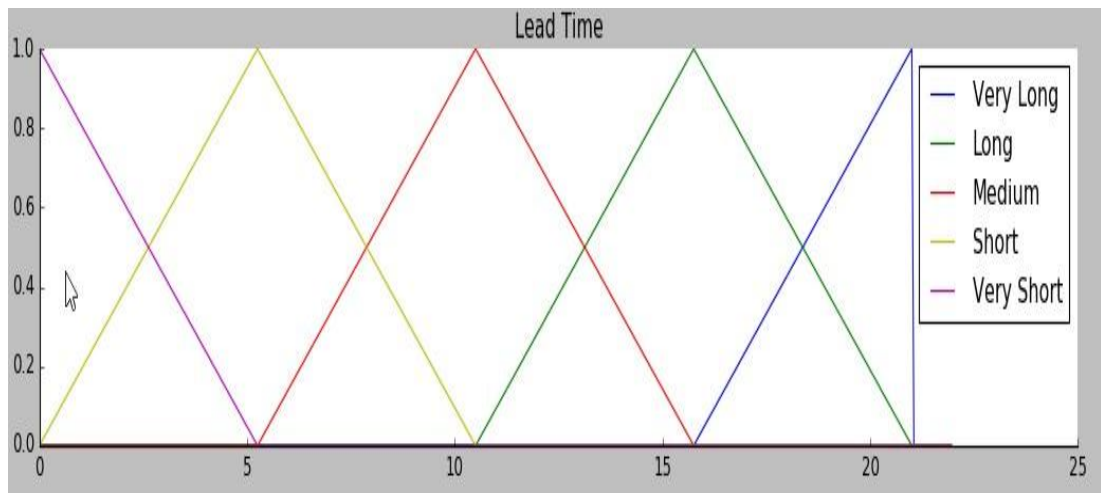


Figure 5.3: Lead Time Membership Functions:

Table 5.2: Lead Time Membership Functions

Fuzzy Membership Function	Range	Equation of the Line
Very Short	$0 \leq x \leq 5.25$	$y = 1 - (4/21) x$
Short	$0 \leq x \leq 5.25$	$y = (4/21) x$
Short	$5.25 \leq x \leq 10.5$	$y = 2 - (4/21) x$
Medium	$5.25 \leq x \leq 10.5$	$y = -1 + (4/21) x$
Medium	$10.5 \leq x \leq 15.75$	$y = 3 - (4/21) x$
Long	$10.5 \leq x \leq 15.75$	$y = -2 + (4/21) x$
Long	$15.75 \leq x \leq 21$	$y = 4 - (4/21) x$
Very Long	$15.75 \leq x \leq 21$	$y = -3 + (4/21) x$

**c. Re-Order Point Membership Function**

Five equidistant Membership are used. According to the  $2N+1$  rule , this being a single consequent system three membership would have sufficed , but it is always recommended to use extra odd-numbered number of membership function. The graphical representation of the five membership functions is shown in figure 5.3 below and a detailed description of the membership functions is shown in table 5.3 below.

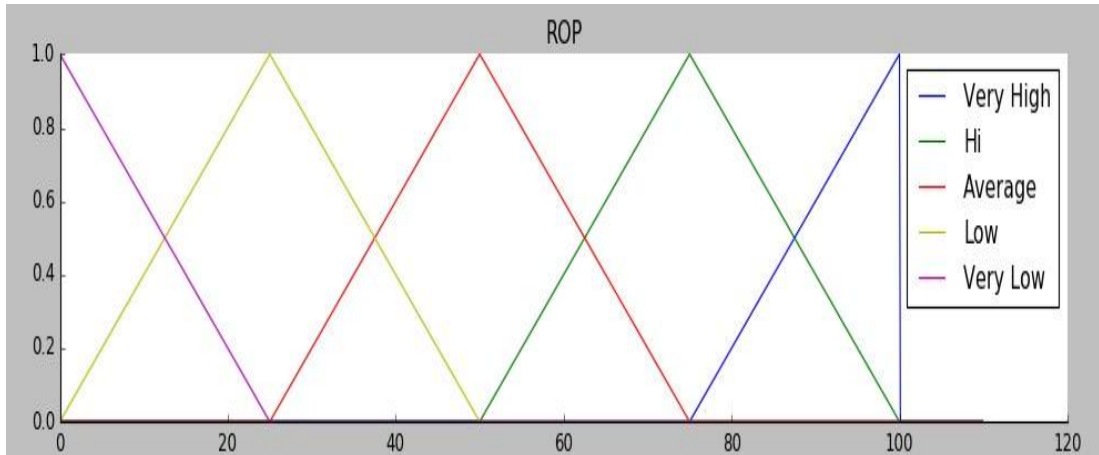


Figure 5.4: ROP Membership Functions

Table 5.3: ROP Membership Functions

Fuzzy Membership Function	Range	Equation of the Line
Very Low	$0 \leq x \leq 25$	$y = 1 - (0.04)x$
Low	$0 \leq x \leq 25$	$y = (0.04) x$
Low	$25 \leq x \leq 50$	$y = 2 - (0.04)x$
Average	$25 \leq x \leq 50$	$y = -1 + (0.04) x$
Average	$50 \leq x \leq 75$	$y = 3 - (0.04)x$
High	$50 \leq x \leq 75$	$y = -2 + (0.04) x$
High	$75 \leq x \leq 100$	$y = 4 - (0.04)x$
Very High	$75 \leq x \leq 100$	$y = -3 + (0.04) x$

**d. Fuzzy Rules**

The fuzzy rule base contains 10 fuzzy rules aggregated down from 25 rules. The 25 non-aggregated rule were generated from a set of 120 training data sets using FISpro (See Appendix C: for Complete Training dataset). The training dataset was generated using Equation 2.1 (found in Chapter 2 - Literature review), but the safety stock was assumed to be zero. The training data was generated from a formula only to assist in initial generation of rules, once the system is running in an actual environment

then actual (real) data sets will be captured from the database and used in the place of the generated data sets. Table 5.4 below shows the 10 aggregated fuzzy rules.

*Table 5.4: Fuzzy Rules*

<b>1</b>	IF DEMAND is HIGH AND LEAD TIME is (LONG or VERY LONG) THEN ROP is AVERAGE
<b>2</b>	IF DEMAND is AVERAGE AND LEAD TIME is (SHORT or MEDIUM or LONG or VERY LONG) THEN ROP is HIGH
<b>3</b>	IF DEMAND is LOW AND LEAD TIME is (VERY SHORT or VERY LONG) THEN ROP is HIGH
<b>4</b>	IF DEMAND is VERY LOW THEN ROP is VERY HIGH
<b>5</b>	IF DEMAND is LOW AND LEAD TIME is (SHORT or MEDIUM or LONG) THEN ROP is VERY HIGH
<b>6</b>	IF DEMAND is HIGH AND LEAD TIME is (VERY SHORT or SHORT or MEDIUM) THEN ROP is HIGH
<b>7</b>	IF DEMAND is (AVERAGE or VERY HIGH) AND LEAD TIME is VERY SHORT THEN ROP is VERY HIGH
<b>8</b>	IF DEMAND is VERY HIGH AND LEAD TIME is (MEDIUM or SHORT )THEN ROP is HIGH
<b>9</b>	IF DEMAND is VERY HIGH AND LEAD TIME is VERY LONG THEN ROP is LOW
<b>10</b>	IF DEMAND is VERY HIGH AND LEAD TIME is LONG THEN ROP is AVERAGE

***e. Procedure to determine to determine reorder point level***

Below is the process followed in order to determine the ROP level from the fuzzy inference engine.

- i. The Automatically scheduled PHP script triggers the Python script that will determine the ROP.
- ii. Python runs in a non-windowed terminal session and it checks the database for the inventory table which contains average Demand values, Maximum stock values and average lead time values. This values are updated automatically by the Periodic PHP script that checks the Orders, Sales and Purchases tables

computing to determine the current average values. The input for demand is the Percentage of the demand to maximum stock capacity.

- iii. The inputs demand (demand ratio of the maximum stock capacity in the range of 0 to 100) and lead time are mapped onto their respective membership functions (Fuzzified). The inputs will usually fall within two membership functions and as such the input will be assigned to the Linguistic variable (Fuzzy Input) corresponding to where it has a higher degree of membership.
- iv. The crisp inputs are now fuzzy inputs and are then checked against the fuzzy rule base and a fuzzy output is determined.
- v. The fuzzy output is then defuzzified in order to get a crisp value, the Defuzzification method is the centroid method.
- vi. After Defuzzification the crisp output is returned to the database in the respective row where the inputs are from
- vii. The process repeats until all row where the inputs values have been changed (By the periodic PHP script) are reconciled with a new matching ROP levels. The ROP level is also a percentage ratio of the maximum stock capacity in the range 0-100.

#### ***5.1.5 Product Lifetime***

The product life time module is implemented in PHP and is an automatically executed at regular weekly intervals. It is scheduled to automatically execute by the UNIX scheduler Cron. Once the module executes, it simply runs a query on all inventory items to determine which products are expired. It then sets the items it has determined to be expired as obsolete by changing a value in the items respective row. The quantity of item in inventory is reduced by the quantity of expired product. Management will be notified that a certain inventory Item has expired while in stock and needs to be removed from the physical inventory.

## **5.2 Testing**

Testing of the system was done through simulation of the transaction processing of issuing and receiving ART medicines. Actual testing at the centres could not be done due to inability to gain permission to carry out a live test. The simulation was also preferred because a major aspect of the system is automatically learning and

modifying several inputs over time, something that could not be achieved with the small amount of time at the researcher's disposal.

The simulation was incorporated a separate module(undocumented) whereby several key inputs could be set that would be used in simulating the transactional processing of issuing and receiving ART medicines and commodities at either a distribution centre or an intermediary storage centre. The key input demand was randomized but the random values were set to be between the average daily demands plus/minus the standard deviation of average daily demand. Unit Testing was carried out first on each of the key modules and then a collective integration and system test was carried out.

### ***5.2.1 Unit Testing: Real-Time Inventory Monitoring***

The real time inventory monitoring was tested by simulating the lowering the quantity of selected inventory items to a level near their respective ROP levels (computed by the fuzzy inference engine). Through a web interface that mimics a point-of-sale (POS) interface, the inventory items were issued repeatedly. Once the ROP level was reached on each respective item, the system issued a message signalling that ROP had been reached and that a reorder should be placed. The test was carried out several times and responded as expected every time.

### ***5.2.2 Unit Testing: The Periodic Reconciliation Script***

The periodic reconciliation script was tested by simulating transactions over a week long period. The simulation was achieved by executing a PHP script that populated the database with sales, orders and purchases records of a period of time (through backdating records). The periodic script was then added to a scheduled Cron Job to execute at a set period in time. Moments after the set time for the Cron Job had elapsed the database was checked to see if the script had executed. The average demand and lead time values for inventory items had been reconciled as expected. It was also noted that the ROP values had been changed to correspond with the new Average demand and lead time values for each respective inventory item meaning that the python script that implements the fuzzy inference engine had been called and had successfully executed. The process was repeated ten times and performed as expected each time.

### 5.2.3 Unit Testing: Fuzzy Inference Engine

The fuzzy module to determine the reorder based on input of demand and lead time was tested using 50 generated input dataset pairs. The ROP values from the test data were compared to their respective ROP result from the fuzzy module to determine the ROP. The Random Mean Square Error (RMSE) technique was used to determine the accuracy of the predictions by the fuzzy inference engine. The underlying assumption when presenting the RMS Error is that the errors are unbiased and follow a normal distribution. Thus, using the RMSE helps to provide a complete picture of the error distribution (Chai & Draxler, 2014). The Random Mean Error formula used (i.e. equation 5.1) is shown below and the summary of the RMS error obtained is shown in table 5.5 below (For the complete testing data sets see Appendix E :).

$$rms_{error} = \sqrt{\frac{\sum_{i=1}^{50} (real - fuzzy)^2}{(\# outputs) \times (\# datasets)}}$$

*Equation 5.1:  
RMS Error  
Formula Used*

Table 5.5: Summary of RMS Error Test

Maximum observed deviation from Actual Value	9.076
Maximum Possible Deviation from an Actual Value	12
Total RMS error	4.315710736

The total RMS error of 4.315710736 observed from the data to test the fuzzy ROP module shows that the fuzzy inference engine based on the provided fuzzy rules and membership functions gets the prediction of the reorder point accurately with a 4.3% standard deviation difference from the actual testing data set valued. It is noted that when the membership functions are increased usually the RMS error lowers. Also when the system is in actual use then the fuzzy rules will be updated based on actual examples whereby stockouts do not occur (example where stockouts occur are not suitable), and the model will definitely improve and the RMS error will reduce. One technique to reduce the RMS error is the use of a Neuro-Fuzzy back propagation engine (not implemented in this research) such as the one implemented by Paul and

Azeem (2011), that keeps going back and forth until the RMS error can no longer be improved on.

#### **5.2.4 Unit Testing: Product Lifetime Monitor**

The Product lifetime monitor was tested by scheduling a Cron Job to execute the PHP script that implements this module. The expiry of selected inventory items was set to be before the time the Cron Job was to execute. Moments after the Cron Job was scheduled to execute, the database was checked and the script had been executed because all the inventory items set to have expired were indicated as such.

#### **5.2.5 Integration and System Testing**

Integration and System Testing were carried out together. Integration testing is the phase in software testing in which individual software modules are combined and tested as a group. It occurs after unit testing and before validation testing. System Testing is a level of the software testing where a complete and integrated software is tested. The purpose of this test is to evaluate the system's compliance with the specified requirements. The inventory monitoring system test was carried out as an aggregation of unit tests to see if when the individual single modules were integrated and tested collectively as a whole system they would work. The test showed that all modules worked as expected when integrated together. It can therefore be concluded that integration and system success showed the inventory monitoring system is a success.

#### **5.2.6 Usability Testing**

In usability testing basically the tester tests the ease with which the user interfaces can be used (Virothaisakun, 2014). It tests that whether the application or the product built is user-friendly or not. The implementation of the model developed in this research was limited to a proof of concept prototype, as such being that the core functionalities of implemented prototype run in non-windowed interfaces (i.e. Terminal or Command Line), the usability tests on this non-windowed functionalities such prediction of the ROP, involved seeing whether the modules executed in a timely manner as scheduled and whether they executed fast enough. With regard to the non-functional requirements "performance" and "speed" the systems usability was verified to be satisfactory. The scripts were timed to ensure that there is no trade-off between

the two non-functional requirements. The speed was fast enough almost scripts ran under one (1) second.

Some of the few GUI's implemented in the prototype included the ART drugs issuing web interface and the report generation web interface. A third party individual performed tests to verify their usability and determined them to be usable. The interfaces' functionalities all worked and the GUI was easy to learn (understand) and use. All instructions on the web interface were properly visible and the interface was understandable without need for an explicit user manual.

### ***5.2.7 System and Model Validation***

All the functional requirements were successfully implemented and tested. Everything worked as expected and the key system feature which predicts the appropriate inventory level on when to place an order worked properly. It can then be concluded that the web based inventory model and its system were a success. Below is table 5.6 showing the summary of implementation and testing of the functional requirements.

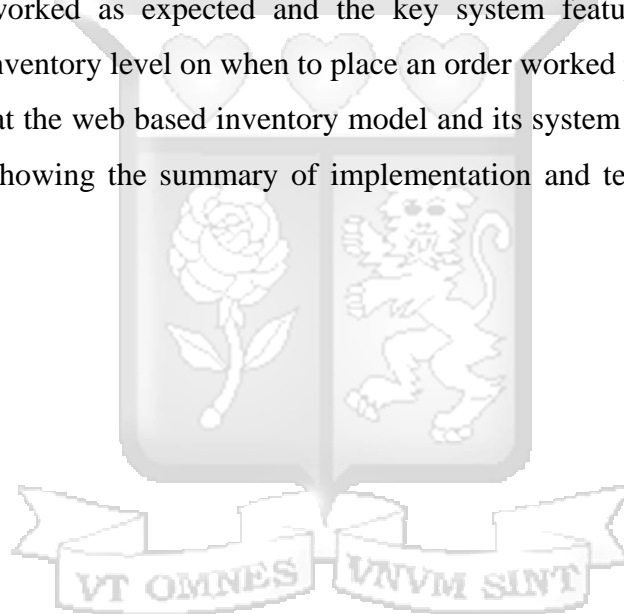


Table 5.6: System Validation against Requirements.

Functional Requirement	Implementation and Testing Result
The system should be able to monitor inventory quantity changes in the database in real time.	Implemented and working as expected. System is able to track inventory items as they are issued or received.
The system should be able to monitor inventory of multiple items collectively.	Implemented and working as expected. System collectively monitors all items in inventory database.
System should be able to notify the users and management when inventory of an item is learning low.	Implemented and working as expected. Notices are sent when ROP level is triggered.
The systems should be able to learn and change average periodic demand and lead time automatically.	Implemented and working as expected. System is able to compute the values successfully. A Scheduled Cron Job enables the automated invocation of the module that implement this functionality
The system should be able to predict the Re-order point using the fuzzy inference engine.	Implemented and working as expected. It able to predict the ROP level accurately with a 4.3% margin of error.
The System should be able to track the Product lifetime (Item's Shelf Life).	Implemented and working as expected. Able to periodically traverse the inventory database and render expired products as such and notify on the same.

## Chapter 6 : Discussion

The purpose of this chapter is to discuss the implications of this research and its developed inventory monitoring model with regard as to what was improved on in comparison to what exist now as well as in comparison to the other models reviewed in literature. This chapter also discusses the differences between the reviewed model and the developed model, and finally the chapter looks at where this research fell short.

### 6.1 Comparison between the developed model with the reviewed models

The inventory monitoring model was implemented into a web based system. Fuzzy logic through the use of a fuzzy inference engine was used to determine when to order (Reorder point) so as to minimize the likelihood of stockouts occurring. The model was validated through the testing of the system and it worked as required. In comparison to the other models reviewed in this research, the model developed in this research is most suitable for the situation considered in this research, which is for monitoring of ART medicines and commodities. Unlike the model by Anigbogu et al. (2011), the model developed in this research uses two antecedent inputs in demand and lead time, and with regard to the fuzzy inference engine implementation, the model implemented in this research is much more appropriate. The use of a single antecedent fuzzy model by Anigbogu et al. (2011), meant that their system did not take into account of the demand variable, this makes their model less effective in predicting the reorder point (ROP). The model developed by Anigbogu et al. (2011), also does not consider product lifetime, it assumes products do not go obsolete, but just like their model, the model developed in this research also includes automatic learning of demand and leadtime variables.

Comparing this model to the fuzzy-based model by Dutta and Kumar (2013), it can also be stated that the model developed in this research is a better fit for the situation considered in this research. Their model assumes demand to be constant, unlike the developed model that applies automatic learning to change the demand over time. Considering the model by Priya and Iyakutti (2011), the model developed in this research can be considered more appropriate for the situation in this research, this is due to fact that the model by Priya and Iyakutti (2011), considers lead time to be zero. Their model however does consider deteriorating items like the developed model.

Comparing the model developed in this research to the model by Paul and Azeem (2011), also shows that the model developed in this research is better than their model with regard to the fact that theirs does not consider lead time (assumes it to be zero) and also it does not consider deteriorating items. Their model is however better with regard to the fact that it uses a feedforward-backpropagation network algorithm from Artificial Neural Network to improve and optimize the prediction of the reorder point (ROP). The backpropagation training algorithm keeps going forward and backwards as the name suggest to improve upon the predicted output accuracy in comparison to a training data set.

## **6.2 Main Research Contributions**

The main contribution of this research is development of a model that is adaptable with regards to changing the ROP prediction over time, this is achieved by automatically learning changes in the Demand and Lead time from the transactions in the database and through the use of fuzzy logic to predict the ROP which does not require explicit knowledge of the relationship between the antecedents (i.e. Demand and Lead time) and the consequent (i.e. ROP).

With regard to the current systems in use for monitoring ART medicines and commodities, this research offers a much more improved solution than their current non-computerized systems for inventory monitoring. With regard to the reviewed models, the model developed (and consequent system) improved upon the collective shortfalls of the other systems.

## **6.3 Limitations of the Research**

The limitations of this research are as follows:

- i. An actual field test could not be carried out, as such the testing was done through simulation.
- ii. The model developed does not consider cost factors, it only addresses monitoring of inventory quantity levels.

## **Chapter 7 : Conclusion**

This chapter presents the summary conclusion for this research and defines whether the research was a success or not. This chapter also presents recommendations and thereafter suggestions for future research.

### **7.1 Conclusion**

The objectives of this research were to look at the current situation in ART medicines and commodities Inventory control and monitoring, and then to offer a web-based solution for the problems determined. It was seen from the reviewed literature that there is generally a lack of proper and systematic inventory control and monitoring system in place for ART medicines and commodities. The findings of the interviews conducted with several members who were of knowledgeable and involved in distribution, storage and disbursement of the medicines also indicated that the inventory control and monitoring systems in use are inadequate and still highly manual despite the use of computerized systems for distribution and disbursement of the medicines. This research then went ahead and developed a real-time model for inventory monitoring to address the issues that were seen. To help validate the model, it was implemented as a web based system (Actually a prototype). The implemented system was then tested and worked as expected according to the functional requirements. The model was therefore validated by simulating transactional processing of ART medicines and commodities at ART medication issuing centres, and it worked as expected. It can therefore be said that the research objectives were implemented, and the research questions were answered and as such this research can be concluded as a success.

### **7.2 Recommendations**

The most important recommendation is for the public institutions that are involved in the process of distribution and disbursement of ART medicines and commodities to make use of computerized inventory control and monitoring systems. The use of inadequate and manual inventory control and monitoring systems as seen in reviewed literature tends to negatively affect the availability of this critical lifesaving medicines. As seen in this research such systems can be cost effectively

developed using free and open source software which are platform independent, thereby saving costs on purchasing costly readymade proprietary solutions.

### **7.3 Suggestions for future research**

Below are suggestions for future research which can build upon this research as a reference point:

- i. There is need to research into models for prediction of demand for ART medicines and commodities. This will enable for even better forecasting beyond what was implemented in this research whereby only the reorder point was predicted.
- ii. Another suggestion is to carry out research into be the use of a feedforward-backpropagation network algorithm from ANN to help retrain the fuzzy inference engine's rule base and to help reduce the RMS Error of 4.3% seen in this research. The suggested model would therefore be a Neuro-Fuzzy Model which simply refers to an ANN model that is trained by fuzzy rules. A feedforward-backpropagation network, is a network that is trained with a backpropagation training algorithm. The backpropagation training algorithm subtracts the training output from the target (desired answer) to obtain the error signal. It then goes back to adjust the weights and biases in the input and hidden layers to reduce the error (Auer, Burgsteiner, & Maass, 2008).

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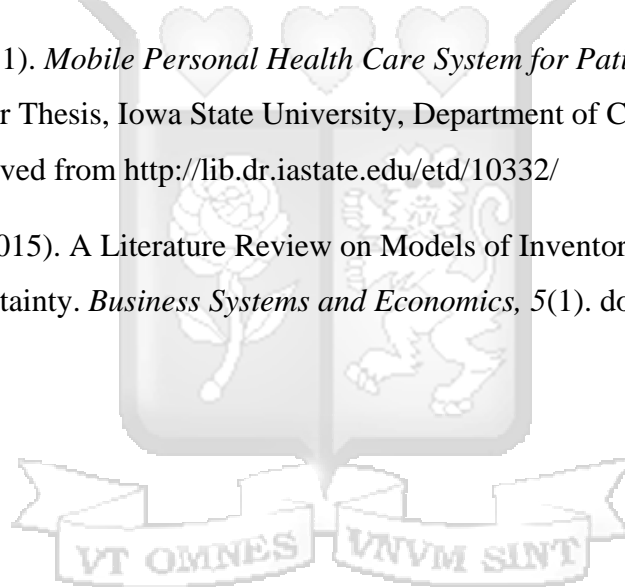
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## Appendix A: TurnItIn Originality Report



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## Appendix B: Letter of introduction

Raymond Stephen Alick,  
+254737779765,  
Alick.Raymond@strathmore.edu

12<sup>th</sup> January, 2016


Through  
Faculty Manager,  
Faculty of Information Technology,  
Strathmore University.

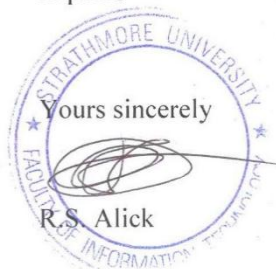
To Whom It May Concern,

**RE: Introduction Letter**

My Name is Raymond Stephen Alick, A student at Strathmore University (Student ID: 078374) pursuing a Master of Science in Information Technology. I am currently researching the limitations of the current inventory control and monitoring systems for antiretroviral drugs and commodities.

I am requesting to be allowed to interview to several personnel in charge of either distribution, inventory management, purchases or disbursement of Antiretroviral drugs at your organization/institution/place-of-work so that I may get information needed to undertake my research. The information obtained will strictly be used for academic purposes only. I shall make available to you the results of my findings upon your request.

Yours sincerely  
  
R.S. Alick



## Appendix C: Training dataset

Below is the training dataset that was used to generate the 25 non-aggregated fuzzy rules, which in turn were used to generate the 10 final aggregated rules. The training data was generated using Equation 2.1 (found in Chapter 2 - Literature review), but the safety stock was assumed to be zero. FISpro 3.5 is used to generate the fuzzy rules from this set of 120 scenarios. The scenarios were generated such that all 25 possibilities based on the fuzzy membership functions of the antecedents and consequent were presented.

**Table Appendix C.1: Training datasets**

#	Demand	Ling	Membership	Lead Time	Ling	Membership	ROP	Ling	Membership	Rule Weight
1	94.302000	VERY HIGH	0.772080	21.000000	VERY LONG	1.000000	34.900000	LOW	0.604000	0.466336
2	93.085200	VERY HIGH	0.723408	21.000000	VERY LONG	1.000000	35.740000	LOW	0.570400	0.412632
3	88.218000	VERY HIGH	0.528720	21.000000	VERY LONG	1.000000	39.100000	AVERAGE	0.564000	0.298198
4	79.700400	HIGH	0.811984	21.000000	VERY LONG	1.000000	44.980000	AVERAGE	0.799200	0.648938
5	77.266800	HIGH	0.909328	21.000000	VERY LONG	1.000000	46.660000	AVERAGE	0.866400	0.787842
6	74.833200	HIGH	0.993328	21.000000	VERY LONG	1.000000	48.340000	AVERAGE	0.933600	0.927371
7	73.616400	HIGH	0.944656	21.000000	VERY LONG	1.000000	49.180000	AVERAGE	0.967200	0.913671
8	49.280400	AVERAGE	0.971216	21.000000	VERY LONG	1.000000	65.980000	HIGH	0.639200	0.620801
9	48.063600	AVERAGE	0.922544	21.000000	VERY LONG	1.000000	66.820000	HIGH	0.672800	0.620688
10	27.378000	LOW	0.904880	21.000000	VERY LONG	1.000000	81.100000	HIGH	0.756000	0.684089
11	26.161200	LOW	0.953552	21.000000	VERY LONG	1.000000	81.940000	HIGH	0.722400	0.688846
12	24.944400	LOW	0.997776	21.000000	VERY LONG	1.000000	82.780000	HIGH	0.688800	0.687268
13	1.825200	VERY LOW	0.926992	21.000000	VERY LONG	1.000000	98.740000	VERY HIGH	0.949600	0.880272
14	0.608400	VERY LOW	0.975664	21.000000	VERY LONG	1.000000	99.580000	VERY HIGH	0.983200	0.959273
15	88.218000	VERY HIGH	0.528720	19.000000	VERY LONG	0.619048	44.900000	AVERAGE	0.796000	0.260533
16	62.665200	HIGH	0.506608	19.000000	VERY LONG	0.619048	60.860000	AVERAGE	0.565600	0.177380
17	61.448400	AVERAGE	0.542064	19.000000	VERY LONG	0.619048	61.620000	AVERAGE	0.535200	0.179594
18	13.993200	LOW	0.559728	19.000000	VERY LONG	0.619048	91.260000	VERY HIGH	0.650400	0.225362
19	12.776400	LOW	0.511056	19.000000	VERY LONG	0.619048	92.020000	VERY HIGH	0.680800	0.215383
20	1.825200	VERY LOW	0.926992	19.000000	VERY LONG	0.619048	98.860000	VERY HIGH	0.954400	0.547685
21	76.050000	HIGH	0.958000	17.000000	LONG	0.761905	57.500000	AVERAGE	0.700000	0.510933
22	74.833200	HIGH	0.993328	17.000000	LONG	0.761905	58.180000	AVERAGE	0.672800	0.509189
23	61.448400	AVERAGE	0.542064	17.000000	LONG	0.761905	65.660000	HIGH	0.626400	0.258704

24	49.280400	AVERAGE	0.971216	17.000000	LONG	0.761905	72.460000	HIGH	0.898400	0.664793
25	35.895600	LOW	0.564176	17.000000	LONG	0.761905	79.940000	HIGH	0.802400	0.344910
26	18.860400	LOW	0.754416	17.000000	LONG	0.761905	89.460000	VERY HIGH	0.578400	0.332460
27	16.426800	LOW	0.657072	17.000000	LONG	0.761905	90.820000	VERY HIGH	0.632800	0.316796
28	94.302000	VERY HIGH	0.772080	15.000000	LONG	0.857143	53.500000	AVERAGE	0.860000	0.569133
29	93.085200	VERY HIGH	0.723408	15.000000	LONG	0.857143	54.100000	AVERAGE	0.836000	0.518374
30	89.434800	VERY HIGH	0.577392	15.000000	LONG	0.857143	55.900000	AVERAGE	0.764000	0.378109
31	88.218000	VERY HIGH	0.528720	15.000000	LONG	0.857143	56.500000	AVERAGE	0.740000	0.335360
32	87.001200	HIGH	0.519952	15.000000	LONG	0.857143	57.100000	AVERAGE	0.716000	0.319102
33	82.134000	HIGH	0.714640	15.000000	LONG	0.857143	59.500000	AVERAGE	0.620000	0.379780
34	62.665200	HIGH	0.506608	15.000000	LONG	0.857143	69.100000	HIGH	0.764000	0.331756
35	50.497200	AVERAGE	0.980112	15.000000	LONG	0.857143	75.100000	HIGH	0.996000	0.836736
36	49.280400	AVERAGE	0.971216	15.000000	LONG	0.857143	75.700000	HIGH	0.972000	0.809162
37	24.944400	LOW	0.997776	15.000000	LONG	0.857143	87.700000	VERY HIGH	0.508000	0.434460
38	23.727600	LOW	0.949104	15.000000	LONG	0.857143	88.300000	VERY HIGH	0.532000	0.432791
39	5.475600	VERY LOW	0.780976	15.000000	LONG	0.857143	97.300000	VERY HIGH	0.892000	0.597112
40	1.825200	VERY LOW	0.926992	15.000000	LONG	0.857143	99.100000	VERY HIGH	0.964000	0.765960
41	0.608400	VERY LOW	0.975664	15.000000	LONG	0.857143	99.700000	VERY HIGH	0.988000	0.826248
42	88.218000	VERY HIGH	0.528720	13.000000	MEDIUM	0.523810	62.300000	AVERAGE	0.508000	0.140690
43	45.630000	AVERAGE	0.825200	13.000000	MEDIUM	0.523810	80.500000	HIGH	0.780000	0.337153
44	43.196400	AVERAGE	0.727856	13.000000	MEDIUM	0.523810	81.540000	HIGH	0.738400	0.281521
45	39.546000	AVERAGE	0.581840	13.000000	MEDIUM	0.523810	83.100000	HIGH	0.676000	0.206027
46	24.944400	LOW	0.997776	13.000000	MEDIUM	0.523810	89.340000	VERY HIGH	0.573600	0.299789
47	22.510800	LOW	0.900432	13.000000	MEDIUM	0.523810	90.380000	VERY HIGH	0.615200	0.290162
48	21.294000	LOW	0.851760	13.000000	MEDIUM	0.523810	90.900000	VERY HIGH	0.636000	0.283758
49	1.825200	VERY LOW	0.926992	13.000000	MEDIUM	0.523810	99.220000	VERY HIGH	0.968800	0.470418
50	76.050000	HIGH	0.958000	11.000000	MEDIUM	0.904762	72.500000	HIGH	0.900000	0.780086
51	74.833200	HIGH	0.993328	11.000000	MEDIUM	0.904762	72.940000	HIGH	0.917600	0.824670
52	73.616400	HIGH	0.944656	11.000000	MEDIUM	0.904762	73.380000	HIGH	0.935200	0.799305
53	51.714000	AVERAGE	0.931440	11.000000	MEDIUM	0.904762	81.300000	HIGH	0.748000	0.630363
54	50.497200	AVERAGE	0.980112	11.000000	MEDIUM	0.904762	81.740000	HIGH	0.730400	0.647695
55	24.944400	LOW	0.997776	11.000000	MEDIUM	0.904762	90.980000	VERY HIGH	0.639200	0.577038
56	23.727600	LOW	0.949104	11.000000	MEDIUM	0.904762	91.420000	VERY HIGH	0.656800	0.564003
57	9.126000	VERY LOW	0.634960	11.000000	MEDIUM	0.904762	96.700000	VERY HIGH	0.868000	0.498655
58	1.825200	VERY LOW	0.926992	11.000000	MEDIUM	0.904762	99.340000	VERY HIGH	0.973600	0.816565
59	0.608400	VERY LOW	0.975664	11.000000	MEDIUM	0.904762	99.780000	VERY HIGH	0.991200	0.874975

60	94.302000	VERY HIGH	0.772080	9.000000	MEDIUM	0.714286	72.100000	HIGH	0.884000	0.487513
61	93.085200	VERY HIGH	0.723408	9.000000	MEDIUM	0.714286	72.460000	HIGH	0.898400	0.464221
62	88.218000	VERY HIGH	0.528720	9.000000	MEDIUM	0.714286	73.900000	HIGH	0.956000	0.361040
63	45.630000	AVERAGE	0.825200	9.000000	MEDIUM	0.714286	86.500000	HIGH	0.540000	0.318291
64	94.302000	VERY HIGH	0.772080	7.000000	SHORT	0.666667	78.300000	HIGH	0.868000	0.446777
65	83.350800	HIGH	0.665968	7.000000	SHORT	0.666667	80.820000	HIGH	0.767200	0.340620
66	49.280400	AVERAGE	0.971216	7.000000	SHORT	0.666667	88.660000	VERY HIGH	0.546400	0.353782
67	48.063600	AVERAGE	0.922544	7.000000	SHORT	0.666667	88.940000	VERY HIGH	0.557600	0.342940
68	37.112400	LOW	0.515504	7.000000	SHORT	0.666667	91.460000	VERY HIGH	0.658400	0.226272
69	7.909200	VERY LOW	0.683632	7.000000	SHORT	0.666667	98.180000	VERY HIGH	0.927200	0.422576
70	0.608400	VERY LOW	0.975664	7.000000	SHORT	0.666667	99.860000	VERY HIGH	0.994400	0.646800
71	94.302000	VERY HIGH	0.772080	5.000000	SHORT	0.952381	84.500000	HIGH	0.620000	0.455895
72	93.085200	VERY HIGH	0.723408	5.000000	SHORT	0.952381	84.700000	HIGH	0.612000	0.421644
73	74.833200	HIGH	0.993328	5.000000	SHORT	0.952381	87.700000	VERY HIGH	0.508000	0.480582
74	65.098800	HIGH	0.603952	5.000000	SHORT	0.952381	89.300000	VERY HIGH	0.572000	0.329010
75	63.882000	HIGH	0.555280	5.000000	SHORT	0.952381	89.500000	VERY HIGH	0.580000	0.306726
76	59.014800	AVERAGE	0.639408	5.000000	SHORT	0.952381	90.300000	VERY HIGH	0.612000	0.372684
77	52.930800	AVERAGE	0.882768	5.000000	SHORT	0.952381	91.300000	VERY HIGH	0.652000	0.548157
78	49.280400	AVERAGE	0.971216	5.000000	SHORT	0.952381	91.900000	VERY HIGH	0.676000	0.625278
79	48.063600	AVERAGE	0.922544	5.000000	SHORT	0.952381	92.100000	VERY HIGH	0.684000	0.600972
80	41.979600	AVERAGE	0.679184	5.000000	SHORT	0.952381	93.100000	VERY HIGH	0.724000	0.468314
81	38.329200	AVERAGE	0.533168	5.000000	SHORT	0.952381	93.700000	VERY HIGH	0.748000	0.379819
82	24.944400	LOW	0.997776	5.000000	SHORT	0.952381	95.900000	VERY HIGH	0.836000	0.794420
83	23.727600	LOW	0.949104	5.000000	SHORT	0.952381	96.100000	VERY HIGH	0.844000	0.762899
84	22.510800	LOW	0.900432	5.000000	SHORT	0.952381	96.300000	VERY HIGH	0.852000	0.730636
85	1.825200	VERY LOW	0.926992	5.000000	SHORT	0.952381	99.700000	VERY HIGH	0.988000	0.872255
86	0.608400	VERY LOW	0.975664	5.000000	SHORT	0.952381	99.900000	VERY HIGH	0.996000	0.925487
87	89.434800	VERY HIGH	0.577392	3.000000	SHORT	0.571429	91.180000	VERY HIGH	0.647200	0.213536
88	88.218000	VERY HIGH	0.528720	3.000000	SHORT	0.571429	91.300000	VERY HIGH	0.652000	0.196986
89	79.700400	HIGH	0.811984	3.000000	SHORT	0.571429	92.140000	VERY HIGH	0.685600	0.318112
90	55.364400	AVERAGE	0.785424	3.000000	SHORT	0.571429	94.540000	VERY HIGH	0.781600	0.350793
91	54.147600	AVERAGE	0.834096	3.000000	SHORT	0.571429	94.660000	VERY HIGH	0.786400	0.374819
92	52.930800	AVERAGE	0.882768	3.000000	SHORT	0.571429	94.780000	VERY HIGH	0.791200	0.399112
93	51.714000	AVERAGE	0.931440	3.000000	SHORT	0.571429	94.900000	VERY HIGH	0.796000	0.423672
94	45.630000	AVERAGE	0.825200	3.000000	SHORT	0.571429	95.500000	VERY HIGH	0.820000	0.386665
95	43.196400	AVERAGE	0.727856	3.000000	SHORT	0.571429	95.740000	VERY HIGH	0.829600	0.345045

96	12.776400	LOW	0.511056	3.000000	SHORT	0.571429	98.740000	VERY HIGH	0.949600	0.277314
97	0.608400	VERY LOW	0.975664	3.000000	SHORT	0.571429	99.940000	VERY HIGH	0.997600	0.556184
98	94.302000	VERY HIGH	0.772080	1.000000	VERY SHORT	0.809524	96.900000	VERY HIGH	0.876000	0.547515
99	93.085200	VERY HIGH	0.723408	1.000000	VERY SHORT	0.809524	96.940000	VERY HIGH	0.877600	0.513937
100	91.868400	VERY HIGH	0.674736	1.000000	VERY SHORT	0.809524	96.980000	VERY HIGH	0.879200	0.480232
101	89.434800	VERY HIGH	0.577392	1.000000	VERY SHORT	0.809524	97.060000	VERY HIGH	0.882400	0.412445
102	88.218000	VERY HIGH	0.528720	1.000000	VERY SHORT	0.809524	97.100000	VERY HIGH	0.884000	0.378362
103	84.567600	HIGH	0.617296	1.000000	VERY SHORT	0.809524	97.220000	VERY HIGH	0.888800	0.444147
104	74.833200	HIGH	0.993328	1.000000	VERY SHORT	0.809524	97.540000	VERY HIGH	0.901600	0.724997
105	65.098800	HIGH	0.603952	1.000000	VERY SHORT	0.809524	97.860000	VERY HIGH	0.914400	0.447063
106	63.882000	HIGH	0.555280	1.000000	VERY SHORT	0.809524	97.900000	VERY HIGH	0.916000	0.411753
107	62.665200	HIGH	0.506608	1.000000	VERY SHORT	0.809524	97.940000	VERY HIGH	0.917600	0.376318
108	61.448400	AVERAGE	0.542064	1.000000	VERY SHORT	0.809524	97.980000	VERY HIGH	0.919200	0.403358
109	60.231600	AVERAGE	0.590736	1.000000	VERY SHORT	0.809524	98.020000	VERY HIGH	0.920800	0.440340
110	51.714000	AVERAGE	0.931440	1.000000	VERY SHORT	0.809524	98.300000	VERY HIGH	0.932000	0.702749
111	50.497200	AVERAGE	0.980112	1.000000	VERY SHORT	0.809524	98.340000	VERY HIGH	0.933600	0.740741
112	49.280400	AVERAGE	0.971216	1.000000	VERY SHORT	0.809524	98.380000	VERY HIGH	0.935200	0.735275
113	37.112400	LOW	0.515504	1.000000	VERY SHORT	0.809524	98.780000	VERY HIGH	0.951200	0.396948
114	35.895600	LOW	0.564176	1.000000	VERY SHORT	0.809524	98.820000	VERY HIGH	0.952800	0.435157
115	24.944400	LOW	0.997776	1.000000	VERY SHORT	0.809524	99.180000	VERY HIGH	0.967200	0.781230
116	20.077200	LOW	0.803088	1.000000	VERY SHORT	0.809524	99.340000	VERY HIGH	0.973600	0.632956
117	12.776400	LOW	0.511056	1.000000	VERY SHORT	0.809524	99.580000	VERY HIGH	0.983200	0.406762
118	3.042000	VERY LOW	0.878320	1.000000	VERY SHORT	0.809524	99.900000	VERY HIGH	0.996000	0.708177
119	1.825200	VERY LOW	0.926992	1.000000	VERY SHORT	0.809524	99.940000	VERY HIGH	0.997600	0.748621
120	0.608400	VERY LOW	0.975664	1.000000	VERY SHORT	0.809524	99.980000	VERY HIGH	0.999200	0.78919

## Appendix D: Training dataset generated Non-Aggregated Rules

The various scenarios in the training datasets (i.e. in Appendix C) were used to generate the 25 non-aggregated rules as can be seen in table Appendix D.1 below. For each specific set of antecedents and corresponding consequents, multiple scenarios were realized in the training dataset. The 25 selected non-aggregated rules are selected because they contain the highest rule weights among conflicting scenarios (i.e. similar antecedents and consequents) in the training dataset.

**Table Appendix D.1: Training dataset generated Non-Aggregated Rules**

Non-Aggregated Rule Number	Rule number in the Training Dataset	Non-aggregated Rule
1	1	IF DEMAND is VERY HIGH AND LEAD TIME is VERY LONG THEN ROP is LOW
2	6	IF DEMAND is HIGH AND LEAD TIME is VERY LONG THEN ROP is AVERAGE
3	8	IF DEMAND is AVERAGE AND LEAD TIME is VERY LONG THEN ROP is HIGH
4	11	IF DEMAND is LOW AND LEAD TIME is VERY LONG THEN ROP is HIGH
5	14	IF DEMAND is VERY LOW AND LEAD TIME is VERY LONG THEN ROP is VERY HIGH
6	21	IF DEMAND is HIGH AND LEAD TIME is LONG THEN ROP is AVERAGE
7	28	IF DEMAND is VERY HIGH AND LEAD TIME is LONG THEN ROP is AVERAGE
8	35	IF DEMAND is AVERAGE AND LEAD TIME is LONG THEN ROP is HIGH
9	37	IF DEMAND is LOW AND LEAD TIME is LONG THEN ROP is VERY HIGH
10	41	IF DEMAND is VERY LOW AND LEAD TIME is LONG THEN ROP is VERY HIGH
11	51	IF DEMAND is HIGH AND LEAD TIME is MEDIUM THEN ROP is HIGH
12	54	IF DEMAND is AVERAGE AND LEAD TIME is MEDIUM THEN ROP is HIGH
13	55	IF DEMAND is LOW AND LEAD TIME is MEDIUM THEN ROP is VERY HIGH
14	59	IF DEMAND is VERY LOW AND LEAD TIME is MEDIUM THEN ROP is VERY HIGH

<b>15</b>	60	IF DEMAND is VERY HIGH AND LEAD TIME is MEDIUM THEN ROP is HIGH
<b>16</b>	71	IF DEMAND is VERY HIGH AND LEAD TIME is SHORT THEN ROP is HIGH
<b>17</b>	73	IF DEMAND is HIGH AND LEAD TIME is SHORT THEN ROP is VERY HIGH
<b>18</b>	78	IF DEMAND is AVERAGE AND LEAD TIME is SHORT THEN ROP is VERY HIGH
<b>19</b>	82	IF DEMAND is LOW AND LEAD TIME is SHORT THEN ROP is VERY HIGH
<b>20</b>	86	IF DEMAND is VERY LOW AND LEAD TIME is SHORT THEN ROP is VERY HIGH
<b>21</b>	98	IF DEMAND is VERY HIGH AND LEAD TIME is VERY SHORT THEN ROP is VERY HIGH
<b>22</b>	104	IF DEMAND is HIGH AND LEAD TIME is VERY SHORT THEN ROP is VERY HIGH
<b>23</b>	111	IF DEMAND is AVERAGE AND LEAD TIME is VERY SHORT THEN ROP is VERY HIGH
<b>24</b>	115	IF DEMAND is LOW AND LEAD TIME is VERY SHORT THEN ROP is VERY HIGH
<b>25</b>	120	IF DEMAND is VERY LOW AND LEAD TIME is VERY SHORT THEN ROP is VERY HIGH



## Appendix E: Testing Data Sets for the Fuzzy ROP Prediction

To confirm the prediction accuracy of the fuzzy inference engine (i.e. predicting the reorder point) a set of 50 testing data sets were used. This data sets were selected from 50 (out of 120) of the training data sets (training data sets in Appendix C). The demand and lead time values were fed into the fuzzy inference engine and the predicted ROP was recorded. Afterwards, the RMS Error (see Equation 5.1) technique was used to determine the accuracy of the predictions with regard to all the testing data sets. The RMS error basically represents the testing data set's standard deviation of the differences between predicted and actual ROP values. The total RMS error was 4.315710736. The 50 testing data sets used and their actual and predicted ROP values can be seen in table Appendix E.1 below:

**Table Appendix E.1: Data Testing Fuzzy ROP Module**

Test Number	Demand	Lead Time	Actual ROP	Fuzzy ROP	Absolute Difference
1	94.302	21	34.9	31.715	3.185
2	74.8332	21	48.34	50.248	1.908
3	69.966	11	74.7	72.23	2.47
4	26.1612	21	81.94	75	6.94
5	59.319	5	90.25	90.85	0.6
6	76.05	17	57.5	48.424	9.076
7	94.302	15	53.5	54.677	1.177
8	50.4972	15	75.1	74.514	0.586
9	24.9444	15	87.7	91.54	3.84
10	30.42	4	96	91.31	4.69
11	74.8332	11	72.94	71.82	1.12
12	50.4972	11	81.74	85.3	3.56
13	24.9444	11	90.98	91.62	0.64
14	77.571	11	71.95	71.812	0.138
15	94.302	9	72.1	75.64	3.54
16	94.302	5	84.5	76.62	7.88
17	74.8332	5	87.7	91.68	3.98
18	49.2804	5	91.9	91.68	0.22

<b>19</b>	24.9444	5	95.9	91.68	4.22
<b>20</b>	0.6084	5	99.9	91.68	8.22
<b>21</b>	50.4972	1	75.1	74.514	0.586
<b>22</b>	74.8332	1	97.54	91.44	6.1
<b>23</b>	50.4972	1	98.34	91.44	6.9
<b>24</b>	24.9444	1	99.18	91.44	7.74
<b>25</b>	65.403	7	84.95	80.23	4.72
<b>26</b>	73.6164	21	49.18	51.935	2.755
<b>27</b>	72.3996	21	50.02	53.444	3.424
<b>28</b>	27.378	5	95.5	91.63	3.87
<b>29</b>	68.7492	11	75.14	72.44	2.7
<b>30</b>	31.3326	18	81.46	78.978	2.482
<b>31</b>	69.0534	17	61.41	56.953	4.457
<b>32</b>	37.4166	6	92.62	90.32	2.3
<b>33</b>	70.2702	9	79.21	75.97	3.24
<b>34</b>	66.6198	10	78.1	76.34	1.76
<b>35</b>	68.7492	18	59.32	58.05	1.27
<b>36</b>	35.5914	15	82.45	79.055	3.395
<b>37</b>	38.3292	20	74.8	75.54	0.74
<b>38</b>	40.1544	12	84.16	80.819	3.341
<b>39</b>	89.739	19	43.95	35.697	8.253
<b>40</b>	94.302	20	38	31.715	6.285
<b>41</b>	72.7038	5	88.05	91.633	3.583
<b>42</b>	55.0602	8	85.52	81.7	3.82
<b>43</b>	44.7174	10	85.3	91.388	6.088
<b>44</b>	23.4234	13	89.99	90.412	0.422
<b>45</b>	15.8184	8	95.84	90.41	5.43
<b>46</b>	73.008	73.008	59.2	66.4	7.2
<b>47</b>	69.6618	18	58.78	57.22	1.56
<b>48</b>	75.7458	3	92.53	88.73	3.8
<b>49</b>	91.5642	14	57.86	59.111	1.251
<b>50</b>	75.1374	11	72.83	71.816	1.014

## Appendix F: Fuzzy Inference Engine Sample Code

#Fuzzy Inference Engine to calculate the reorder point Implemented in Python3.4

#By Raymond S. Alick --- WinPython SciPy Bundle with Sci-Kit fuzzy for fuzzy Logic

```
import numpy as np
```

```
import skfuzzy as fuzz
```

```
import matplotlib.pyplot as plt
```

```
# generate universe variables for demand, Lead Time, ROP
```

```
x_dem = np.arange(0, 110, 0.1)
```

```
x_lt = np.arange(0, 22, 0.05)
```

```
x_rop = np.arange(0, 110, 0.1)
```

```
# Generate fuzzy membership functions
```

```
# Demand Membership Functions
```

```
dem_vhi = fuzz.trimf(x_dem, [75, 100, 100])
```

```
dem_hi = fuzz.trimf(x_dem, [50, 75, 100])
```

```
dem_avg = fuzz.trimf(x_dem, [25, 50, 75])
```

```
dem_low = fuzz.trimf(x_dem, [0, 25, 50])
```

```
dem_vlow = fuzz.trimf(x_dem, [0, 0, 25])
```

```
# Lead Time Membership Functions
```

```
lt_vlong = fuzz.trimf(x_lt, [15.75, 21, 21])
```

```
lt_long = fuzz.trimf(x_lt, [10.5, 15.75, 21])
```

```
lt_med = fuzz.trimf(x_lt, [5.25, 10.5, 15.75])
```

```
lt_short = fuzz.trimf(x_lt, [0, 5.25, 10.5])
```

```
lt_vshort = fuzz.trimf(x_lt, [0, 0, 5.25])
```

```
# ROP Membership Functions
```

```
rop_vhi = fuzz.trimf(x_rop, [75, 100, 100])
```

```
rop_hi = fuzz.trimf(x_rop, [50, 75, 100])
```

```
rop_avg = fuzz.trimf(x_rop, [25, 50, 75])
```

```
rop_low = fuzz.trimf(x_rop, [0, 25, 50])
```

```
rop_vlow = fuzz.trimf(x_rop, [0, 0, 25])
```

### # the activation of the fuzzy membership functions

```
dem_level_vlow = fuzz.interp_membership(x_dem, dem_vlow, demandValue)
```

```
dem_level_low = fuzz.interp_membership(x_dem, dem_low, demandValue)
```

```
dem_level_avg = fuzz.interp_membership(x_dem, dem_avg, demandValue)
```

```
dem_level_hi = fuzz.interp_membership(x_dem, dem_hi, demandValue)
```

```
dem_level_vhi = fuzz.interp_membership(x_dem, dem_vhi, demandValue)
```

```
lt_level_vshort = fuzz.interp_membership(x_lt, lt_vshort, leadTimeValue)
```

```
lt_level_short = fuzz.interp_membership(x_lt, lt_short, leadTimeValue)
```

```
lt_level_med = fuzz.interp_membership(x_lt, lt_med, leadTimeValue)
```

```
lt_level_long = fuzz.interp_membership(x_lt, lt_long, leadTimeValue)
```

```
lt_level_vlong = fuzz.interp_membership(x_lt, lt_vlong, leadTimeValue)
```

### # Fuzzy Rules

#### #Non-Aggregated Rules used to due to ease-straightforwardness of coding them

```
active_rule1 = np.fmin(dem_level_vhi, lt_level_vlong)
```

```
active_rule2 = np.fmin(dem_level_hi, lt_level_vlong)
```

```
active_rule3 = np.fmin(dem_level_avg, lt_level_vlong)
```

```
active_rule4 = np.fmin(dem_level_low, lt_level_vlong)
```

```
active_rule5 = np.fmin(dem_level_vlow, lt_level_vlong)
```

```
active_rule6 = np.fmin(dem_level_hi, lt_level_long)
```

```
active_rule7 = np.fmin(dem_level_vhi, lt_level_long)
```

```
active_rule8 = np.fmin(dem_level_avg, lt_level_long)
```

```
active_rule9 = np.fmin(dem_level_low, lt_level_long)
```

```
active_rule10 = np.fmin(dem_level_vlow, lt_level_long)
```

```
active_rule11 = np.fmin(dem_level_hi, lt_level_med)
```

```
active_rule12 = np.fmin(dem_level_avg, lt_level_med)
```

```
active_rule13 = np.fmin(dem_level_low, lt_level_med)
```

```
active_rule14 = np.fmin(dem_level_vlow, lt_level_med)
```

```
active_rule15 = np.fmin(dem_level_vhi, lt_level_med)
```

```

active_rule16 = np.fmin(dem_level_vhi, lt_level_short)
active_rule17 = np.fmin(dem_level_hi, lt_level_short)
active_rule18 = np.fmin(dem_level_avg, lt_level_short)
active_rule19 = np.fmin(dem_level_low, lt_level_short)
active_rule20 = np.fmin(dem_level_vlow, lt_level_short)
active_rule21 = np.fmin(dem_level_vhi, lt_level_vshort)
active_rule22 = np.fmin(dem_level_hi, lt_level_vshort)
active_rule23 = np.fmin(dem_level_avg, lt_level_vshort)
active_rule24 = np.fmin(dem_level_low, lt_level_vshort)
active_rule25 = np.fmin(dem_level_vlow, lt_level_vshort)

```

```

rop_activation_low = np.fmin(active_rule1, rop_low)

```

```

rop_activation_avg = np.fmax(np.fmin(active_rule2,
rop_avg),np.fmax(np.fmin(active_rule6, rop_avg),np.fmin(active_rule7, rop_avg)))

```

```

rop_activation_hi = np.fmax(np.fmin(active_rule3, rop_hi),
np.fmax(np.fmin(active_rule4, rop_hi),
np.fmax(np.fmin(active_rule8, rop_hi),
np.fmax(np.fmin(active_rule11, rop_hi),
np.fmax(np.fmin(active_rule15, rop_hi),
np.fmin(active_rule16, rop_hi))))))

```

```

rop_activation_vhi = np.fmax(np.fmin(active_rule5, rop_vhi),
np.fmax(np.fmin(active_rule9, rop_vhi),
np.fmax(np.fmin(active_rule10, rop_vhi),
np.fmax(np.fmin(active_rule12, rop_vhi),
np.fmax(np.fmin(active_rule13, rop_vhi),
np.fmax(np.fmin(active_rule14, rop_vhi),
np.fmax(np.fmin(active_rule17, rop_vhi),
np.fmax(np.fmin(active_rule18, rop_vhi),
np.fmax(np.fmin(active_rule19, rop_vhi),

```

```
np.fmax(np.fmin(active_rule20, rop_vhi),
np.fmax(np.fmin(active_rule21, rop_vhi),
np.fmax(np.fmin(active_rule22, rop_vhi),
np.fmax(np.fmin(active_rule23, rop_vhi),
np.fmax(np.fmin(active_rule24, rop_vhi),
np.fmin(active_rule25, rop_vhi)))))))))))))
```

```
rop0 = np.zeros_like(x_rop)
```

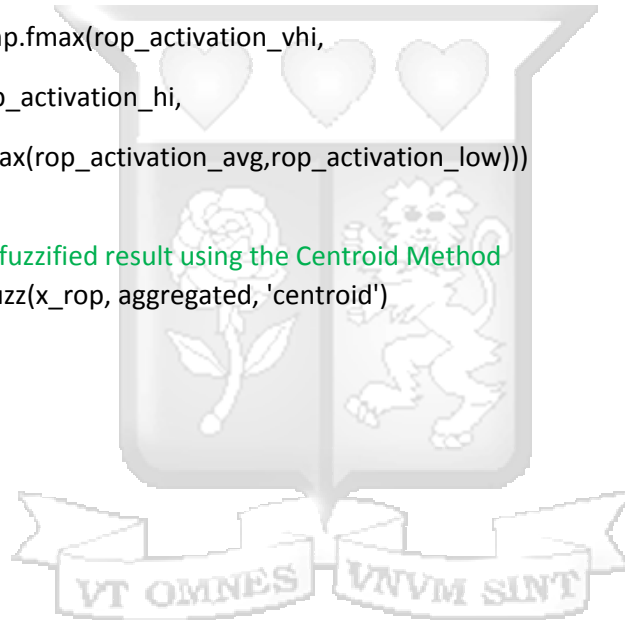
```
# End of Fuzzy Rules
```

```
# Aggregate all output membership functions together
```

```
aggregated = np.fmax(rop_activation_vhi,
np.fmax(rop_activation_hi,
np.fmax(rop_activation_avg,rop_activation_low)))
```

```
# calculate defuzzified result using the Centroid Method
```

```
rop = fuzz.defuzz(x_rop, aggregated, 'centroid')
```



## Appendix G: Determine Demand Average of all inventory items

### Sample Code

```
<?php
require_once 'dbconnect.php';

$result2 = mysqli_query($conn,"SELECT * FROM `db-invmot`.tbl_stock_description ");
if ($result2->num_rows > 0) {

    // output data of each row
    while($row = $result2->fetch_assoc()) {

        $stockID = $row["stockID"];

        $sum = 0;

        $sdDem = 0;

        for($counter = 1; $counter < 11; $counter++){

            $demWk = "demWk". + $counter ;

            $sum = $sum + ($row[$demWk]);

        }

        $avgDem = $sum / 10;

        for($counter2 = 1; $counter2 < 11; $counter2++){

            $demWk = "demWk". + $counter2 ;

            $value = ($row[$demWk]);

            $sdDem = $sdDem + ((pow(($value - $avgDem),2)) / (10));

        }

        $sdDem = sqrt($sdDem);

        echo "<br>Stock ID : ".$stockID." Average = ".$avgDem." std Deviation : ".$sdDem ;
        $result3 = mysqli_query($conn,"UPDATE tbl_stock_description SET
avDemand='".$avgDem',stdDevDemand='".$sdDem' WHERE stockID='".$stockID' ");

    }

} else {

    echo "0 results";

}

mysqli_close($conn);//Kill DB Connection MySQLi

?>
```

## Appendix H: Structured Interview Questionnaire

### Section A: Current system satisfaction

**Q A-1.** You currently have an electronic supply chain managements system in place

Yes       No

**Q A-2.** Can you briefly outline the key components (major Functionalities) of your current E-SCM?

*(E.g. Transaction processing, Billing, Reporting, Ordering, Inventory Monitoring)*

.....  
.....

**Q A-3.** Who specifically uses the electronic system (Can select more than one)

*Managers (For Decision support or Reporting)/Logistics Personnel*

*(Inventory/Stock/Planning)/Data Entry Personnel (For Routine Transactional Data e.g. Entering orders)*

.....  
.....

**Q A-4.** In your opinion what does the current system actually get used for most of the time?

*(e.g., Transaction processing, Decision support and Planning, Inventory control, Reporting etc.)*

.....  
.....

**Q A-5.** In your opinion can you say that the deployment of the electronic system has greatly improved the logistics performance post its implementation?

Yes       No

**Q A-6.** I understand previously you Operated on a Push System, and Now Operates on a Pull system, Is this the Case for ARV medicines as well? (Allocation or “push” systems)(Requisition or “pull” systems)

Yes       No       Hybrid       Not Sure

*Explain Further*

.....  
.....

## **Section B: Limitations of the current system**

**Q B-1.** Do you believe the system could use improvements?

Yes       No       Not Sure

*Explain Further*

.....  
.....

**Q B-2.** How would you rate the performance of the current system based on optimality (Efficiency)

1       2       3       4       5

*(With 1= Lowest efficiency; 5= Highest efficiency)*

**Q B-3.** What current limitations/Problems/Bottlenecks are clearly evident in the system?

.....  
.....

**Q B-4.** Do cases of stockouts, excess stock and obsolete stock occur?

.....  
.....

**Q B-5.** What current limitations/Problems/Bottlenecks are clearly evident in the system?

.....  
.....



## **Section C: Inventory Monitoring and Control**

**Q C-1.** To what extent does the electronic system get used for decision support with regard to inventory monitoring and control?

Yes       No       Not Sure

*Explain Further*

.....  
.....

**Q C-2.** Do you use safety stock, if yes are you employing the most effective method to calculate your safety stock levels?

Yes       No       Not Sure

.....  
.....  
**Q C-3.** Who determines the optimal frequency ordering products?

- cross-functional team    Planning Managers

*Please Explain Further*

.....  
.....

**Q C-4.** With regard to re-ordering ART medicines, when are orders placed?

- During a stockout                       When a Pre-determined Level is reached  
 After a fixed amount period

*Please Explain Further*

.....  
.....

**Q C-5.** Does the demand of the ART medicines vary over time or is it constant always?

- Constant                       Varies Slightly                       Unpredictable

*Please Explain Further*

.....  
.....

**Q C-6.** How is the inventory quantity level of various ART medicines and commodities tracked?

- Manually                       Automated                       Hybrid

*Please Explain Further*

.....  
.....

**Q C-7.** What factors are considered for inventory level monitoring and re-ordering?

- Re-order Point                       Inventory Quantity                       Lead Time                       Average Demand

*Please List Any other*

.....  
.....

**Q C-8.** Does your current E-SCM contain historical Data that can be used for decision making for future planning?

- Yes                       No                       Not Sure

**Q C-9.** In general how would you comment on the current system with regard to inventory monitoring?

.....  
.....

**Section D: Closing questions**

**Q D-1.** My research deal with developing a prototype that optimizes the inventory monitoring and re-ordering, do you believe such a thing would be helpful here?

Yes       No       Not Sure

*Explain Further*

.....  
.....

**Q D-2.** Are there any components that you might advise me to incorporate in my inventory monitoring prototype?

.....  
.....

**Q D-3.** Is there anything you believe that may help me that I have forgotten to ask?

.....  
.....

**Q D-4.** Any comments regarding this Interview?

.....  
.....

***Thank you for taking your time to respond.***

## Appendix I: Sample Screenshots

Below is a Figure (figure Appendix i-1) showing a sample screenshot of a report generating web interface. The report in the window shows a report generated from the database showing the inventory status of all the medicine stock reflected in the database.

**invmot** art drugs inventory monitoring

homepage reports about help

links

- [Add Inventory](#)
- [Issue Inventory](#)
- [Management Interface](#)
- [DB Connect](#)
- [ROP vd](#)
- [Simulation](#)
- [Learn Demand](#)
- [rule Base](#)
- [Reconcile Quantity](#)
- [Reconcile All](#)
- [Users](#)

select report to generate

Select Report To Generate: Select All Drugs Inventory Report Generate Report

inventory levels

StockID	Quantity	Inventory Consumed	Inventory Label	Max Capacity	ROP
1	4000	20	SAFE	5000	87.932844
2	5000	16.6666666666667	SAFE	6000	90.362037
3	6000	14.285714285714	SAFE	7000	88.535145
4	800	80	SAFE	4000	90.331456
5	800	73.3333333333333	SAFE	3000	90.939955
6	800	60	SAFE	2000	90.999322
7	800	77.142857142857	SAFE	3500	90.999322
8	800	20	SAFE	1000	90.537833
9	700	91.25	BEYOND ROP	8000	90.999322

Total Time To Execute Script 0.044518947601318 seconds

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Figure Appendix i-1: Report Generation Window

Below is figure (Figure Appendix i-2) showing an alert message (popup) being displayed on the ART medicine issuing web interface when a medication in the inventory database has gone below its reorder point.

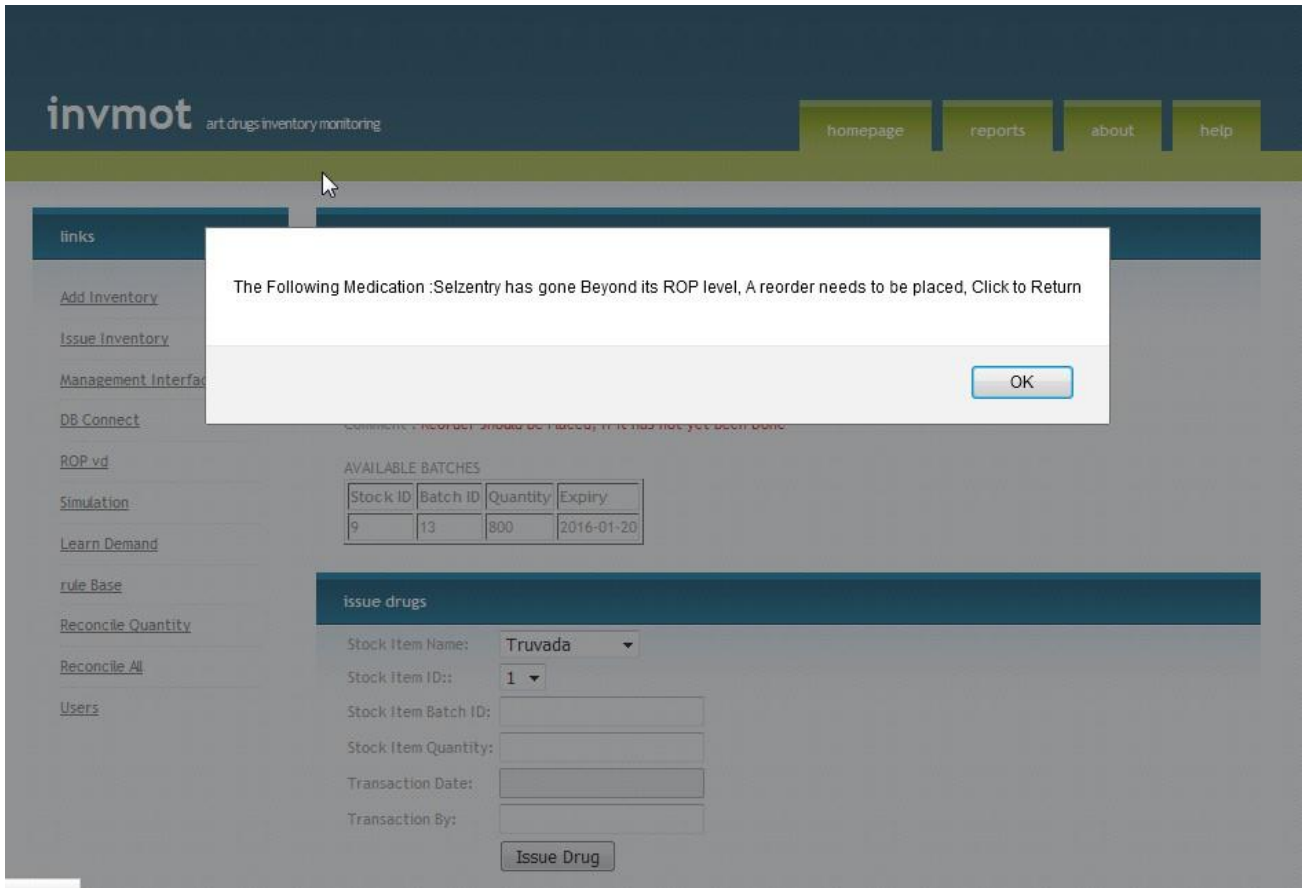


Figure Appendix i-2: ART Medicine Issuing Interface with ROP Trigger Message

