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HOSPITAL INVENTORY MANAGEMENT: A SYSTEMATIC REVIEW OF THE LITERATURE

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ABSTRACT

Hospitals and clinics provide an essential service to the populace, assisting people to overcome a range of ailments. In order to do so physicians are reliant on the tools and inventory they have at their disposal. When stock levels appear frighteningly low or even become depleted, physicians begin to order more than the ideal amount causing overstocking and consequently, wastage. This paper performs a systematic literature review in order to identify the causes for the unsatisfactory inventory management currently experienced in South African healthcare facilities.

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1. INTRODUCTION

Health services provide the essential medication, vaccines and life changing operations which citizens rely on during times of need. In South Africa there are 5,083 dispensaries⁴ which provide roughly 119,155 hospital beds to patients [1]. Each of these dispensaries require a great deal of medical supplies in order to treat patients on a daily basis. Stock orders are placed which exceed the necessary amount to ensure stock availability. According to research conducted by Western Cape News Online [2] approximately R14.2 million in medication was discarded between April 2011 and April 2012 from dispensaries overstocking. Despite this, Sowsetan newspaper [3] reported that six of South Africa's nine provinces experienced antiretroviral⁵ shortages during 2012. It was estimated that during 2016 South Africa experienced 110,000 deaths as a result of AIDS, had 270,000 new HIV infections and 7.1 million citizens which were still living with HIV [4].

2. PROBLEM STATEMENT

In order to accommodate the sizeable demand resulting from the HIV/AIDS epidemic, as well as other ailments, many hospitals are resorting to overstocking as an immediate solution. Overstocked inventory leads to expired products which get discarded, wasting both money and valuable resources. Dispensaries need to take another look at their inventory management policies, re-evaluate their order quantities, consider implementing modern decision support systems, and review their organisational structures.

3. OBJECTIVES

In order to learn more about the causes of poor inventory management being experienced in dispensaries this paper will perform a detailed review on the available literature surrounding the problem.

4. METHODOLOGY: AN INTRODUCTION TO THE SYSTEMATIC LITERATURE REVIEW

The *Systematic Literature Review* (SLR) is a powerful tool for acquiring relevant research papers befitting the topic with reproducible results [5], [6]. This is to say that should another researcher pursue the same topic at the same time, they should ultimately arrive at the same conclusions. The SLR is performed sequentially by a five step process [8].

1. **Scoping:** An introduction to the topic. The research objectives and target audience should be clearly defined. Do an initial search for anyone who might have already conducted a SLR on the defined topic.
2. **Planning:** Identify the topic interests and create a list of primary keywords which will be used as search terms during the *Searching* step.
3. **Searching:** Select at least one appropriate search engine from which literature will be acquired. Using the search terms defined in the *Planning* step, perform several filtered searches using the selected search engine database(s). Do not perform searches which merely filter through literature titles, author keywords or abstracts, but rather explores all fields.
4. **Screening:** Export details of the found literature for further review. Some important information would include the record title, abstract, year, citation count and author name(s). The final selection process involves reading the title and abstract of each record to identify topic related literature.
5. **Analysis:** Obtain the actual documentation of the remaining (chosen) literature. Carefully read through the entirety of each chosen paper and draw relevant information for the study.

5. SCOPING

The topic has been described in Sections 1, 2 and 3. A search through *Google*, *Google Scholar*, *Scopus* and *Web of Science* produced no indication of any similar SLR having been conducted. The SLR will review the following parameters:

1. The research dates of the literature.
2. The types of records found to be discussing this topic.
3. The industries to which these records are focussed.
4. The full topic list under discussion in the found literature.
5. The geographic results of where the literature was conducted, tested or observed.

⁴ Hospitals and clinics.

⁵ Medication used to treat HIV/AIDS.

6. PLANNING

Filters were used to find the most appropriate, topic-related literature. The keywords used in the Searching step of the SLR can be grouped into three individual searches, as shown in Table 1. Larger clinics employ a number of similar operations to hospitals. For this reason, all three searches had to include either the keyword “hospital” or “clinic” and helps to broaden the scope of the search to other relevant literature.

7. SEARCHING

Two search engines, namely *Scopus* and *Web of Science*, were selected to each perform the three searches. Both search engines are use reliable academic databases and provide all record information (author, title, abstract, citations, year, type, etc.). This information will be required during the Screening step.

Table 1: Search terms and findings, 25 May 2018.

| # | Search terms | Scopus | Web of Science | # Duplicate records | Final count |
|---|-------------------------------------------------------------------------------------------------------------------------|--------|----------------|---------------------|-------------|
| 1 | ("hospital" OR "clinic") AND "inventory management" AND "decision support system" | 10 | 3 | 2 | 11 |
| 2 | ("hospital" OR "clinic") AND "inventory" AND "pharmacy" AND ("policy" OR "lead time" OR "order quantity" OR "lot size") | 68 | 8 | 7 | 69 |
| 3 | ("hospital" OR "clinic") AND "ward" AND "organizational structure" | 108 | 6 | 6 | 108 |
| | TOTAL | | | | 188 |

Table 1 identifies the number of records found from each search using the two search engines. Only articles, technical reports, journals, book chapters and conference proceedings were considered. No restrictions were set on dates. Records which were found in both search engines (duplicates) were identified, reducing the findings to 188 records. No duplicate records existed between the different searches, indicating that each search defined a unique concept.

8. SCREENING

The 188 record abstracts were collected from either Scopus or Web of Science before thoroughly being read through. This step was important to ensure that only relevant literature would be selected for the full review. It was found that 41 of the 188 records were relevant to the topic and chosen for acquisition. This selection process is described in Figure 1.

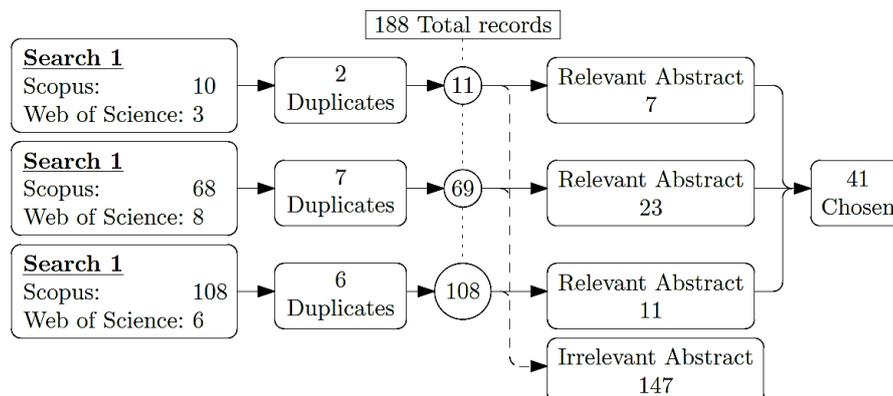


Figure 1: Selection of chosen records.

Some topics which were encountered and rejected include:

- Determining practical solutions to paediatric pain control.
- Manufacturing policies for drug production.
- Negative patient feedback.
- Nurse experience surveys.

- Organisational requirements for mass burn incidents.
- Patient experience surveys.
- Patient safety questionnaires.
- Training of advanced nurse practitioners.
- Trauma centre characteristics effect on patient outcomes.

Figure 2 shows the acquisition process. There were 19 openly accessible English records, of which one was an abstract list. Two records were only available in a foreign language and twenty records had to be specifically requested. Requests were sent both to the Stellenbosch University Library and directly to the authors via ResearchGate. Eight of these records were made available bringing the number of acquired records to 26.

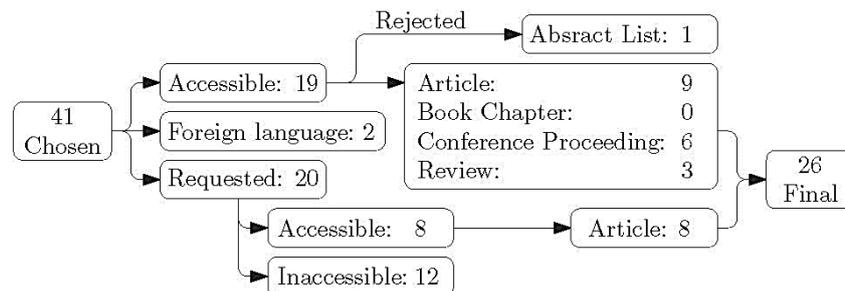


Figure 2: Acquisition of records.

Figure 3 takes a comparative look at the publication dates for the 188 records and chosen 41 records. The earliest found record dates back to 1972, and the earliest chosen record was 1974. More publications on the topic arose in 1981, but had settled down by 1990s which only contributed two records towards the chosen list. The largest activity can be seen from the start of the twenty-first century and become densely discussed between 2008 and 2018.

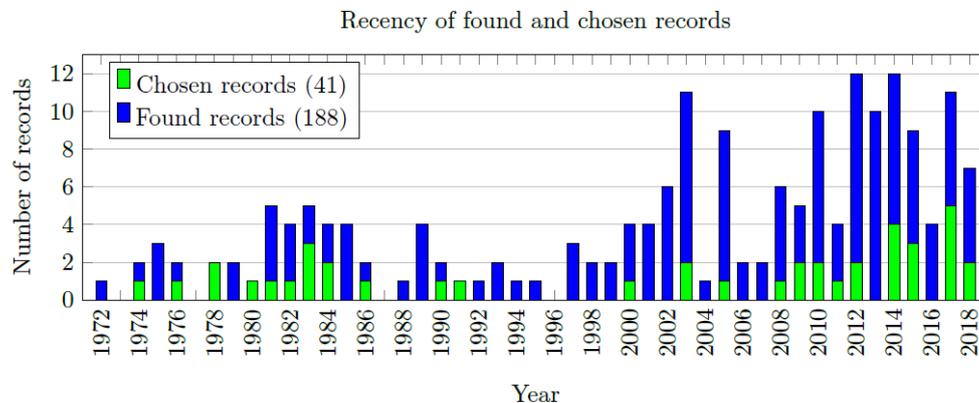


Figure 3: Number of found and chosen records, sorted by date of publication.

Figure 3 helped to understand the time-spread of the chosen records. The chosen literature may be useful to assist both modern and old-fashioned systems. An additional chart reviewing the dates of the acquired 26 records is presented in Figure 4. The acquired records appear to remain well distributed across the timeline, with exception to the gap from 1985 and 2002. Six of the earliest records were still obtainable and will be able to provide insight into past studies. The majority of acquired records were published during the twenty-first century.

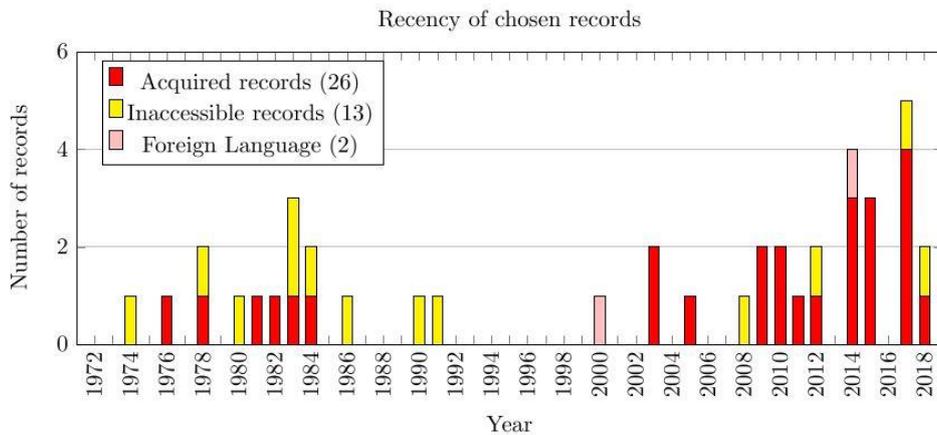


Figure 4: Number of acquired and inaccessible records, sorted by date of publication.

Knowing the source which published the record can be helpful for researchers that may want to find more papers in that field of study. 73% of the found literature were articles. Articles accounted for 65% of the acquired literature. Conference proceedings contribute 17% of the found literature and 23% of the acquired literature. The final four records consist of three reviews and only a single book source. Only one source came up more than once, the “American Journal of Hospital Pharmacy”, and provided five of the chosen records and four of the acquired records.

Five industry types were identified in the abstracts and author-defined keywords: Distribution; Human resources; Supply chain; Healthcare; Information systems. Records may exist in more than one industry type. Figure 5 (a) shows the industry distribution the 41 chosen records in the form of a polar pie chart. Similarly, Figure 5 (b) shows this for the acquired 26 records. The polar pie charts appear very similar, which indicate that the acquired literature still embodies the same proportion of industries as the chosen literature. The two most prominent industries are Supply Chain and Healthcare.

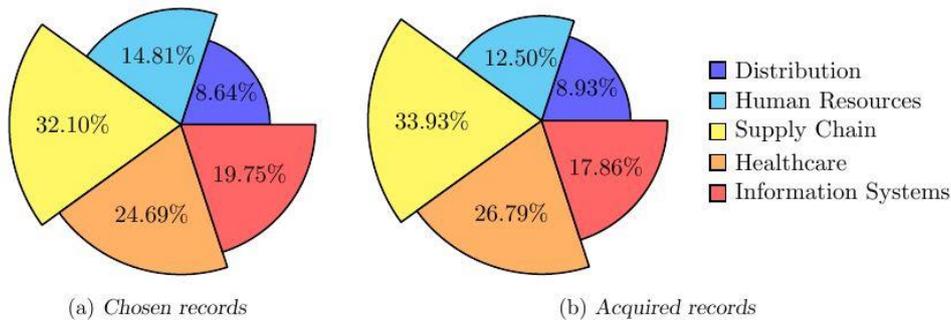


Figure 5: Classification of records by industry type.

Authors often use keywords to help researchers to find their work. A count of the author keywords is listed in Figure 6 for the chosen 41 records, sorted in descending order of frequency. Similar terms were grouped together, such as “Medical care” being grouped with “Healthcare”. The number of keywords assigned to records vary. This is why there appears to be such a small difference between the number of keywords in the acquired and inaccessible records shown in Figure 6. The bar chart will therefore only provide a rough idea of the discussions covered in the literature.

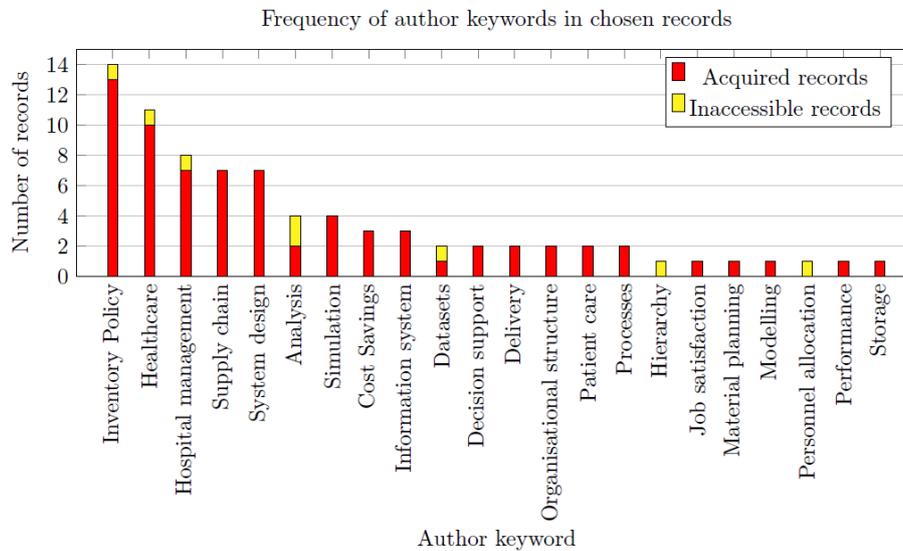


Figure 6: Number of author-defined keyword occurrences.

Countries differ with regards to infrastructure, law, religion(s) and population densities. Studies performed in one region might not be applicable to another region. For example, a wealthy institution in a developed country may publish research on expensive robotics used for manufacture. This information is not helpful to a poor institution in an underdeveloped country which can only afford cheap labour.

Figure 7 provides a visual representation of these regions on the world map (shaded black). None of the acquired records conducted their research within African, much less South Africa. 50% of the acquired records were conducted in the United States of America (USA). Figure 7 shows three distinctive clusters which can be grouped by continent. This continental view of the geographic research shows that Europe also contributed a considerable amount of the research: 50% USA; 38% Europe; 12% Asia.



Figure 7: Geographic locations of acquired records, defined by shaded regions.

9. ANALYSIS

After reading the entirety of each record, the literature was divided into exact. The most evident topic discussed in the literature were “Inventory Policies” which featured in fourteen of the twenty-six acquired records (54%). This corresponds with the bar chart developed in Figure 6. Due to the magnitude of the literature, only “Inventory Policies” will be discussed further for this paper.

9.1 ABC Inventory Control

The first inventory management concept to be discussed from the literature is the ABC classification. This control method allows managers to focus on the minority of products which are responsible for the majority of inventory investment. As the name “ABC” suggests, there are three categories which products can be divided into [9]. Figure 8 graphically represents the ABC concept. *Category A* refers to the smallest number of products (10-15%) that make up the majority of the inventory costs (70-80%). These are the products which managers should direct most of their attention to. *Category B* populates 20-25% of the inventory and constitute 15-20% of the inventory costs and *Category C* are the majority of products (60-70%) which comprise the smallest inventory costs (10-15%) [10], [11].

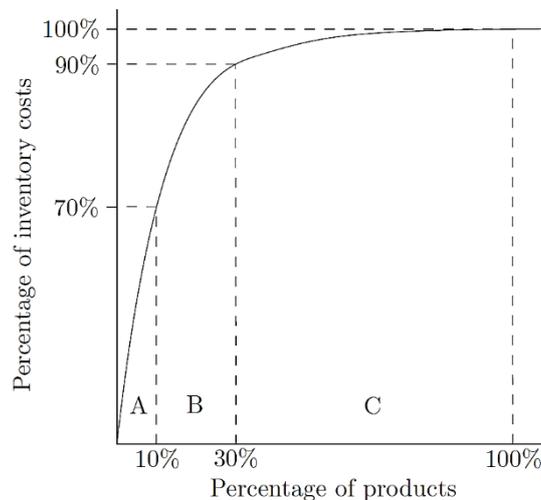


Figure 8: ABC classification.

9.2 Economic Order Quantity

The Economic Order Quantity (EOQ) was discussed in six of the fourteen inventory policy records (43%). It refers to the stock quantity ordered that exists at the point where the inventory carry costs are equivalent to the ordering costs, yielding the lowest total annual costs for that product [12], [13]. This is shown in Figure 9.

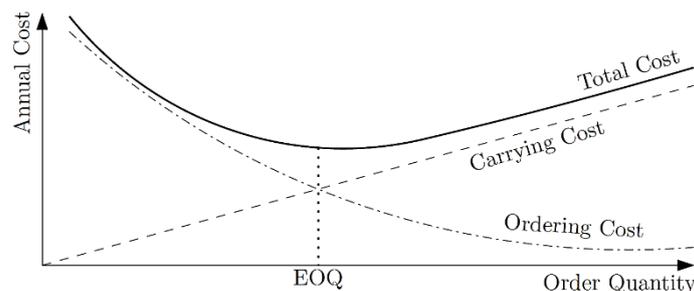


Figure 9: Economic Order Quantity curve, adapted from [9].

The EOQ is calculated using Equation 1. Additionally, the total annual cost can be calculated using Equation 2 [10], [13], [14]. The equation variables are: annual demand (D); the purchase cost of each unit (P); the annual inventory carrying cost expressed as a percentage (C); and the order cost per order (A); actual size of order placed (Q). Q is often the EOQ value rounded up to the nearest specified batch size.

$$EOQ = \sqrt{\frac{2DA}{CP}} \quad (1)$$

$$\text{Total cost} = PD + \frac{DA}{Q} + \frac{QCP}{2} \quad (2)$$

9.3 Types of Inventory Policies

According to Wilson *et al.* [15] inventory policies can be categorised into two primary control models namely “continuous review” and “periodic review”. Continuous review refers to a system which undergo unceasing inventory level checks. This means that the moment an inventory level is reduced to the reorder point, s , a new order will be placed. Periodic reviews only perform inventory checks intermittently. This interval (period) between reviews can be as short as one day or as long as one month (30 days) and is commonly referred to as the review period, R .

Noel [9] states that the periodic inventory method offers users simplicity and may generate lower costs, but creates a lack of control and causes unnoticed shortages to occur. Wilson *et al.* [15] further subdivides these two review methods into “fixed order quantity” and “order-up-to” models. The fixed order quantity model orders pre-determined lot sizes, Q , when the inventory is smaller than or equal to the reorder point. The order-up-to model changes the lot size of each new order based on a pre-determined maximum par level, S .

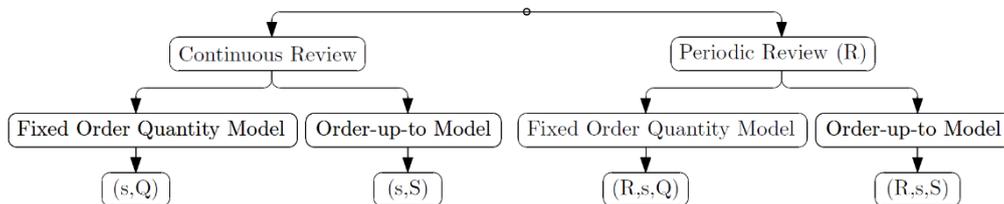


Figure 10: Types of Inventory Policies.

Figure 10 is a flow diagram describing this classification of the four possible inventory policies. The literature described several variations of determining the s , S and Q and the consequent inventory policies thereof. The following variables will be used generically for the policies listed in Table 3, Table 3 and Table 4.

- α = service level [%]
- α_c = cycle service level [%]
- μ = average daily demand [units/day]
- σ = standard deviation of daily demand
- σ_L = standard deviation of last L days
- σ_{L+1} = standard deviation of last $L + 1$ days
- C_{BI} = cost of inventory levels at beginning of year [\\$]
- C_{EI} = cost of inventory levels at end of year [\\$]
- C_P = cost of inventory purchases during the year [\\$]
- $COGS$ = cost of goods sold [\\$]
- D = annual demand [units/year]
- DL = expected demand during lead time [units/ L]
- DR = expected demand during review period [units/ R]
- DOH = days on hand [days]
- E_L = expected number of expired items during lead time [units/ L]
- EOQ = economic order quantity (see page 7) [units]
- I = inventory level (stock on hand (SOH)) [units]
- I_L = expected inventory level one lead time away [units]
- L = lead time [days]
- OL = operational levelling factor
- R = review period [days]
- s = reorder point [units]
- S = par level [units]
- SS = safety stock [units]
- TO = inventory turnover ratio
- U = number of units below the reorder point (undershoot) [units]
- z = z score (normal distribution)

Table 2: Inventory policies [#1-2] found in the acquired literature.

| # | Description | Type | Model |
|---|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------|----------------------------------------------------------------------------------|
| 1 | The Par inventory model is a popular order-up-to model which operates using periodic reviews [16]. During each period review the material handler must perform an inventory count of the stock on hand. Each product has a predetermined par-level, S , which is determined using historic demand. Once the material handler has finished counting the stock on hand, orders are placed for the exact number of items which will bring the inventory levels back up to par. Orders are made whenever stock levels fall beneath the par value [17]. This model can thus be mathematically described by [15]. | (R,s,S) | $s = S - 1$ $Q = S - I$ |
| 2 | The Kanban Two-Bin model is designed to make items quick and easy to access to physicians [17]. This method uses two identical bins to hold stock (one lot size, Q) of each product. The containers shelved one behind the other. Physicians take stock out of the front container. Once the last item has been picked the physician must place the empty container to one side (allocated for empty bins) and pull the second container forward [16]. Refilled bins are placed behind the current front container [18]. This model allows busy physicians to take stock without the need to check with the MH every time [15], [19]. | (R,s,Q) | $DL = \mu \times L$ $s = DL + SS$ $SS = 2.3\sqrt{DL}$ $Q = s + EOQ - I$ |

Table 3: Inventory policies [#3-7] found in the acquired literature.

| # | Description | Type | Model |
|---|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 3 | Another periodic review fixed-order-quantity policy was described by vanDerLinde [11]. This tested A-category products, according to the ABC inventory control (see page 7), at St. Luke's Memorial Hospital in 1980. | (R,sQ) | $DL = \mu \times L$ $s = DL + SS$ $SS = 2.3\sqrt{DL}$ $Q = s + EOQ - I$ |
| 4 | Wilson, Hodge and Bivens [15] developed a model which provides the decision maker with two choices for the reorder point. These choices will define the probability that the demand will exceed the inventory level. Using $\mu + 3\sigma$ will yield the lowest chance of stock-out, but may be more costly than using $\mu + 2\sigma$. | (s,Q) | $s = \begin{cases} \mu + 2\sigma, & 2.270\% \text{ prob}(\text{demand} > I) \\ \mu + 3\sigma, & 0.135\% \text{ prob}(\text{demand} > I) \end{cases}$ $S = 2s$ $DR = \mu \times R$ $U = \left(\frac{(DR)^2}{2(DR)} \right) - \left(\frac{1}{2} \right)$ $Q = S - s + U$ |
| 5 | In order to get a comparative model for the (s,Q) model described in Policy 4, Jensen and Bard's [20] mathematical framework will be considered. | (s,Q) | $DL = \mu \times L$ $s = DL + (z \times \sigma)$ $SS = s - DL$ $Q = EOQ$ |
| 6 | Kelle, Woosley and Schneider [21] designed a model to find an optimal schedule in order to minimise the overall costs to the hospital. To compare this model fairly with the rest of the literature, only the equations concerned with ordering will be considered to prioritise meeting demand rather than optimising costs. A, B, C, D, a_i and b_i are constants calculated using Schneider's Approximation formulas [22]. | (R,s,S) | $s = \mu(L + 1) + (p(y) \times \sigma_{L+1}) - \text{MAX} \left(\frac{\sigma^2}{\mu} - 1; 0 \right) \times \left(\frac{A + By}{C + Dy} \right)$ $y = \left(\frac{Q \times (1 - \alpha)}{\sigma_{L+1}} \right)$ $p(y) = \left(\frac{a_0 + a_1 w + a_2 w^2 + a_3 w^3}{b_0 + b_1 w + b_2 w^2 + b_3 w^3 + b_4 w^4} \right)$ $w = \sqrt{\ln \left(\frac{E}{y^2} \right)}$ $S = s + Q - U$ $Q = EOQ$ $U = \left(\frac{\mu^2 + \sigma^2}{2 \times \mu} \right)$ |

| | | | |
|---|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 7 | Wilson, Hodge and Bivens [15] modelled a periodic order-up-to policy for use in a cancer centre's ambulatory care clinic. The model is intended to operate mechanically in the same manner as the Kanban Two-Bin model (see policy #2). The <i>DOH</i> equations were found at <i>Accounting-Explained</i> [23] and <i>Finance Train</i> [24]. | (R,s,S) | $COGS = C_{BI} + C_p - C_{EI}$ $TO = \left(\frac{COGS}{Average\ Annual\ Inventory} \right)$ $DOH = \left(\frac{365}{TO} \right)$ $OL = \left(\frac{DOH}{2} \right)$ $s = (\mu + 2\sigma)OL$ $S = 2s$ $U = \left(\frac{(DR)^2}{2(DR)} \right) - \left(\frac{1}{2} \right)$ $Q = S - s + U$ |
|---|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

Table 4: Inventory policies [#8-11] found in the acquired literature.

| # | Description | Type | Model |
|----|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 8 | There are two variations of this inventory policy described by Gebicki <i>et al.</i> [14]. The first policy (this one) makes use of the ABC inventory control to select an appropriate z-value. | (R,s,Q) | $DL = \mu \times L$ $s = DL + (\sigma \times z \times \sqrt{L})$ $Q = s + EOQ - I$ $S = s + Q$ <hr/> $z = \begin{cases} 1.96, & \alpha = 97.5\% \text{ (Category C)} \\ 2.33, & \alpha = 99.0\% \text{ (Category B)} \\ 3.09, & \alpha = 99.9\% \text{ (Category A)} \end{cases}$ |
| 9 | This policy is the second variation of policy #8 described by Gebicki <i>et al.</i> It uses an equation to calculate an appropriate z-value. | (R,s,Q) | <p>Same as Policy #8</p> <hr/> $z = \left(\frac{s_{t-1} - DL}{\sigma L} \right)$ |
| 10 | The final policy tested by Gebicki <i>et al.</i> achieved the lowest average cost and stockout values making it the most promising policy discussed in the paper. For this model Gebicki <i>et al.</i> fixed the z-value for all products to the highest service level. | (R,s,Q) | $DL = \mu \times L$ $s = DL + (\sigma \times z \times \sqrt{L})$ $I_L = I - DL - (\sigma \times z \times \sqrt{L}) - E_L$ $Q = s - I_L$ $S = s + Q$ <hr/> $z = 3.09 \text{ (} \alpha = 99.9\% \text{)}$ |
| 11 | An additional inventory model not found in the SLR, but worth testing is presented by Chopra and Meindl [25]. In this inventory model a cycle service level, α_c , is calculated based on the expected demand during the lead time and used instead of the predefined service level, α . This cycle service level, α_c , determines the probability that the current reorder point, s, will be able to support the expected demand during lead time, DL. | (R,s,Q) | $\sigma_L = \sigma \sqrt{L}$ $DL = \mu \times L$ $\alpha_c = Prob(DL \leq s)$ $= F(s, DL, \sigma_L)$ $[Excel] = NORM.DIST(s, DL, \sigma_L, 1)$ $SS = F^{-1}(\alpha_c, DL, \sigma_L) - DL$ $[Excel] = NORM.INV(\alpha_c, DL, \sigma_L) - DL; \quad \alpha_c \neq 1.0$ $s = SS + DL$ $Q = EOQ$ |

10. TESTING THE INVENTORY POLICIES

This section will test and evaluate the inventory policies discovered during the SLR. South Africa's department of health released a "Master Procurement Catalogue" on the 13th July 2018 [26] which lists 1174 individual contracts commissioned between 2013 and 2018. Each contract defines a unique order agreement (product, package size, etc.) and discusses roughly 1062 medicines and vaccines provided by approximately 78 suppliers. The promised lead times are shown in Figure 11. There are only 25 items expected to be delivered in less than 7 days. The majority of products are delivered after roughly two weeks (14 days). There are 10 items which take three weeks for delivery, three items which take four weeks for delivery and two items which take three months for delivery. These lead times are much larger than described in the literature, which regularly assumed lead times of less than a week.

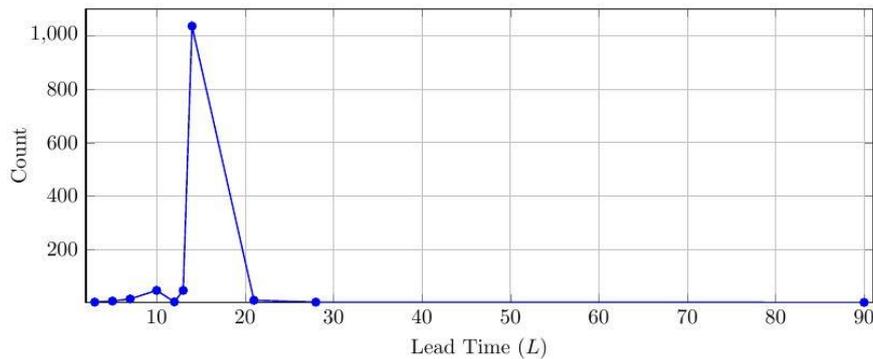


Figure 11: Lead time frequency for medical products.

10.1 Test parameters

Before proceeding to test the inventory policies found in the SLR, four custom policy models have been created by integrating different aspects of the equations found in the literature. These four custom inventory policies are listed as policies 12–15.

Policy 12 - (s,Q)

$$SS = z \times \sigma \times \sqrt{L}$$

$$DL = \mu \times L$$

$$s = DL + SS$$

$$Q = EOQ$$

Policy 13 - (s,Q)

$$SS = z \times \sigma \times \sqrt{L}$$

$$DL = \mu \times L$$

$$s = DL + SS$$

$$S = 2 \times s$$

$$Q = S - I$$

Policy 14 - (R,s,S)

$$E_L = I - \mu$$

$$DL = \mu \times L$$

$$SS = z \times \sigma \times \sqrt{L}$$

$$I_L = I - DL - SS - E_L$$

$$s = DL + SS$$

$$Q = s - I_L$$

$$S = s + Q$$

Policy 15 - (R,s,S)

$$DL = \mu \times L$$

$$SS = z \times \sigma \times \sqrt{L}$$

$$s = DL + SS$$

$$S = 2 \times s$$

$$Q = S - I_L$$

All fifteen policies were tested with six demand sets containing 1095 days (3 years) data. Figure 12 shows the first 365 days (1 year) data for these six sets. The fifteen policies were tested using all combinations of lead times (L) and review periods (R) ranging from 1 to 28 days. This means that each policy was tested $28 \times 28 = 784$ times in each demand set.

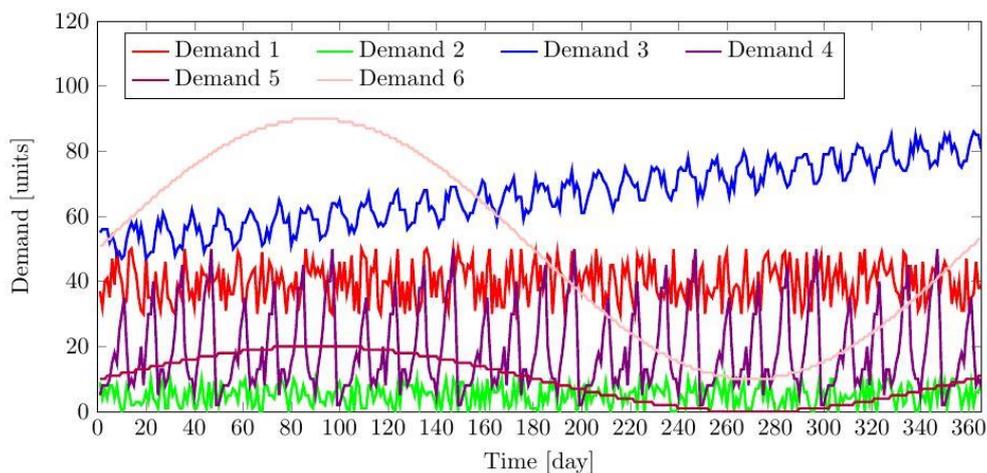


Figure 12: First year demand sets used to test Policies 1–15.

These tests will not consider minimising costs, but rather focus on determining how well the policies can meet patient demand. For this reason the test results were compared by looking at the percentage of days for which the policy was unable to meet the full demand (E). For example, a policy that failed to meet the full demand for 100 days of the three year period scored $E = \frac{100}{1095} \times 100\% = 9.1\%$. Additionally, the maximum and minimum inventory levels experienced over the three-years was recorded. Assumptions had to be made for certain models:

- In all cases, the starting inventory level was 350 units.
- Unmet demand must still be accommodated. Patients unable to get medication at that time are likely to ask when new stock will be available and return for it.
- The average daily demand, μ , was calculated using a moving average of the last 25 days' demand.
- The service level, α , was fixed at 99%, unless stated otherwise.
- For the EOQ: The purchase cost per unit was set to $P = \$100.00$, the annual inventory carrying cost was set to $C = 10\%$, and the order cost per unit was set to $A = R20.00$.
- The days on hand, DOH , equation used in Policy 7 requires company-specific values which cannot merely be made-up. For this reason the days on hand was changed to twice the longest contributing period, $DOH = 2 \times MAX(L; R)$.

10.2 Findings

Firstly, policies using the *EOQ* appeared to perform fine for smaller lead times ($L \leq 3$ days) and review periods ($R \leq 3$ days), but failed completely for any longer periods. The reason for this is that the *EOQ* equation does not consider the lead time, nor review period. The order quantity will only scale with the current annual demand value, calculated using the last 365 days. Any recent developments in demand would barely have an effect on the order quantity. The *EOQ* value thus remained fairly unchanged throughout all tests. This means policies 2, 5, 6, 11 and 12 (which all use the *EOQ*) were already experiencing E values exceeding 90% by $L < 7$ and $R < 14$ days, and as early as $L = 2$ and $R = 2$ days.

Policy 11 experienced a problem with increasing demand sets. As the demand continued to increase the cycle service level, α_c , would gradually decrease. As α_c decreased the safety stock, SS , decreased. Additionally, as the demand increased, DL increased and SS further decreases. This relationship between the SS and DL values caused the reorder point, $s = SS + DL$, to remain constant despite the change in demand. The increasing difference between the DL and s values gradually reduced α_c to zero causing an error in the "NORM.INV" function. The rest of the code would eventually fail as a result.

Policies 2, 5, 6, 11 and 12 at this point have all failed to perform acceptably. **Error! Reference source not found.** shows E -value results for all $[L \in \{1, 2, \dots, 28\}, R \in \{1, 2, \dots, 28\}]$ combinations of the remaining ten policies (Policies 1, 3, 4, 7, 8, 9, 10, 13, 14 and 15) obtained from each demand set. The greatest factor influencing the results was the review period. Even for the lowest lead time ($L = 1$ day) E -values were often above 20% for $R \geq 3$ days. The best results were most often achieved from demand sets 2 and 4. This was likely due to the lower demand values experienced in the sets. Demand set 5 was also showing low demand values, but due to the consistent change in seasonality the policies battled to manage the demand.

The greatest problem was a lack of recovery. None of the inventory policies incorporated unmet demand into the next order quantities. This meant that policies were assuming unmet demand is gone forever. At a dispensary, patients will be likely to ask when new stock will be available and return for it. New stock should first be used to accommodate the waiting demand and then still be sufficient to satisfy any new demand. Figure 13 identifies two examples of where inventory levels were unable to replenish because the order quantities had not considered the unmet demand.

The best results were obtained by policies 7, 10, 13 and 15. Each of these policies appeared to perform well within certain parameters. Policy 7 performed best overall and obtained near-perfect results in demand sets 2 and 4. This was because of the order quantity's relation to both the review period (with the undershoot value) and the lead time (with the reorder point that is related to the operational levelling factor). However, for the remaining demand sets policy 7 only performed very well for $R \gg L$. This may have been a result of changing the DOH formula. Regardless, Policy 7 shows promise for determining lot sizes with relation to lead time and review period values.

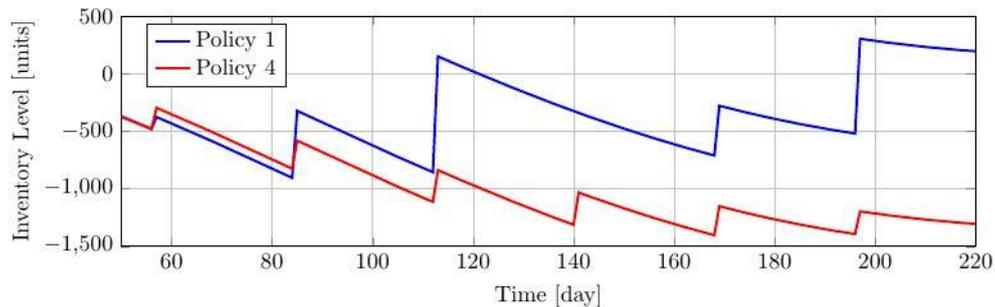


Figure 13: Inventory levels over the first 220 days for Policies 1 and 4 in demand set 5 with $L=28$ and $R=28$ days.

Policies 10, 13 and 15 achieved their best results where $L \gg R$. The reason for this was how each of these policies' order quantities scaled with the lead time. Additionally, shorter review periods produce more frequent orders being placed, allowing the policies to respond better to unexpected demands.

11. CONCLUDING REMARKS

Hospitals and clinics should not be treated as a regular "supply and demand" industry. Patients are reliant on dispensaries to acquire the necessary medication and treatment they cannot get elsewhere. Inventory policies should thus include unmet demand in its reorder decision making process.

The inventory policies found during the systematic literature review came primarily from first world countries with short lead times and using electronic systems to provide accurate, regular reviews. South Africa, however, is still in the process of improving the healthcare supply chain and has to be aware of the effects of longer lead times and review periods. The current inventory policies used in South Africa are causing a large amount of wastage from discarding expensive products. New policies should be explored to prioritise meeting demand rather than minimising cost. By reducing stockouts and the degree of overordering, dispensaries can save money from the lowering of wastage.

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