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A DECISION SUPPORT TOOL FOR QUANTIFYING THE RISK PROFILE OF SOUTH AFRICA'S PHARMACEUTICAL SUPPLY DISTRIBUTION NETWORK

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ABSTRACT

South Africa is facing a serious burden of disease, which is exacerbated by a dysfunctional public health care system. Blind, general estimates are often made in respect of crucial pharmaceutical inventory variables. This results in slow-moving pharmaceutical drugs being overstocked and fast-moving drugs being understocked at outlets and distribution centres. Consequently, large wastages are incurred in terms of drugs being discarded in bulk after passing their expiration date. As a result, patients are deprived of essential medicines due to enduring stock-outs. This paper aims to present the conceptual design of a decision support tool, which aids decision makers in determining pharmaceutical inventory variables that align with key objectives and keep the best interest of patients in mind.

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1. INTRODUCTION

1.1 Background

For decades South Africa has been burdened by epidemics such as the human immunodeficiency virus (HIV/AIDS), tuberculosis (TB) and malaria. According to WHO, HIV/AIDS was the leading cause of death of South Africans, killing 202 100 people in 2012 [1]. Not only is the country haunted by a high frequency of communicable diseases, it also faces staggering numbers of non-communicable diseases, perinatal and maternal mortality, and violence-related injuries. South Africa therefore faces a quadruple burden of disease [2]. Patients receiving chronic medication related to communicable or non-communicable diseases often need to adhere strictly to their prescribed regimen in order to prevent drug resistance [3]. For this reason it is crucial that the right medicine is available to affected South Africans at all times.

It is not common knowledge that a large portion of primary health care facilities in the public health sector experience stock shortages of essential medicines on a regular basis. The Stock Outs National Survey, published in 2015, reported that on the day of contact approximately one in five facilities was affected by stock-outs of antiretroviral (ARV) and TB medicines, and one in ten experienced vaccine stock-outs [4]. Furthermore, 70% of stock-outs in South Africa lasted more than a month, indicating poor provincial supply management and a lack of emergency protocols. For this reason, initiatives such as the Stop Stockouts Project (SSP) exist. This project was established as a result of the Mthatha depot crisis in the Eastern Cape in 2013, where poor management led to the depot staff going on an unprotected strike, which subsequently led to stock shortages at the 300 medical facilities serviced by the depot [5].

The SSP monitors the availability of all essential primary health care medicines and children's vaccines by conducting annual telephonic surveys and logging reports through its SSP hotline. All gathered data are added to the case-management database, which is used to track reported national stock-outs up to a sub-district level. The SSP makes its gathered information available to the National Department of Health (NDoH), so that the department can attend to inadequate services experienced by citizens [4]. Regrettably, the annual survey has been discontinued, but the SSP hotline is still available and reports are still logged on *stockouts.org*.

In order to address the problem of stock-outs in the country, the NDoH commissioned multiple companies to develop solutions that can be implemented nationally. The Centralised Chronic Medicines Dispensing and Distribution (CCMDD) programme was introduced and implemented in 2014. It was developed in order to provide improved access to patients in need of chronic medication, as well as to decrease patient congestion at public health care facilities. By the end of 2014, the CCMDD covered prescriptions for 183 989 patients [6]. In 2015, electronic stock management solutions (ESMS) were implemented in 39 hospitals in order to monitor the availability of medicines and to effectively enhance demand planning [6]. In 2016, a proactive drug monitoring system, called Stock Visibility Solution (SVS), was introduced and implemented in 1 849 clinics across South Africa [7]. SVS is a platform developed by Mezzanine Ware in partnership with Vodacom to track stock levels at clinics in remote areas. SVS makes use of the capability of smartphones to scan barcodes and utilises Vodacom's vast mobile network to collect data in a central database. Trained medical staff are required to log their available stock once a week by scanning the barcode on a specific medicine and specifying the amount available of a particular drug, as well as its expiry date. The information is stored on a cell phone, until it can be uploaded to the central database via mobile network. The resulting database is a real-time status of the available stock of essential drugs across the network of participating clinics. In this manner clinics can be identified that are low on stock and need to be assigned a higher priority for resupply, but also to single out clinics that continually run out of stock and require further investigation by the NDoH's supply chain managers [8].

By August 2017, the CCMDD programme covered the prescriptions of 1 252 000 patients in need of chronic medicine, the ESMS was implemented at 123 hospitals, and SVS was implemented at 3 121 clinics. Additionally the Minister of Health, Dr Aaron Motsoaledi, stated that through the implementation of SVS the availability of ARV and TB medication has increased from 69.5% to 92.5% and from 65.7% to 88.5%, respectively [8].

The above-mentioned solutions address the stock management problem on an end-user outlet level and facilitate an important step towards end-to-end visibility in the South African pharmaceutical supply chain. These technologies, however, are not the solution to South Africa's primary health care supply problem, but are rather tools that can be utilised in the pursuit towards a functional and efficient demand-driven pharmaceutical supply chain.

1.2 Problem Statement

Primary health care workers in the South African public health care sector are overburdened and sacrifice a lot of time to capture stock data so that managers in the various levels of the NDoH have an overview of how specific facilities are performing. While solutions such as SVS have greatly simplified the stock-taking procedure and guarantee reliable data, the heavy burden of having to report on a regular basis and justify minor wastages persists. Having stock and demand visibility on a facility level is a very important step towards achieving an effective supply chain, but should not be treated as the solution − it is rather the beginning of a solution. The next step should be to establish inventory visibility between supply-chain nodes to allow for effective planning at all levels of the pharmaceutical supply chain and to move towards a preventative strategy rather than a reactive strategy.

This study addresses the problem of ineffective and inefficient inventory management across the South African pharmaceutical supply chain and proposes a possible solution to said problem by the conceptual design of a technology platform aimed at lending decision support to key role players of the pharmaceutical supply chain by providing them with drug priority rankings for each health district.

1.3 Scope and Objectives

To address the problem outlined in Section 1.2, the following objectives are pursued as part of this ongoing research for which preliminary results are presented in this paper:

I. *Review* the academic literature relevant to this project;
II. *Identify* the system user requirements and subsequent system specifications from the literature and related documents.
III. *Propose* a conceptual framework of an ideal modular decision support platform that encapsulates data sourcing, analysis and user interaction, assuming that perfect data are available;
IV. *Identify* possible sources of data that can be used to predict demand patterns of specific drugs, extract performance indicators, develop risk profiles, identify supply-chain bottlenecks, and build user profiles for various role players in the South African pharmaceutical supply chain;
V. *Outline* the planned future work.

1.4 Research Methodology

The *systems development life cycle* (SDLC) is used as a guideline throughout this research and the design of the system is conducted according to a top-down approach, starting at the systems level and delving deeper into the various sub-systems. More specifically, an adaptation of the waterfall model of software development will form the roadmap of this ongoing research, as depicted in Figure 1.

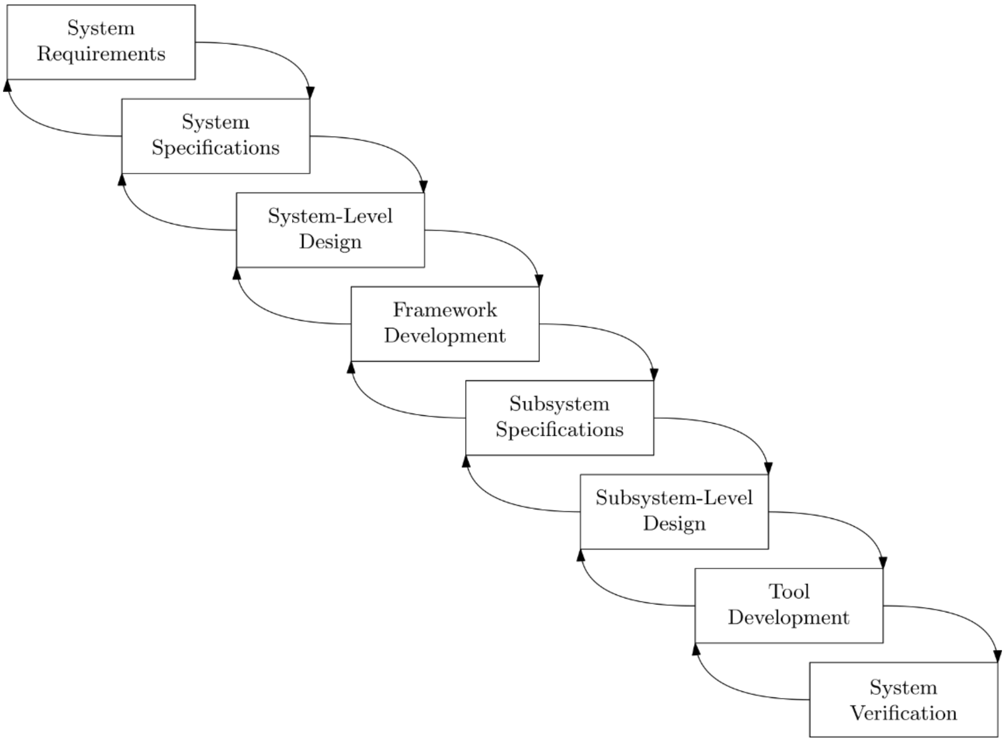

Figure 1: An adaptation of the waterfall methodology

This paper will only span the process up to and including an initial framework development.

2. LITERATURE REVIEW

This section contains a brief overview of the literature relevant to this project.

2.1 Supply Chain Concepts

The concepts reviewed in this section include *demand-driven supply-chain management* (DDSCM), *supply chain visibility* (SCV), the bullwhip- and ripple-effect, the *visibility and analytics network* (VAN), and *supply chain risk management* (SCRM).

2.1.1 Demand-Driven Supply Chain Management (DDSCM)

A demand-driven supply chain, otherwise known as an agile supply chain, responds to the actual product consumption instead of attempting to anticipate demand in advance through general, standardised heuristic forecasting techniques. This concept is most often applied to industries that cater to the distribution of a variety of different products with different properties where the demand is volatile, such as the retail and health care industries.

Capturing actual consumption data through modern visibility technologies allows decision makers to visualise the current area and quantity of demand of specific products, and also allows for a responsive management strategy. To implement a demand-driven supply chain requires *demand-driven supply-chain management* (DDSCM). A DDSCM strategy allows for timely and accurate order fulfilment and ensures customer satisfaction by providing the right product at the right time in the right quantity. This is achieved by focusing primarily on real-time information sharing, advanced inventory-management techniques, lead time reduction, and stakeholder collaboration [9].

2.1.2 Supply Chain Visibility (SCV)

Supply Chain Visibility (SCV) is defined by Goh *et al.* [10] as follows: *"SCV is the capability of a supply chain player to have access to or to provide the required timely information/knowledge about the entities involved in the supply chain from/to relevant supply chain partners for better decision support."*

SCV can be further characterised by having visibility of the process status, the current amount of inventory, the demand pattern, and visibility of exceptions and events in the supply chain, as visualised in Figure 2.

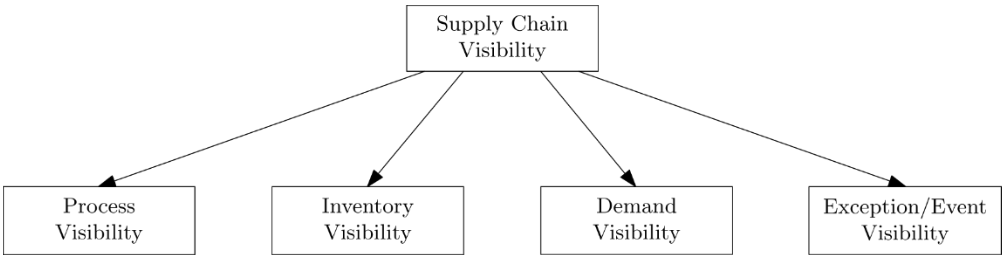

Figure 2: The concept of supply chain visibility adapted from Goh *et al*. [10]

2.1.3 Bullwhip-effect and Ripple-effect

The term bullwhip-effect refers to the phenomenon of increasing variability in order-frequency and order-quantity along a supply chain, due to a misinterpreted perception of demand-variability at the end-user level. The bullwhip-effect is often associated with high-frequency and low-impact disruptions, such as lead time and demand fluctuations, that can be rectified and balanced out within a short amount of time [11].

The ripple-effect, on the other hand, is the phenomenon of disruption propagation in a supply chain and its impact on the output performance [12]. The ripple-effect applies to low-frequency, high-impact disruption events, that might have long-lasting consequences for either the whole supply chain or dependants of the supply chain [13]. The disruption events can be caused by natural disasters, political conflicts, terrorism, and other force majeure events. Figure 3 contains a visualisation of the risk associated with the bullwhip-effect and the ripple-effect respectively, in the form of a risk matrix.

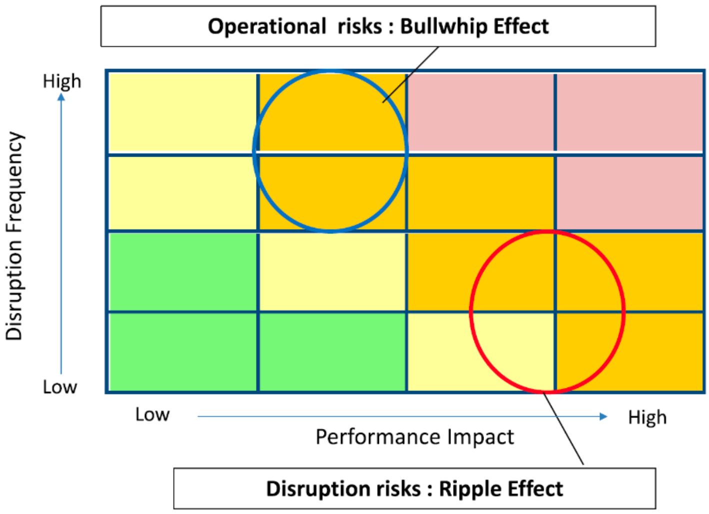

Figure 3: The bullwhip-effect and the ripple-effect on a disruption frequency versus performance impact matrix from Ivanov [13]

2.1.4 Visibility and Analytics Network (VAN)

To improve the availability of medicine in the public sector in Sub-Saharan African countries, the *Visibility and Analytics Network* (VAN) framework was developed in 2015 with funding from the Bill & Melinda Gates Foundation. Theoretically, the VAN is applied to a supply chain and, if implemented correctly, continuously improves the performance of the supply chain by capturing, aggregating, and analysing data and acting on gained insights.

For the VAN to work effectively, it is required that there be end-to-end visibility across the supply chain, meaning that reliable data are available at every node across the supply chain. The various data sets need to be combined and analysed, such that meaningful insights can be gained [14].

Currently the South African medical supply chain functions on an "uninformed pull" system, in which the medical staff are required to place orders based on simple heuristic calculations. This puts considerable unnecessary stress on the medical staff who are often not trained in stock management and can lead to stock-outs and wastage. To disburden the medical staff and allow them to focus on their duties as health care practitioners, the South African medical supply chain needs to transition to an "informed push" system and ultimately to an "informed pull" system [15].

2.1.5 Supply Chain Risk Management

The concept of risk is defined by Schlegel and Trent as: *"The probability of realising an unintended or unwanted consequence that leads to an undesirable outcome such as loss, injury, harm, or missed opportunity."* [16]

Risk is a subject of perspective and context. Risk is often viewed as something to be avoided completely, modelled as the concept of risk aversion in the decision-making process. Risk may, however, also be viewed as an opportunity that needs to be seized, while accepting the possible consequences if it means that there is a chance of achieving something greater.
In the context of the pharmaceutical supply chain, there are, of course, consequences that should not be gambled with, such as the possibility of losing lives, but if the consequence is a non-permanent one, decision makers might be inclined to take some measure of risk.

In his book on strategic risk taking, Damodaran [17] outlines three important distinctions in various definitions of risk: risk versus probability, risk versus threat, and all outcomes versus negative outcomes. It is emphasized that the more comprehensive definitions of risk address both the probability of an event occurring as well as its consequences.

Furthermore, an emphasis is made on low probability, high negative impact events. These events are commonly referred to as threats if they cannot be associated with a probability, due to their unforeseeable nature. Of course, some geographical areas are more prone to certain threats and tell-tale signs can often be discerned prior to the event, but these instances call for fast and efficient emergency response and often cannot be avoided.

Lastly, some definitions consider only the negative impacts of risk and aim to minimise the probability and contain the outcome, while other definitions consider all variability as risk and aim to exploit the positive outcomes.

On this subject Damodaran points out the relevance of the Chinese symbol for risk, which is a combination of the symbols of danger and opportunity. This represents the definition of risk and accurately captures the two opposing sides of risk [17].

An important concept to highlight with regards to risk, is that risk can neither be controlled nor avoided, but it can be managed to some extent in search of the best possible outcome.

Schlegel and Trent define *supply-chain risk management* (SCRM) as the minimisation of risk to a system, by ensuring that all components are obtained from trusted, identifiable, and top-grade sources [16].

Another definition by Wieland and Wallenburg [18], describes SCRM as the management of daily and exceptional risks along the supply chain through the implementation of strategies that ensure the continuous assessment of risk with the objective of vulnerability reduction and ensured continuity.

The most popular method to assess risk is the one of a risk matrix scoring method [19]. Here the likelihood of an event occurring is weighted against the impact of the event. The most basic form of this method adopts a high, medium and low scale for both variables, as can be seen in Figure 4.

IMPACT \ LIKELIHOOD	Low	Medium	High
High	Medium	High	High
Medium	Low	Medium	High
Low	Low	Low	Medium

Figure 4: Basic risk matrix

While this concept is valuable, it does not include the perception of risk, the willingness with respect to exposure to risk, and the uncertainties that come with making risky decisions [19]. When signing an agreement with an investment manager, clients often have to fill out a risk profile questionnaire. This includes questions that assess the amount of risk clients would be willing to subject themselves to for an increased chance at a higher return on investment. Their resilience and level of tolerating losses in particular are central to these types of questions. Oxford Risk is a company that specialises in improving financial decisions through the application of concepts from behavioural science. The company has developed a risk tolerance questionnaire that informs investors of their level of risk tolerance and advises them on the type of investments they should make, based on their behavioural risk profile [20]. This concept aligns well with decision making in a supply chain context, except that a risk profile needs to be developed for the organisation as a whole, its various sub-components and the specific decision makers.

A relevant example of risk tolerance in a medical supply chain context would be the risk associated with vaccine inventory. The extremes of this example would be a total stock-out on the one end of the spectrum and a complete over-supply on the other. A complete stock-out would mean that a newly born infant would be deprived of their first immunisation against polio and tuberculosis which might put them at great risk of potential infection. Furthermore, if a mass immunisation programme runs out of stock before the whole population has received its immunisation booster, it might run the risk of the population not being protected against preventable diseases [21].

On the other hand, over-supply could lead to wastage in terms of vaccines passing their expiration dates or spoilage may occur due to incorrect storage, resulting in possible financial losses [22]. Decision makers have to decide on which side of the spectrum they should operate. In the case of vaccinations, the risk of overstocking may lead to a potential financial loss, which is deemed a less-serious outcome than the alternative. The adoption of a risk aversion strategy should, however, not invoke thoughtless caution, which is where supply chain visibility is a very important concept.

Tolerance with respect to risk is a critical part of assessing risk, but another concept that many risk assessment techniques omit, is the use of time-based risk dimensions. The impact of an event might not be evident immediately after it occurs; it might take a while for the negative or positive effects of the event to unfold. On the other hand, the impact might be felt immediately, but might take a while to subside [23].

An example of a 3-dimensional risk matrix can be seen in Figure 5. This concept includes the conventional probability versus severity matrix, but expands into the third dimension of expected time until impact [24].

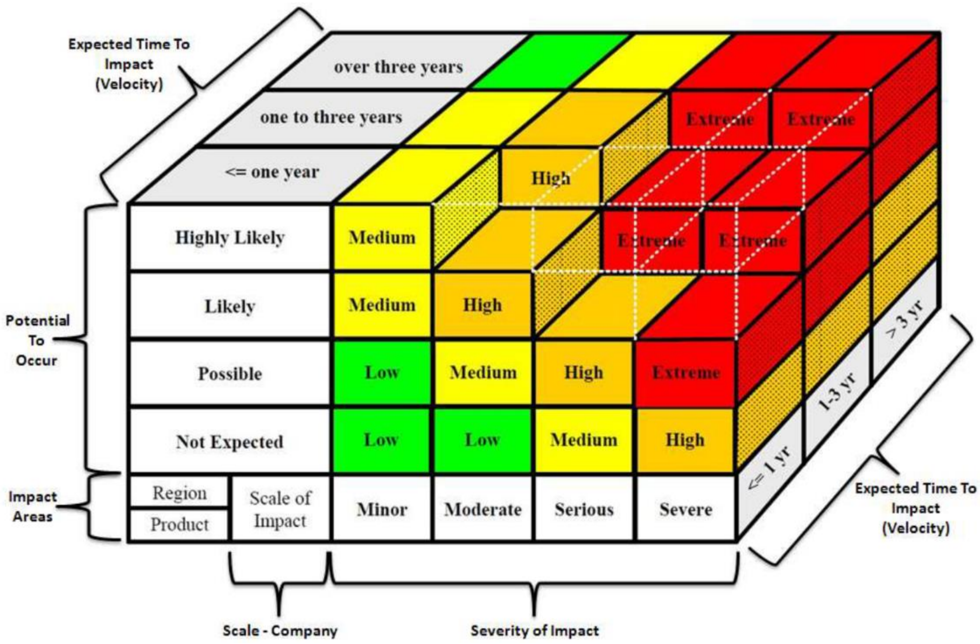

Figure 5: An example of a 3D risk matrix [24]

The crisis at the Mthatha depot, mentioned in Section 1.1, is a very relevant example of the time dimension of risk. It was not predicted that an unprotected strike would lead to 300 medical facilities running out of stock and it was not predicted how long it would take to rectify the situation.

To build on the concept of perception of risk and 3-dimensional risk, one may consider the concept of risk vectors. Hubbard [25] states that one cannot assume a person to be risk-neutral, and thus should not present them with a single value of risk. Instead he suggests leaving the quantity of risk in its separate components in a tabular format and using the entire table as the risk vector quantification. In this way all the outcomes and their associated probabilities for one event can be represented in a tabular format, such that decision makers can see the full picture and decide for themselves whether they are comfortable with the amount of risk to which they are subjecting themselves. A visual representation of a risk vector quantification in a 3-dimensional risk space can be seen in Figure 6.

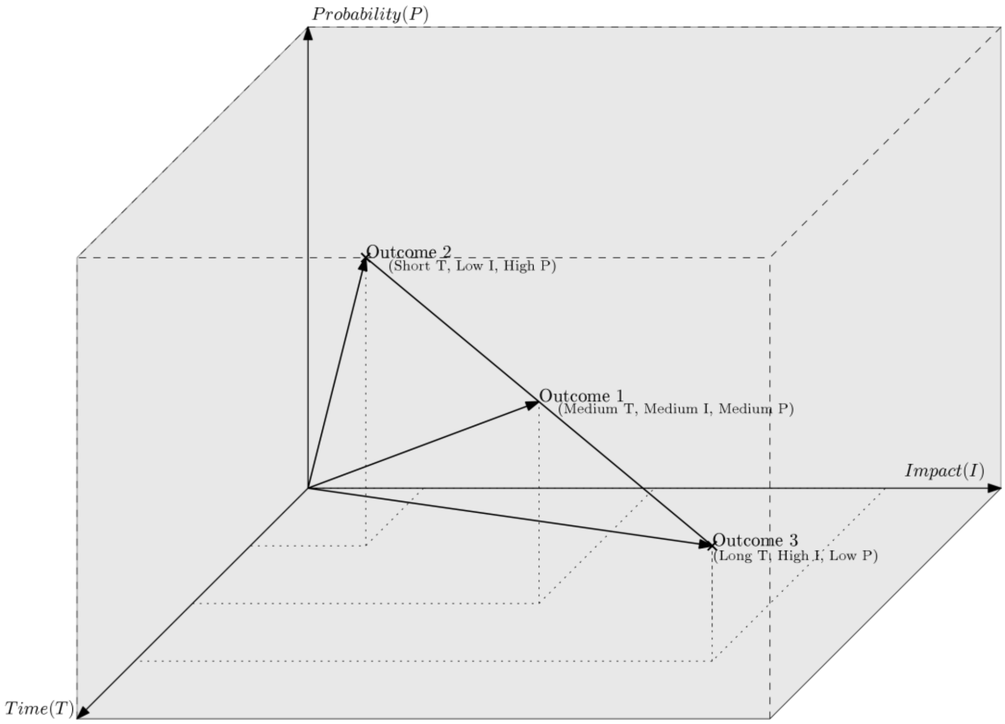

Figure 6: Visual representation of a risk vector quantification

The idea is to provide a decision maker with a direct comparison of all the possible outcomes of an event. This can be achieved in the form of a table, with measured numerical values for probability and impact. The table may then be represented in a 3-dimensional or 2-dimensional space.

2.2 Decision Support Systems

Power *et al.* [26] define decision support systems (DSS) as follows:
"DSS is a general term for any computer application that enhances a person or group's ability to make decisions. In addition, DSSs refer to an academic field of research that involves designing and studying DSSs in their context of use. In general, DSSs are a class of computerized information system that supports decision-making activities."

This definition is a very broad one, but it encapsulates the general purpose of any DSS. There is an abundance of different decision support systems of various types and purposes, and each one is designed to support decisions to a specific kind of problem. DDSs can be stand-alone applications or can form a functional part of an information system. In general, a DSS is used as an inclusive term for various types of information systems [27].

Decision making is a complex concept in the sense that there is no single right or wrong answer to most practical problems. Although there might be an answer that is more applicable than another, there is no guarantee that it is right [28]. It is mostly a matter of perspective or priority – a certain course of action may be a good answer from an economical point of view, but not from an ethical one or *vice versa*. In such instances a DSS only provides indicative outputs instead of definitive ones.

Currently the field of DSS research is dominated by buzz phrases such as Big Data Analytics, Business Intelligence, Internet of Things, Enterprise Information Systems, Cloud Computing, and others [29–31]. What all these concepts have in common is the exceptionally fast growth of internet connectivity, especially through mobile networks, and the abundance of available data. New methods of data creation are being readily implemented. Machine learning techniques are being implemented to uncover previously undiscovered avenues of analysis and insight generation. The age of digital information capture and analysis has made it possible to provide visibility of human behaviour in a real-time manner, where experts previously had to provide broad forecasts and make general assumptions about population groups [32, 33].

Modern day DSSs in conjunction with machine learning techniques have made it possible to provide decision makers with information that is custom-tailored to their preferences and the problems they are trying to solve. Furthermore, the extensively competitive research and development with respect to online application hosting has made it possible to develop web-based DSSs. The design of a Web-DSS is based on a three-tier web architecture: A webpage consisting of a *graphical user interface* (GUI) and a web-server as a front-end, an application server as middleware, and a relational database as the back-end [34].

The concept of web-based DSSs facilitates collaboration by many stakeholders and decision makers in different geographic locations, by providing them with universally relevant information but also with customised information based on their particular roles and what kind of information they would like to see.

3. SYSTEM DESIGN

This section outlines the process followed in the design of the DSS framework. First the user requirements are collected, followed by the identification of relevant data sources. The specifications for a DSS are deduced from the user requirements and a framework is drafted as a starting point for the detailed design and implementation of the system. Lastly, the different dimensions of risk are outlined in the context of the pharmaceutical supply chain.

3.1 System User Requirements

Before the design of a system is attempted, the requirements set out by the end user should be identified. For this project, the requirements were sourced from a collection of documents related to the management of South Africa's pharmaceutical supply chain, as shown in Table 1.

As this project aligns with the concept of DDSCM, it is fitting to design the system with the key success factors of DDSCM in mind. Bvuchete [35] summarised the key concepts that ensure the success of DDSCM in practise and categorised these concepts by visibility, technology, collaboration, change management, distribution management, and performance management. The concept categories best suited for supporting the identified user requirements have been included in the user requirement table.

Table 1: User Requirements

UR_ID	*User Requirement*	*DDSCM Concept Category* [35]	*Source*
1	Identify Distribution Challenges and Bottlenecks	Visibility	[36]
2	View the current state of stock availability	Visibility	[36]
3	Investigate accusations of underperformance	Performance Management	[37]
4	Simulate outcome of different scenarios	Technology; Change Management	[38]
5	Plan for different seasons and demand spikes	Distribution Management	[36]
6	Share information	Visibility	[38]
7	View concise reports	Visibility; Performance Management	[36]
8	A decision recommendation capability within a what-if scenario context.	Technology; Change Management; Collaboration	[38]
9	Recommended maximum and minimum stock levels	Distribution Management	[36]
10	Recommended stock reporting schedules	Performance Management	[36]
11	Pre-emptive stock-out predictions	Performance Management; Distribution Planning; Visibility	[36]
12	User-friendly graphical user interface	Technology	[36], [38]
13	Usable by people with narrow operations research knowledge	Collaboration;	General

		Change Management; Distribution Management; Performance Management	
14	Various visualisation capabilities	Visibility; Technology	[36], [38]
15	Current system compatibility	Technology	General
16	Nurture collaboration	Collaboration	[39]
17	Can be upgraded and easily maintained	Technology	General
18	Multiple different user profiles	Collaboration	[36]
19	Restricted access through internet	Technology	[36]
20	National stock level performance	Performance Management	[36]
21	Identify high and low priority drugs	Visibility; Distribution management; Performance Management	[38]

3.2 South African Data Sources

The identification of possible quantitative data sources is a crucial part of designing a DSS. Apart from general, public statistics on international websites such as those of WHO and UNAids, the most relevant data sources have been summarised in Table 2.

Table 2: Relevant South African data sources

DS_ID	***Name***	***Status***	***Data Type***	***Description***
1	**Master Procurement Catalogue**	**Online, Public**	**Excel and Report**	A list of all essential medicines and medical supplies for South Africa. Includes names, lead times, manufacturers, barcodes, and therapeutic class.
2	**StopStockouts**	**Online, Public**	**Report and online Hotspot Map**	An organisation that allows citizens to report a drug stock-out. All reports are logged in a database and compiled in an annual report, and are shown on their hotspot map on stockouts.org
3	**District Barometer**	**Online, Public**	**Excel and Report**	An annual report published by the Health Systems Trust, outlining the annual health statistics of each health district. The data presented in the report are also available in an electronic spreadsheet format.
4	**DHIS2**	**Online, Restricted Access**	**Database**	The District Health Information System is an open source, online, cloud-based health data repository. It features health demographics, district level headcounts, and other health-related statistics, and is run by the NDoH.
5	**SVS**	**Online, Restricted Access**	**Database**	Stock Visibility Solution is a database of logged clinic inventory levels.
6	**SVS User Stories**	**Online, Public**	**Report**	Mezzanine Ware interviewed employees of the NDHoH and determined the features they'd like to see on a user dashboard. This document summarises the user hierarchy as well as a portion of the user profiles.

7	etr.net	Online, Registered Access	Database	An online register for TB patients.

Of these data sources the stock visibility solution, the master procurement plan, and the district health barometer seem to have promising potential to be employed in the context of for a quantitative analysis of the South African pharmaceutical supply chain. The stock visibility solution is a structured database, which is essential for quantitative analysis. The master procurement plan gives an indication of drug prices and theoretical lead times. The district health barometer is a collection of the most relevant information from the DHIS2 database and gives an indication of annual health statistics per health district.

3.3 Technical Specifications

From the identified user requirements, as well as their supporting DDSCM concepts, preliminary technical system specifications have been deduced, as shown in Table 3.

Table 3: System specifications

SS_ID	*System Specification*	*Reference User-requirement No.*	*Tools and Techniques*
1	Global, relational database	2, 5,6,7	SQL database
2	Broad user proficiency compatibility	12,13	Basic and advanced settings
3	Web-based system	19	Web-API development
4	Modular system	17	Component Based Software Engineering
5	Multi-module model base	8, 14, 15, 17, 18	Application server
6	Current and projected inventory control risk profiles	5, 11, 20, 21	Based on Seasonal district health profiles, Stock event severity profiles with probabilities, Strategy simulation outputs, Calculated inventory control variables
7	Supply disruption reporting module	5, 11	Social media scanning and app
8	Seasonal district health profiles	5	Time dependent clustering
9	Strategy simulation module	4	Agent-based model
10	Inventory control variable calculation	9, 10	Inventory management
11	Compatibility with current NDoH information systems	15, 16	Open source DHIS2 development kit or Tableau
12	Stock-event severity profiles	5	Bayes-Network, decision trees
13	Geographical visualisation	1, 3, 12, 14, 20	Google Maps API, QGIS, Tableau
14	Statistical visualisation	1, 3, 14, 20	Boxplots, cluster plot, distribution charts,
15	Data integrity confirmation module	15	Correct file type, structure and statistical feasibility

These specifications are a basic collection of tools and concepts that will be used in the design and/or will form part of the development of this system. The project is still ongoing and more specific specifications of the sub-systems will be developed as part of the future work.

3.4 System-level Functional Decomposition

The basic functionality of the DSS was based on collected requirements and specifications and is envisioned to conform to the structure in Figure 7.

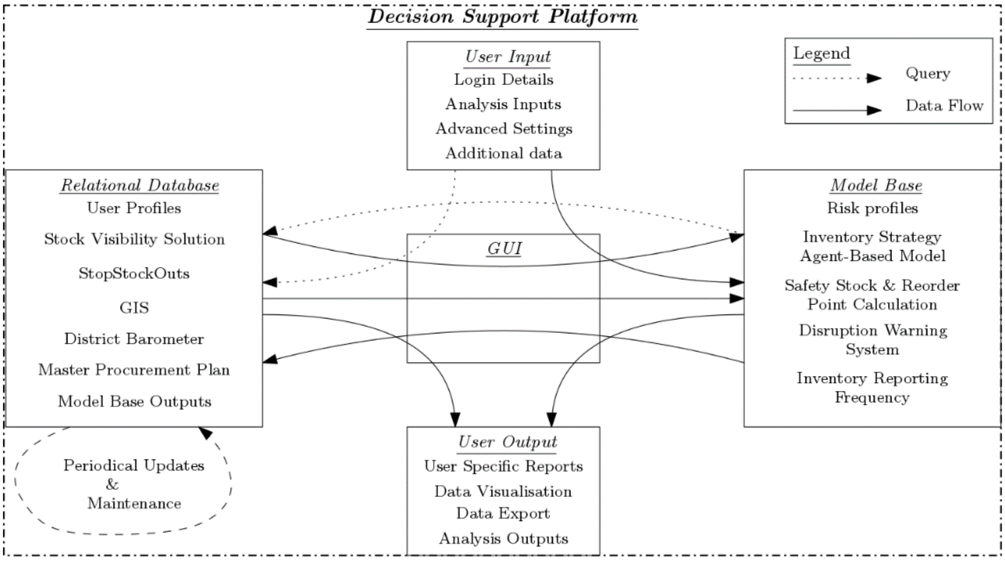

Figure 7: Decision Support Platform Framework

The idea is that the user provides his/her login details through the GUI. The user details are queried with the relational database and the user's profile is retrieved by the GUI. The default user settings are sent to the model base, and these settings are used as an input for the relevant modules. The model base queries the database and receives the data necessary for analysis. The data are sent through the GUI to the model base, where an analysis is carried out. The necessary outputs are then sent to the GUI, where the aggregated information is displayed to the user. This forms the baseline of operation, which occurs automatically upon login. From this point the user can choose to perform more in-depth analyses, and to view more detailed information.

3.5 Dimensions of risk in pharmaceutical supply network

This section aims to expand on the concept of dimensions of risk as defined in Section 2.1.5, and to put it into context for stock-management risk.

The two main risks in a stock management environment are a stock-out, and an over-supply of stock. If one were to attempt to quantify the risk of a stock-out, it would be of no help to provide a decision maker with a single risk value, as this does not provide enough information to manage the risk effectively. It would be more useful to provide all the possible outcomes that fall under the category of a stock-out. A very basic example of this concept can be seen in Table 4. In this example the length of a stock-out is weighed against its impact, and the probability of it occurring.

Table 4: Basic example of the risk of a stock-out as a vector quantity

Event	***Probability***	***Impact***	***Time***
Trivial stock-out	High	Low	Short
Minor stock-out	Medium	Medium	Medium
Enduring stock-out	Low	High	Long

Another example of a more specific stock-out event can be seen in Table 5. In this example the probability of a pharmaceutical needed by a patient is weighed against the impact of its unavailability to the patient, and the timeframe until the impact is felt by the patient.

Table 5: Basic example of the risk of unavailable pharmaceuticals to patients, as a vector quantity

Event	*Probability*	*Impact*	*Time*
Analgesic	High	Low	Long - Not at all
HIV/AIDS medicine	Medium	Medium	Short - Medium
Snake bite anti-venom	Low	High	Immediate – Short

These two cases serve merely as examples of how risk quantification can be attempted in a pharmaceutical supply context. There are many avenues that can be explored, and these examples do not yet include the dimension of hierarchy (*i.e.* if a hospital pharmacy runs out of stock or is shut down, all the dependent clinics will be affected as well).

4. FUTURE WORK AND POSSIBLE IMPACT

The next phase of this project is to develop a concept demonstrator of the system proposed above. It is planned to use Tableau as a front-end user-interface. Tableau is a data visualisation software suite that has already been implemented in some sectors of the department of health.

A back-end application will be built, which can successfully aggregate structured data contained in a relational database, to quantify the risk associated with the state of current drug inventory levels in a district. The application will be developed within the programming language R. The concept demonstrator will aim to form a base structure for other decision support tools.

The decision support tool developed for this specific project will aim to rank drugs according to their priority levels, which will be based on their specific risk profiles. Users can specify which dimension of risk they'd like to see, be it the risk of over-stocking or of a complete stock-out. Furthermore, the user can specify whether they know of any supply disruption event that has occurred, so that it will be included in the analysis. It can be specified where such an event has occurred, and it will be determined which facilities will be affected by the event. This will allow for effective emergency and pre-emptive planning and could possibly decrease the effect of enduring stock-outs and supply disruptions.

The plan is to use machine learning techniques, such as Naïve-Bayes Classification and Kernel-Support Vector Machines, to determine the probability of a stock-out occurring within a sub-district, based on historical data. If this is done successfully, the use of more sophisticated machine learning techniques, such as artificial neural nets can be considered.

The quantification of risk of a supply disruption, such as a stock-out, could have a significant impact on the future planning of decision makers along the pharmaceutical supply chain in South Africa.

5. CONCLUSION

In this paper, the problem of an inefficient and dysfunctional pharmaceutical supply chain was addressed by proposing a preliminary conceptual top-level design of a decision support platform aimed at helping decision makers evaluate the current state of the supply chain and what sectors and products require more attention from a management perspective.

We presented a summary of relevant concepts in the literature that are considered in the system design. These include demand-driven supply chain management, supply chain visibility, the ripple-effect, supply chain risk management, and DSSs.

Following this, a list of user requirements was compiled from different sources and summarised in Table 1. User requirements were also confirmed to be in line with the concept of DDSCM, by indicating their respective categories of key concepts of success for DDSCM, as proposed by Bvuchete [9].

Some of the more prominent data sources of the South African pharmaceutical supply chain that may be used in a DSS were showcased in Table 2. The user requirements from Table 1 were used to compile a collection of basic technical specifications that the proposed system should meet to satisfy the user requirements. These were summarised in Table 3.

The user requirements and system specification were used to draft a simple top-level decision support platform framework that can be used as a starting point in the design of the system and all its sub-systems.

This was followed by bringing the concept of risk dimensions and risk vector quantities into the context of pharmaceutical stock management.

Lastly, planned future work was outlined, as well as the impact that a supply chain risk quantification decision support tool could have on the pharmaceutical supply chain.

The Stock Visibility Solution developed by Mezzanine Ware is a valuable and crucial first step towards a functional and efficient medicine supply chain.

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