

---

# Strategic Inventory Management for Disaster Relief

---

*by*

Estelle van Wyk

25023099

Project leader: Prof. VSS Yadavalli

*submitted in partial fulfilment of the requirements for the degree of*

BACHELORS OF INDUSTRIAL ENGINEERING

*in the*

FACULTY OF ENGINEERING, BUILT ENVIRONMENT  
AND INFORMATION TECHNOLOGY

UNIVERSITY OF PRETORIA

October 2010

---

# Acknowledgement

*I wish to thank my project leaders, Prof. Yadavalli and Me. Wilna Bean (CSIR), for all the leadership and invaluable assistance that they gave me in the process of compiling this project.*

# Executive Summary

Not much can be done to prevent the occurrence of a disaster, but one can be prepared in the event of such a disaster. Pre-positioning of aid supplies has become a crucial part of disaster management, providing the means to overcome the impact of a disaster and to reduce the suffering and loss of life associated with these events.

Natural and man-made disasters are largely unpredictable, therefore disasters need to be researched and their impact fully understood so that the aid supplies required to maintain survival during and after disaster events will be available.

The member states within the South African Development Community (SADC) are the countries of interest for this project, as research conducted on inventory pre-positioning for disaster response in these countries has been insufficient. It is imperative to anticipate the needs of disaster victims for potential disasters. This need is evaluated according to the types and amounts of aid supplies required. All the natural and man-made disasters that have manifested in these countries over the last 30 years are identified, as well as the appropriate aid supplies required to successfully address the impact of such disasters.

General research contributions applied to humanitarian operations have progressed significantly, whilst operations research methods have not yet been comprehensively introduced to cater for disaster-related problems.

A literature review examines the problems associated with the disaster preparedness phase and the existing models used to solve these problems. This project proposes two generic mathematical models that can be used to effectively determine the types and quantities of aid supplies required in pre-positioning facilities within the SADC. A Disaster Recovery Plan (DRP) model is formulated to enhance the survival capability of people in the region directly after the occurrence of any of the disasters identified and a stochastic inventory model is presented to minimise the total cost of the aid supplies kept in inventory. Finally, various methods are utilised to illustrate the functionality of the models.

# Contents

<b>Contents</b>	<b>i</b>
<b>List of Figures</b>	<b>iii</b>
<b>List of Tables</b>	<b>iv</b>
<b>1 Introduction</b>	<b>1</b>
1.1 The Importance of Disaster Management . . . . .	1
1.2 Research Design . . . . .	2
1.3 Research Methodology . . . . .	3
<b>2 Literature Review</b>	<b>5</b>
2.1 An Overview of Disasters in the SADC . . . . .	5
2.2 Aid Supplies . . . . .	6
2.2.1 Non-food Items . . . . .	6
2.2.2 First Aid Kit . . . . .	7
2.2.3 Food Supplies . . . . .	7
2.2.4 Water . . . . .	8
2.2.5 Sanitation . . . . .	8
2.3 The Problem Variants . . . . .	9
2.4 Existing Models . . . . .	9
2.5 The Disaster Recovery Plan (DRP) Concept . . . . .	10
2.5.1 The Pre-Processing Procedure . . . . .	11
2.5.2 Model of the Sub-plan Selection Problem . . . . .	12
2.6 A Stochastic Inventory Model . . . . .	13
2.6.1 Stochastic Programming Model . . . . .	14
2.6.2 Developing Demand Scenario Probabilities . . . . .	14
2.7 Solution Approaches . . . . .	15
2.7.1 The Disaster Recovery Plan (DRP) Model . . . . .	15
2.7.2 The Stochastic Inventory Model . . . . .	15
2.8 Conclusion . . . . .	16
<b>3 Model Formulation</b>	<b>17</b>
3.1 The Disaster Recovery Plan (DRP) for the SADC . . . . .	17
3.1.1 Model Adaptations . . . . .	19
3.2 The Stochastic Inventory Model for the SADC . . . . .	19

3.2.1	Model Adaptations . . . . .	20
3.3	Conclusion . . . . .	21
<b>4</b>	<b>Computational Results</b>	<b>22</b>
4.1	The Disaster Recovery Plan (DRP) Model . . . . .	22
4.1.1	Pre-processing Procedure . . . . .	22
4.1.2	Model Results . . . . .	27
4.1.3	Cost-benefit Analysis . . . . .	29
4.2	The Stochastic Inventory Model . . . . .	30
4.2.1	Pre-processing Procedure . . . . .	30
4.2.2	Model Results . . . . .	34
4.3	Conclusion . . . . .	36
<b>5</b>	<b>Future Work</b>	<b>37</b>
5.1	Managerial Implications and Recommendations . . . . .	37
5.2	Conclusion . . . . .	38
	<b>Bibliography</b>	<b>39</b>
<b>A</b>	<b>Disaster Recovery Plan (DRP) Model Data</b>	<b>42</b>
<b>B</b>	<b>Stochastic Inventory Model Data</b>	<b>56</b>
<b>C</b>	<b>Disaster Recovery Plan (DRP) <i>LINGO</i> Model</b>	<b>60</b>
<b>D</b>	<b>Stochastic Inventory <i>LINGO</i> Model</b>	<b>65</b>

# List of Figures

1.1	The Disaster Cycle . . . . .	2
2.1	The SADC Countries . . . . .	5
4.1	Overview of the DRP for the SADC countries . . . . .	23
4.2	AHP to determine country weights . . . . .	26
4.3	Cost-benefit Analysis . . . . .	29
4.4	Determining scenario probabilities . . . . .	30
4.5	Model results: Quantities and types of aid supplies . . . . .	35
4.6	Effect of alternating holding and shortage costs . . . . .	36

# List of Tables

4.1	Disaster effects $J$ . . . . .	24
4.2	Aid supply $R$ required by disaster type $I$ . . . . .	25
4.3	Frequency of disaster type $i$ having disaster effect $j$ . . . . .	25
4.4	Probability of disaster type $i$ having disaster effect $j$ ( $f_{ij}$ ) . . . . .	26
4.5	Country importance weights . . . . .	27
4.6	Unit cost of aid supplies ( $c_r$ ) . . . . .	28
4.7	Model results . . . . .	28
4.8	Probability of a disaster occurrence . . . . .	31
4.9	Disaster frequency / Disaster effect . . . . .	31
4.10	Probability of a disaster type having a defined effect . . . . .	32
4.11	Probability of a scenario ( $q_k$ ) . . . . .	32
4.12	Aid supply $i$ required by scenario $k$ ( $x_{ik}$ ) . . . . .	33
4.13	Holding and shortage cost per aid supply (ZAR) . . . . .	34
A.1	Summary of SADC disasters . . . . .	43
A.2	Sets defined . . . . .	47
A.3	Frequency of country $k$ having disaster effect $j$ . . . . .	48
A.4	Probability of country $k$ having disaster effect $j$ ( $h_{jk}$ ) . . . . .	49
A.5	Country criteria . . . . .	50
A.6	Normalised matrix . . . . .	50
A.7	Determining country weights . . . . .	51
A.8	Number of aid supplies $r$ required by sub-plan $s$ ( $u_{rs}$ ) . . . . .	53
A.9	Sub-plan $s$ providing recovery capability for disaster effect $j$ ( $w_{sj}$ ) . . . . .	55
B.1	Model results . . . . .	57
B.2	Constant holding cost $h_i$ and varied shortage cost $s_i$ . . . . .	58
B.3	Constant shortage cost $s_i$ and varied holding cost $h_i$ . . . . .	59

# List of Acronyms

**AHP** Analytical Hierarchy Process

**ARC** American Red Cross

**CBA** Cost-benefit Analysis

**CRED** Centre for Research on the Epidemiology of Disasters

**DRP** Disaster Recovery Plan

**DRSP** Disaster Recovery Sub-plans

**GDP** Gross Domestic Product

**IFRC** International Federation of Red Cross and Red Crescent Societies

**SADC** South African Development Community

**SMIP** Stochastic Mixed Integer Program

**WFP** World Food Programme

# Chapter 1

## Introduction

### 1.1 The Importance of Disaster Management

In November 1998, Hurricane Mitch, a 290 km/h category storm, swept through Central America devastating the economies of Honduras, Nicaragua, and Guatemala. An estimated 10 000 people died whilst 2 million were left homeless. In response to the disaster, Carlos Flores, the President of Honduras, stated [25]:

“We lost in 72 hours what had taken us more than 50 years to build, bit by bit.”

The International Federation of Red Cross and Red Crescent Societies (IFRC) were not prepared for the disaster and failed to manage it. The IFRCs failure to consider pre-positioning of supplies caused a slow incoming of relief supplies and as a result, the staff were not sufficiently prepared to respond to the crisis [25].

Throughout history, disasters around the world have caused endless suffering, loss of human life and environmental damage. Annually thousands of people are affected by both natural and man-made disasters which, according to the Centre for Research on the Epidemiology of Disasters (CRED) [11] are increasing substantially, leading to a greater need for efficient disaster management.

Tomasini and Wassenhove [30] define disaster management as the result of a long and structured process of strategic process design, ultimately resulting in successful execution. Disaster management can be divided into four phases: mitigation, preparedness, response and recovery. These phases are known collectively as the disaster operations life cycle. Mitigation is the application of measures that either prevent the onset of a disaster or reduce the impact should a disaster occur. Preparedness relates to the community’s ability to respond when a disaster occurs; response refers to the employment of resources and emergency procedures as guided by plans to preserve life, property, and the governing structure of the community. Finally, recovery involves actions taken to stabilise the community subsequent to the immediate impact of a disaster [1]. The disaster cycle is illustrated in Figure 1.1<sup>1</sup>.

Tomasini and Wassenhove [30] emphasise that the first 72 hours after a disaster has occurred are crucial in order to save the maximum amount of human lives. Saving lives, however, relies on the correct quantity and types of aid supplies, which would be a fairly effortless resolution,

---

<sup>1</sup>Adapted from: Ciottone [10]



Figure 1.1: The Disaster Cycle

if all disaster effects could be predicted. Arminas [4] suitably describes this predicament as follows:

“... purchasing and logistics for major disaster relief is like having a client from hell: You never know beforehand what they want, when they want it, how much they want and even where they want it sent.”

As a consequence of this complexity, it is vital that relief supplies be pre-positioned to improve emergency response times. This forms part of the preparedness phase in the disaster operations life cycle. Demand for aid supplies will vary in type and quantity depending on the specific disaster and the level of destruction it causes. These supplies must meet the immediate needs of those affected and will include items such as food, medicine, tents, sanitation equipment, tools and related necessities [33].

Considering the problem of preparing for a disaster, a research gap has been identified for the pre-positioning of aid supplies in Southern Africa and therefore this project will focus on the countries that are member states of the South African Development Community (SADC). Potential disasters for these countries are identified as well as the associated inventory which would be necessary for survival. Even though there are programmes in place to improve disaster preparedness in these countries [16], the lack of research could lead to inadequate solutions regarding the quantity and type of aid supplies required in a pre-positioning facility.

## 1.2 Research Design

The main problem areas of immediate response lie in the pre-positioning of aid supplies against the unpredictability of demand [30]. The severe consequences of inadequate preparation for disaster response makes it important to address the following question:

*What would be an appropriate way to determine the types and amounts of aid supplies to be kept in inventory at a pre-positioned facility in a disaster response network within the SADC region?*

This project encourages the formulation of a mathematical model as a means of anticipating the types and quantities of aid supplies to be kept in a pre-positioned facility. Eccles and Groth [14] describe the reason for addressing problems with technologies such as mathematical modelling as follows:

“Problems often impose demands that cannot be met given the natural human cognitive and physical limitations. One solution is to adapt oneself to the problem through training and practice, but when humans are unable or unwilling to adapt themselves, they often turn to adapting the environment, by creating technologies, to augment their problem-solving capabilities.”

For the above reason, the proposed solution will be the formulation of a mathematical model. This model will provide a generic approach that can be applied to any pre-positioned facility for disaster preparedness within the SADC countries, by simply entering relevant input values, such as disaster types and their estimated impacts.

The solution will be based on previous models formulated for the purpose of inventory pre-positioning. The proposed model will aim to maximise the recovery capability of disaster victims. The formulation will ensure the inclusion of all relevant disasters that can occur, taking into account the possible effect and impact of the disaster. The output of the model shall provide for the amount and types of aid supplies required after a disaster has occurred. These supplies will be retained in inventory at the pre-positioned facilities. It must however be anticipated that supplies may be damaged during a disaster event and that perishables will have to be replaced if they are not used within a certain time period. This will evidently affect the types and quantities of aid supplies to be stocked. Section 1.3 presents the research and resources of a proposed solution.

### **1.3 Research Methodology**

The aim of this research is to fully comprehend the impact of disasters in the SADC and to provide sufficient relief to victims in the process of disaster management.

An extensive literature review is presented in Chapter 2 to consider previous models developed for the purpose of stock pre-positioning for disaster relief. The gathered information, is used as a framework to serve as a basis to develop a generic inventory model for the SADC countries.

The impact of possible disasters in the SADC countries is identified in terms of the number of people affected, in order to obtain an indication of the nature and quantity of aid supplies required. The variety of supplies varies with time, during and after a disaster, and these varying needs are addressed.

The model is based on knowledge of existing models and the data gathered during research. Population size, disaster type and the disaster impact are used as data input for the model. Based on these inputs, the model is formulated to give an output of the amounts and types of inventory to be kept at a pre-positioned facility, to satisfy demand.

There are two ways to solve a mathematical model namely by heuristics or by solving it exactly, with the use of optimisation software. A heuristic is an algorithm which will produce an acceptable solution, albeit not necessarily an optimal solution. This method is used when

it is difficult to find the optimal solution within a reasonable time period. An exact solution approach, however, often yields the optimal solution to a given problem. Once the formulation of the model is complete, it will be obvious how this model should be implemented. Once the model is created, a sensitivity analysis will be done to test various cases. These results will provide a guide to determine how the model can be applied and improved.

The remainder of this report is structured as follows: Chapter 2 reviews literature addressing the problem variants associated with disaster relief and existing models that have been developed to accommodate these areas. Chapter 3 presents the generic models formulated to effectively determine the types and amounts of aid supplies for the SADC countries. Chapter 4 addresses the computational results of the models. Chapter 5 concludes with future research developments and propositions.

## Chapter 2

# Literature Review

### 2.1 An Overview of Disasters in the SADC

The South African Development Community (SADC) consists of the majority-ruled states in Southern Africa, including the following countries: Angola, Botswana, the Democratic Republic of Congo, Lesotho, Madagascar, Malawi, Mauritius, Mozambique, Namibia, Seychelles, South Africa, Swaziland, Tanzania, Zambia and Zimbabwe [20]. These countries are shown in Figure 2.1<sup>2</sup> below.



Figure 2.1: The SADC Countries

These countries have been susceptible to natural and man-made disasters in the past. Natural disasters have occurred in the form of drought, famine, earthquakes, epidemics, extreme temperatures, floods, storms and wildfires. Man-made disasters have occurred in the form of industrial accidents, transport accidents (road, rail and air), terrorism, political disasters and crime [11].

The timeframe to be considered for the purpose of this project spans over a period of 30

---

<sup>2</sup>Figure obtained from SADC [24].

years, from the year of the formal establishment of the SADC in 1980 until 2009 [24]. The disaster types listed according to each country can be viewed in Table A.1 (Appendix A). The table shows the history of disaster impacts according to the average number of people affected and the number of people killed in previous disasters, based on data that has been obtained from the International Disaster Database [11]. The disaster research uses the following criteria: ten or more people are reported killed, a hundred or more people are reported affected, declaration of a state of emergency and call for international assistance [11].

The information in Table A.1 indicates that most countries in the SADC have been greatly affected by drought, floods and epidemics. A major type of man-made disaster comprises transport accidents, more specifically road accidents. The information in this table makes it possible to identify the most frequent disasters and the supplies that are essential for surviving these disasters. The number of people affected per event will simplify determining the quantities of aid supplies. In Section 2.2, the aid supplies required per person will be determined. The amount of supplies required per person will then be multiplied by the number of persons affected, to arrive at an estimate of the total quantity of supplies required to survive such eventualities. These quantities will be used as part of the input for the model.

## 2.2 Aid Supplies

Humanitarian operations include a wide range of activities such as the delivery of goods and essential services aiming at supporting a community in its survival or to reduce suffering [7]. These operations comprise food aid and nutrition programmes, water, sanitation and hygiene equipment, provision of shelter and other non-food items. The items discussed in the ensuing sections are selected on account of their functional and cost effective characteristics.

### 2.2.1 Non-food Items

Victims of a disaster should have access to basic necessities to survive. Tom Henderson researched this proposition and designed a box consisting of the most urgently required aid supplies, known as the “ShelterBox” [27]. The ShelterBox offers a sense of security to those affected, both physically and mentally. Aid supplies required for this project will be based on the concept of the ShelterBox, as it is a functional and cost effective means to satisfy the demand of victims in any disaster. The durable plastic box includes the following items:

- Mosquito nets
- Waterproof ponchos
- Waterproof ground mats
- Children’s activity pack
- Durable plastic box
- Collapsible water containers and water purifying equipment
- Custom-designed ten-person tent

- Thermal fleece blankets
- Stove and cooking equipment
- Toolkit

The box provides relief for up to 10 people, and can be given to one family or in some cases be shared between two families. The tents are easy to pitch and will provide a waterproof environment for the families. To reduce the distress of children involved in the disaster, a children's activity pack is included. Water purifying equipment can be used to prevent the spread of diseases through water, but in cases of drought, water tanks are also to be supplied. The aid supplies associated with disasters may vary, and therefore the items identified above will be stored separately and not in boxes as with the ShelterBox concept. For medical purposes, a first aid kit is essential. The contents of this kit are discussed below.

### **2.2.2 First Aid Kit**

It is important to consider the medical needs of people in distress. The arrival of medical staff may be delayed in which event a temporary solution would be required for injuries sustained in a disaster. A first aid kit is included to provide interim medical assistance for 10 people.

According to the American Red Cross (ARC), a first aid kit should contain aid supplies to treat cuts, scrapes, pain and swelling [3]. The essential items of the kit should include the following:

- Antibiotics
- Bandages
- Sanitiser packs
- Aspirin tablets
- Scissors
- First aid guide

### **2.2.3 Food Supplies**

Victims of natural or man made disasters not only lose their personal belongings, but may be forced into hunger and eventually starvation. The World Food Programme (WFP) has identified the basic food requirements per person and created a food basket for emergency situations. The basket provides the daily portion of 2,100 kilocalories required by each individual. The food supplies kept in inventory will be based on this basket, with canned food added as an additional item, ensuring a means for any affected population to survive by pre-positioning non-perishable foods. The basket includes the following components per person per day [32]:

- 400 g of cereal flour/rice/bulger
- 60 g of pulses

- 25 g of oil (vitamin A fortified)
- 50 g of fortified blended foods (corn soy blend)
- 15 g of sugar
- 15 g of iodised salt

The nutritional value of the above ingredients not only supplies the required calories but also provides the daily nutritional requirements of 58 g of protein and 43 g of fat. The food basket incorporates micronutrients such as vitamin A, iron, iodine and zinc, and addresses the occurrence of deficiencies and other forms of malnutrition [32].

#### **2.2.4 Water**

One of the most important aid supplies in almost all possible disasters, is the supply of water. Even though the “ShelterBox” includes water purification equipment and cooking equipment, as mentioned in Section 2.2.1, water may become a limited resource in cases of drought. It is therefore essential that a supply of water be kept in supply in the pre-positioning facilities.

In countries with water scarcity, access to water can become problematic. Human life is endangered not only by diseases, weapons and starvation, but also by a lack of water [2]. Anderson [2] points out that the minimum water requirement for hydration purposes is estimated to be 3 litres per day for an average person, given average temperature conditions. In addition to drinking requirements, water must also be used for sanitation purposes and for the disposal of human waste [2]. The effective disposal of waste will also control the spreading of diseases. Furthermore, humans have basic hygiene needs such as personal washing and bathing; water is also used in the preparation of food. Access to water for these purposes will therefore greatly benefit a population.

Drinking, sanitation and hygiene needs constitute the basic human survival needs for water [2]. The minimum quantity of water required to satisfy the above-mentioned needs is approximately 50 litres per person per day. This quantity is sufficient to maintain an individual’s water balance and to provide benefits vital for human health [2].

The supply of water will be based on the capacity of JoJo Tanks which are used for storage of water and can contain 5 500 litres [17]. Considering the minimum quantity of water required per person as determined above, on average one JoJo Tank will supply 110 people with an adequate quantity of water for one day.

#### **2.2.5 Sanitation**

The final necessity, sanitation supplies, is of great importance in disaster relief. Ciottone [10] supports this view by stating that sewage lines and sewage treatment are disrupted by most natural and man-made disasters. Many countries have poor infrastructures, do not have any toilets, underground sewage or sewage treatment in rural districts. For this reason, sanitation supplies should be pre-positioned to prevent the incidents of poor sanitation and potential spreading of epidemics [10].

Sanitation supplies include portable toilets and waste bins. According to Oxfam, one toilet for every 20 persons and one 240 litres waste bin for every 120 persons will be necessary for

immediate response [22]. These supplies are based on the sanitation equipment provided by JoJo Tanks [17].

## 2.3 The Problem Variants

Considerable literature has addressed the management of disaster relief organisations. Much of this deals with the social and organisational implications of responding to disasters in all parts of the world, including areas that may lack infrastructure and/or may be involved in hostilities. According to Turoff [31], information systems applications have improved greatly over the past few years and have helped to reduce the impacts of disaster events. Offsetting this, however, are the forces of population increases, human encroachment into high-risk areas, and changing climate patterns [31]. Despite progress that disaster planning, mitigation and new management systems have made, the need for relief when such disasters occur still remains [33]. Improving disaster relief planning and management is a continuous process.

Due to the unpredictable nature of a disaster, disaster management is a process that cannot be one hundred percent controlled. Altay and Green [1] point out that even though it is known that response to disasters requires good planning, it is crucial to leave room for improvisation in order to deal with the unusual challenges that are created. Hills [15] supports this notion by mentioning that the phrase “disaster management” implies a degree of control, which rarely exists in disaster cases. It is for this reason that Standard Management Methods used in the industry may not always apply directly to disaster situations [1].

Rawls and Turnquist [23] raise another concern, namely that the capacities of resource providers are the key components in managing response efforts subsequent to disaster events, but that only a small amount of research has been conducted on the planning of aid supplies kept in inventory at pre-positioned facilities. In addition, Duran et al. [13] maintain that an important assumption to take into account when considering stock pre-positioning is that facilities should always have sufficient inventory to satisfy demand. It should also be considered that stored aid supplies may be destroyed during a disaster event [13]. The pre-positioned stock should thus meet the needs of a disrupted region by taking the effect of the disaster into consideration [8].

In summary, the above-mentioned problem variants should be addressed by focusing on the uncertainty of a disaster and how demand can be addressed. Discussed below are ways in which these problems have been solved in the past.

## 2.4 Existing Models

The majority of favourable solutions to disaster management problems are supported by mathematical programming methods such as operations research. This is described by Mete and Zabinsky [21] as an appropriate tool for planning the preparedness phase of disaster management, due to its ability to handle uncertainty by means of probabilistic scenarios which represent disasters and their outcomes. Very few journal articles address inventory control problems that are related to humanitarian relief.

Rawls and Turnquist [23] present a two-stage Stochastic Mixed Integer Program (SMIP) that provides an emergency response pre-positioning strategy for disaster threats. The algorithm is

formulated as a heuristic algorithm. The model considers uncertainty in demand for stocked supplies but also includes the uncertainty regarding transportation network availability after an event. For the purpose of this project, only inventory decisions will be considered.

A stochastic inventory control model is developed by Beamon and Kotleba [6], in the form of  $(Q_1, Q_2, r_1, r_2)$ . The model uses optimal order quantities and re-order points to determine inventory for a pre-positioned warehouse responding to a complex humanitarian emergency, including the exceedingly variable demand of the warehouse supply items [6]. The model allows for two types of order lot sizes:  $Q_1$  for a regular order and  $Q_2$  for an urgent order.  $Q_1$  is ordered when the inventory reaches level  $r_1$  and  $Q_2$  is ordered when the inventory level reaches  $r_2$ , where  $r_1 > r_2$ . Beamon and Kotleba [6] use simulation to compare the optimal solution of the  $(Q_1, Q_2, r_1, r_2)$  model with a heuristic and naïve inventory model for a pre-positioned warehouse. These approaches do not specify the types of inventory required but only the quantities, and it is therefore not appropriate to use as a solution model for this project.

A Markovian process is also used to solve the demand distribution of inventory. This idea was initiated by Karlin and Fabens [18], claiming that if each demand state is defined by different numbers, a base stock type inventory policy can be obtained. Taskin and Lodree [28] use stochastic programming to determine an optimal order policy so that the demand in each pre-hurricane season period is met and reserve supplies are stored for the ensuing hurricane season in a cost-effective way. This model provides a valid solution if the decision-maker is concerned with providing relief at a minimum cost.

Bryson et al. [8] use optimal and heuristic approaches to solve a number of hypothetical problems. Mixed integer programming is applied to establish the disaster recovery capability of an organisation. The aim of the model is to determine the resources that should be used in order to maximise the total expected value of the recovery capability. The use of mathematical modelling provides an appropriate decision support tool for the successful development of a Disaster Recovery Plan (DRP). This model provides a generic approach which considers different types of resources required to satisfy demand induced by any relevant disaster.

Bryson et al. [8] and Taskin and Lodree [28] both present meaningful solutions to the problem variants. The generic model required for this project will therefore be based on one of these two models.

## 2.5 The Disaster Recovery Plan (DRP) Concept

The DRP as defined by Bryson et al. [8], is a system for internal control and security, specifically focusing on the restoration of organisational services when operational failures occur as a result of natural or man-made disasters. Bryson et al. [8] explains that an effective DRP will integrate the following properties in the results of the model: feasibility, completeness, consistency, and reliability. These properties establish an adept framework when considering different types of resources required to satisfy the demand induced by any relevant disaster.

The purpose of the model is to determine the resources that are required so that the total expected value of the recovery capability is maximised. This model assumes that for each disaster effect, there is a set of Disaster Recovery Sub-plans (DRSP) that are used to provide protection against that effect. A set of DRSPs therefore makes up the entire DRP. Each resource will provide different utilisation levels, and some resources may be used for more than

one disaster effect [8].

To summarise, the DRP must protect a set of business functions from a defined set of possible disasters [8]. Each DRSP has an associated cost, which remains within a budget to simultaneously maximise the recovery capability within the relevant budget. This model provides a generic approach which considers different types of resources required to satisfy demand induced by any relevant disaster.

This approach is used to minimise an expected loss by determining the most important assets in an organisation. Bryson et al. [8] make the following assumptions:

- There are various disasters that can occur.
- Each disaster has a set of possible devastating effects.
- Each effect has the ability to affect a number of business functions.
- To protect against each effect, a set of solution resources are necessary.
- Two strategies are possible: prevention and recovery.
- A recovery resource may be substitutable.
- Substitutable resources may not inevitably provide the same level of efficiency.
- Some resources can be used to handle more than one effect.
- Some resources will require the existence of other resources.
- A DRP is made up of a set of sub-plans, resources, rules, and procedures. The aim is to recover from at least one effect.

Bryson et al. [8] make use of these assumptions to formulate the following pre-processing procedure and a relevant model.

### 2.5.1 The Pre-Processing Procedure

Bryson et al. [8] start with the identification of different types of disasters  $I$  that can occur and the associated effects  $J$ . These will be placed in the relevant sets. A disaster recovery sub-plan also needs to be determined for each disaster effect. These parameter values are determined by formulating the relevant matrices as described by Bryson et al. [8]:

Comparing:

- Target infrastructural resources with system resources that support each business function;
- disaster types with disaster effects; and
- disaster effects with business functions.

From this data, a set of disaster recovery sub-plans must be developed for each disaster; and for each disaster recovery sub-plan, a set of solution resources must be identified [8]. The following is then compared in the matrices:

- Disaster effects with disaster recovery sub-plans; and
- disaster recovery sub-plans with solution resources required.

## 2.5.2 Model of the Sub-plan Selection Problem

- $K \triangleq$  set of business functions  
 $R_1 \triangleq$  set of solution resources that occur in real quantities (e.g. time)  
 $R_2 \triangleq$  set of solution resources that occur in integer quantities (e.g. equipment)  
 $R \triangleq$  set of solution resources:  $R = R_1 \cup R_2$   
 $J \triangleq$  set of disaster effects  
 $I \triangleq$  set of disaster types  
 $S \triangleq$  set of recovery sub-plans  
 $S_j \triangleq$  set of sub-plans that can protect against disaster effect  $j$   
 $S_r \triangleq$  set of sub-plans that use resource  $r$   
 $M_q \triangleq$  the  $q$ th set of mutually exclusive plans  
 $Q \triangleq$  a set of indices,  $1, 2, \dots, |Q|$   
 $f_{ij} \triangleq$  the likelihood of disaster type  $i$  having disaster effect  $j$   
 $a_k \triangleq$  the relative importance of business function  $k$   
 $h_{jk} \triangleq$  the likelihood that effect  $j$  would affect business function  $k$   
 $p_j \triangleq$  given a disaster has occurred, the likelihood of experiencing effect  $j$ ,  $p_j = \sum_{i \in J} f_{ij}$   
 $g_j \triangleq$  the relative importance of a disaster effect  $j$  based on its potential business impact where  $g_j = \sum_{k \in K} a_k h_{jk}$   
 $B \triangleq$  budget limit  
 $u_{rs} \triangleq$  the quantity of solution resource  $r$  required by sub-plan  $s$   
 $c_r \triangleq$  the unit cost for solution resource  $r$   
 $e_s \triangleq$  the reliability measure of sub-plan  $s$   
 $e_{avg} \triangleq$  the minimum desired average of the reliability measures for the selected set of sub-plans  
 $v_s \triangleq$  a value measure of the recovery potential of sub-plan  $s$ ,  $v_s = \sum_{j \in J} w_{sj} g_j p_j$   
 $y_s \triangleq$  a binary variable that indicates whether sub-plan  $s$  is acquired is selected  
 $z_r \triangleq$  a binary variable that indicates whether solution resource “ $r$ ” is acquired  
 $w_{sj} \triangleq \begin{cases} 1 & \text{if sub-plan } s \text{ provides recovery capability for effect } j \\ 0 & \text{otherwise.} \end{cases}$

$$\max \quad z = \sum_{s \in S} v_s y_s \quad (2.1)$$

s.t.

$$\sum_{r \in R} c_r z_r \leq B \quad (2.2)$$

$$\sum_{s \in S_j} y_s \leq 1, \quad j \in J \quad (2.3)$$

$$\sum_{s \in S_r} u_{rs} y_s - z_r \leq 0, \quad r \in R \quad (2.4)$$

$$\sum_{s \in S} (e_s - e_{avg}) y_s \geq 0 \quad (2.5)$$

$$y_s \in (0, 1), \quad s \in S \quad (2.6)$$

$$Z_r > 0 \quad \text{and real}, \quad r \in R_1 \quad (2.7)$$

$$Z_r \geq 0 \quad \text{and integer}, \quad r \in R_2 \quad (2.8)$$

The objective function (3.8) of the linear programming model is used to maximise the total recovery capability of a set of sub-plans that have been chosen [8]. The first constraint, Constraint (3.2) provides a budget limit which ensures that the resources selected for the sub-plans do not exceed a specific budget. Constraint (3.3) ensures that only one sub-plan is selected for a given effect. Constraint (3.4) allows the possibility that a resource is obtained for a selected sub-plan. The final constraint, (3.5), ensures that the minimum specified value,  $e_{avg}$ , is exceeded by the average reliability measure for a selected set of sub-plans [8].

## 2.6 A Stochastic Inventory Model

A stochastic inventory model results when one or more of the data elements in a linear program is represented by a random variable [26]. According to Taskin and Lodree [28], stochastic programming methodologies can be used to effectively plan inventory for a disaster occurrence, based on a prediction model.

Taskin and Lodree [28] use demand predictions for a hurricane season which follow a discrete-time Markov chain. It is motivated that this approach allows the inventory manager to adjust inventory decisions as new information regarding the hurricane season and realizations of pre-hurricane season demands are acquired [28].

The model of the stochastic inventory approach is divided into multiple periods. This allows adjustments of the target inventory level of emergency supplies at the beginning of a demand season [28]. Prior to a disaster, the inventory levels are also determined according to stochastic demands. The multiple period stochastic inventory problem is then formulated into a programming model, which creates a solution that specifies cost minimising order/production quantities in which the decision-maker has flexibility to adjust the inventory policy based on updated hurricane season demand information as and when pre-hurricane season demand realizations occur.

The benefit of this model is that it allows a user to overcome the uncertainty of disasters by stocking sufficient aid supplies in a multiple period framework, based on continuous updates of demand surges. Taskin and Lodree [28] also support this model because it offers the benefit to modify decisions before a disaster event [28]. The stochastic model of Taskin and Lodree [28] is given below.

### 2.6.1 Stochastic Programming Model

- $Q_{kt} \triangleq$  The number of items required at the beginning of period  $t$  for demand scenario  $k$
- $c_t \triangleq$  The unit ordering cost
- $x_{kt} \triangleq$  The total expected demand for a single product during period  $t$  for demand scenario  $k$
- $q_{kt} \triangleq$  The probability of a scenario
- $v_{kt} \triangleq$  The excess inventory at the end of period  $t$  of scenario  $k$
- $h_t \triangleq$  The unit holding cost
- $u_{kt} \triangleq$  Number of shortages observed at the end of period  $t$  for scenario  $k$
- $s_t \triangleq$  Unit cost

Using the above notations, Taskin and Lodree [28] formulate the following objective function:

$$\min z = \sum_{t=1}^T \sum_{k=1}^K q_{kt}(c_t Q_{kt} + h_t v_{kt} + s_t u_{kt}) \quad (2.9)$$

*s.t.*

$$Q_{kt} + v_{k(t-1)} u_{kt} - v_{kt} = x_{kt} \quad (2.10)$$

$$v_{k_0} = 0 \text{ where } k = 1, \dots, K \quad (2.11)$$

$$Q_{kt}, v_{kt}, u_{kt} \geq 0, t = 1, \dots, T, k = 1, \dots, K \quad (2.12)$$

The constraints above give the certainty that the decisions made at period  $t$  are not dependent on future data but only on the data available up until period  $t$ ,  $x_{[1,t]}$  [28].

### 2.6.2 Developing Demand Scenario Probabilities

Taskin and Lodree [28] use a Markov chain with hurricane prediction rates to develop demand scenarios. The approach is to use a stationary transition probability  $p_{ij}$  of the Markov chain, which is associated with the probability of predicting hurricane landfall count rate  $j$ , prior to the disaster events, given that the previous predictions were  $i$ .

The formulation of the model required for this project will be based on the adjustable model developed by Taskin and Lodree [28]. Their entire model, however, is based on hurricane

predictions and inventory. The model required for this project will be formulated for the purpose of all disasters that are identified in the SADC region.

## 2.7 Solution Approaches

The models proposed by Bryson et al. [8] and Taskin and Lodree [28] will both be used as a framework to formulate two mathematical models to provide various solutions for the decision-maker.

### 2.7.1 The Disaster Recovery Plan (DRP) Model

The model formulated by Bryson et al. [8] is focused on business functions affected during a disaster event. Their model will be adapted in this project to provide relief for a population instead of a business. The relevant disasters in the SADC, the impacts of the disasters and the associated aid supplies, which have been identified in Section 2.1 and Section 2.2, will be used to identify the various sets of the model.

The parameters of the model will also be adjusted to comply with the SADC requirements. In the first instance it must be appreciated that each disaster has a likelihood of having a certain critical effect. This likelihood can be determined by gathering data of each disaster in the region over the last 30 years and analysing their impacts. Due to inadequate infrastructure, less developed regions are also more prone to a larger scale of destruction once a disaster occurs. Each country is thus given an “importance” rating. The higher the rating the more likely the country will be susceptible to incidents of disasters. Each disaster effect will lead to different types of aid supplies that are needed in different quantities. These quantities will be determined to provide relief for sufficient time periods. Finally, the unit costs of each aid supply will be determined, followed by annual budget estimates for humanitarian organisations.

To test the model, Bryson et al. [8] generate 12 hypothetical problems, using a selection of parameter settings. From this, disaster effects, the number of resource types and the number of resources per sub-plan can be determined [8]. The process is applied with four different approaches and the output results are used to select the most feasible solution.

Testing of the DRP for the SADC countries will be conducted by applying case studies of the region to the model. The parameters will be kept constant while the budget is altered to show how the quantities of each aid supply changes accordingly. Next, a Cost-benefit Analysis (CBA) will be performed to clearly indicate the functionality of the model, and whether any further modifications are required. The solving of the model will be accomplished by using an optimisation software such as *LINGO*.

### 2.7.2 The Stochastic Inventory Model

The hurricane predictions of Taskin and Lodree [28] will be modified to resolve inventory decisions for any relevant disaster. The predictions are also based on hurricane incidents in the United States, which will be adapted to conform to disaster predictions within the SADC.

Each parameter associated with the cost of inventory will be based on the individual costs related to the aid supplies addressed in this chapter. Two time periods are considered by Taskin and Lodree [28] which will be discarded to simplify the model, therefore, instead of assessing the

problem by focusing on various disaster scenarios and the time period  $t$ , the disaster scenarios and the related aid supplies will be considered. Thereafter, the predictions of each disaster will be determined by analysing the number of disasters that have occurred in the SADC during the specified time period and the related impacts of each disaster. The final approach will be to consider the demand for aid supplies related to any possible disaster event in the SADC.

To obtain an optimal ordering policy, Taskin and Lodree [28] use unit ordering costs, shortage costs and holding costs of items kept. As a means to solve the stochastic inventory model for the SADC, the data addressed above will be used as part of the model formulation. The model will be tested by keeping the holding cost of each item constant and then varying the shortage costs, thereafter, the shortage cost of each item will be kept constant and then varying the holding costs. The solving of the model will also be done by using *LINGO*.

## 2.8 Conclusion

It is now apparent that even though there are difficulties associated with disaster preparedness, there are ways to effectively solve these problems. The stochastic inventory model and the DRP both present useful solutions to support a humanitarian organisation with inventory decisions. The adapted formulation of both models is presented in detail in the following chapter.

# Chapter 3

## Model Formulation

The models developed by Bryson et al. [8] and Taskin and Lodree [28] are both used as a framework to formulate a suitable model for the problem variants in this project. From the discussion of both models in the literature review it is apparent that two different approaches are followed. Taskin and Lodree [28] are concerned with the overall cost and thus formulated the model to minimise the costs incurred. The DRP developed by Bryson et al. [8] is primarily concerned with the recovery capability from disaster effects. The way in which these approaches can be applied within the SADC are addressed in this chapter.

### 3.1 The Disaster Recovery Plan (DRP) for the SADC

Assuming a SADC country will be severely affected by a disaster, the primary goal of a humanitarian relief organisation will be to provide relief to as many victims as possible. To limit these “severe” effects, the supplies should be planned and pre-positioned beforehand.

In the first instance the organisation, also known as the decision-maker, will determine a budget limit. Thereafter the model will maximise the total recovery capability of the defined sub-plans, in respect of which each sub-plan represents the amount and type of aid supplies required, without exceeding the budget limit.

The following introduces the sets, variables and parameters, which will be used in the model and constraints as described below:

#### Sets

- $K \triangleq$  set of SADC countries
- $R \triangleq$  set of aid supplies that occur in integer quantities
- $J \triangleq$  set of disaster effects i.t.o population affected
- $I \triangleq$  set of disaster types
- $S \triangleq$  set of recovery sub-plans
- $S_j \triangleq$  set of sub-plans that can protect against disaster effect  $j$ , where  $j \in J$
- $S_r \triangleq$  set of sub-plans that use aid supply  $r$ , where  $r \in R$

### Decision variables

$$y_s \triangleq \begin{cases} 1 & \text{if sub-plan } s \text{ is selected for recovery, where } s \in S \\ 0 & \text{otherwise} \end{cases}$$

$$z_r \triangleq \text{the amount of aid supply } r \text{ that is acquired, where } r \in R$$

### Utility variables

$$p_j \triangleq \text{given a disaster has occurred, the likelihood of experiencing effect } j, \text{ where } j \in J$$

$$g_j \triangleq \text{the relative importance of a disaster effect } j \text{ based on its potential impact on a country, where } j \in J$$

### Parameters

$$f_{ij} \triangleq \text{the likelihood of disaster type } i \text{ having disaster effect } j, \text{ where } i \in I, j \in J$$

$$a_k \triangleq \text{the relative importance of SADC country } k, \text{ where } k \in K$$

$$h_{jk} \triangleq \text{the likelihood that effect } j \text{ would affect country } k, \text{ where } j \in J, k \in K$$

$$u_{rs} \triangleq \text{the quantity of aid supply } r \text{ required by sub-plan } s, \text{ where } r \in R, s \in S$$

$$c_r \triangleq \text{the unit cost for aid supply } r, \text{ where } r \in R$$

$$B \triangleq \text{budget limit}$$

$$w_{sj} \triangleq \begin{cases} 1 & \text{if sub-plan } s \text{ provides recovery capability for effect } j \\ 0 & \text{otherwise.} \end{cases}$$

The total recovery capability of a set of sub-plans can be formulated as follows:

$$\max z = \sum_{s \in S} \sum_{j \in J} w_{sj} g_j p_j y_s \quad (3.1)$$

s.t.

$$\sum_{r \in R} c_r z_r \leq B \quad (3.2)$$

$$\sum_{s \in S_j} y_s \leq 1 \quad \forall j \in J \quad (3.3)$$

$$\sum_{s \in S_r} u_{rs} y_s - z_r \leq 0 \quad \forall r \in R \quad (3.4)$$

$$\sum_{i \in I} f_{ij} = p_j \quad \forall j \in J \quad (3.5)$$

$$\sum_{k \in K} a_k h_{jk} = g_j \quad \forall \quad j \in J \quad (3.6)$$

$$Z_r \geq 0 \quad \text{and integer} \quad \forall \quad r \in R \quad (3.7)$$

The objective function (3.8) of the linear programming model is used to maximise the total recovery capability of a set of sub-plans that have been chosen. Constraint (3.2) provides a budget limit which is identified by the decision-maker. This constraint ensures that the resources selected for the sub-plans do not exceed the specified budget. Constraint (3.3) ensures that only one sub-plan is selected for a given effect. Constraint (3.4) allows the possibility that a resource is obtained for a selected sub-plan. Constraint (3.5) is used to determine the probability of experiencing a certain effect, given that a disaster has occurred. Finally, Constraint (3.6) determines the relative importance of a disaster effect based on its potential impact in a country.

### 3.1.1 Model Adaptations

The model developed by Bryson et al. [8] has been adapted to support the decision-maker with inventory decisions for disaster relief in the SADC countries. The adapted model has altered some of the variables, sets and parameter values.

Bryson et al. [8] assume that some sub-plans are mutually exclusive and incorporates this as a set into the model. This set is removed due to the renewed assumption that certain sub-plans provide relief for more than one disaster. The budget limit, previously determined by identifying the cheapest sub-plan that can cover an effect, is now defined by the decision-maker based on the desired investment. As a result, the model output will determine the optimal implementation of sub-plans which will not exceed the budget limit. Bryson et al. [8] also defines a reliability measure for each sub-plan, as well as a minimum desired average of the reliability measures for a set of sub-plans. These reliability measures have also been excluded due to the assumption that each sub-plan will provide a comprehensive recovery reliability. The final adjustment is made to  $z_r$ , the binary variable defined by Bryson et al. [8], which has been changed to an integer value greater or equal to zero. The adaptation allows the model to provide the user with an integer value which specifies the necessary quantities of aid supplies to keep in the pre-positioned facility.

## 3.2 The Stochastic Inventory Model for the SADC

Humanitarian relief organisations aim to provide relief for as many disaster victims as possible, subject to limited funding. It is therefore useful to consider a model which assists the decision-maker with inventory decisions at the lowest possible cost. The notations of the stochastic inventory model for the SADC are addressed below:

- $Q_{ik} \triangleq$  The number of aid supplies required for demand scenario  $k$   
 $c_i \triangleq$  The unit ordering cost of aid supply  $i$   
 $x_{ik} \triangleq$  The total expected demand for aid supply  $i$  for demand scenario  $k$   
 $q_k \triangleq$  The probability of a scenario  $k$   
 $v_{ik} \triangleq$  The excess inventory at the end of one year of scenario  $k$   
 $h_i \triangleq$  The unit holding cost of aid supply  $i$   
 $u_{ik} \triangleq$  The number of shortages of aid supply  $i$  observed for scenario  $k$   
 $s_i \triangleq$  The shortage cost of aid supply  $i$

These notations are used to formulate the following objective function:

$$\min z = \sum_{i=1}^I \sum_{k=1}^K q_{ik}(c_i Q_{ik} + h_i v_{ik} + s_i u_{ik}) \quad (3.8)$$

*s.t.*

$$Q_{ik} + v_{ik} u_{ik} - v_{ik} = x_{ik} \quad (3.9)$$

$$v_{k_0} = 0, \quad \text{where } k = 1, \dots, K \quad (3.10)$$

$$Q_{ik}, v_{ik}, u_{ik} \geq 0, \quad i = 1, \dots, I, \quad k = 1, \dots, K \quad (3.11)$$

The objective function selects the appropriate quantities and types of aid supplies to minimise the overall cost of inventory kept. Constraint (3.9) guarantees that the number of aid supplies required for a demand scenario corresponds with the expected demand of a scenario, whilst taking excess inventory and shortages into consideration. Constraint (3.10) guarantees that no excess inventory is present during the first usage of the model. Constraint (3.11) ensures that decision variables;  $Q_{ik}$ ,  $v_{ik}$  and  $u_{ik}$ , remain greater or equal to 0.

### 3.2.1 Model Adaptations

The model was adapted to be applicable to the SADC region and as a result a few assumptions are changed to convert the model into a more appropriate solution.

Taskin and Lodree [28] utilise two different time periods which are now discarded to simplify the model for the various disaster scenarios and aid supplies. The inventory kept is now considered for a time period of one year. Hence, it is suggested that the model should be revisited once a year with updated data, given that a disaster has occurred.

According to Taskin and Lodree [28] only one type of item is considered, but the model formulated for the SADC will include all the aid supplies addressed in Chapter 2. The final adjustment is made to the unit cost  $s$  of an aid supply, which is changed to the shortage cost

of an item. It is crucial to address shortage cost, considering that human lives are at stake.

These adaptations ensure that the model is suitable to adhere to the various disasters and the related impacts in the SADC.

### **3.3 Conclusion**

These adjustments have allowed both models to be converted into suitable solutions for disaster preparedness in the SADC countries. The next chapter addresses the application of data for the SADC as input for both the models, followed by the model results and the methods utilised to test the functionality of the models.

## Chapter 4

# Computational Results

This section describes the computational results of the models. Both generic inventory models were coded in *LINGO*, version 8.0, on a standard personal computer. The DRP is solved instantly and has a total of 67 integers, 29 constraints and 118 iterations. The stochastic inventory model is solved in less than 9 seconds. The model has a total of 561 variables, 749 constraints and 764 iterations. Both *LINGO* models can be viewed in more detail in Appendix D. A short description of how the relevant sets and parameter values were obtained is addressed, followed by the results of the models and the methods used to test the functionality of the models.

### 4.1 The Disaster Recovery Plan (DRP) Model

#### 4.1.1 Pre-processing Procedure

The model input was determined by systematically defining each set: the SADC countries, disaster effects, disaster types, disaster recovery sub-plans and the aid supplies required. From these defined sets, the parameter values were determined. Figure 4.1 illustrates the relationships between the parameters and the defined sets of the model, which are ultimately transformed into the required model output, of value to the decision maker.

#### Sets

The sets  $K$  and  $I$ , used in the utility variables  $p_j$  and  $g_j$ , are simply defined by listing the SADC countries  $K$  and the relevant disaster types  $I$  that are associated with these countries. Table A.2 in Appendix A represents sets  $K$ ,  $R$  and  $I$  respectively. The disaster types are identified by listing all the disasters that have occurred in the SADC over the last 30 years as well as the required aid supplies  $R$ , as discussed in Chapter 2.

The set of disaster effects  $J$ , was identified in ten different ranges of population affected. These ranges were estimated by considering all the data of the disasters that have affected population groups in the SADC during the selected time period. The percentiles of the list of values were determined by computing the 10<sup>th</sup> percentile, 20<sup>th</sup> percentile up to the 100<sup>th</sup> percentile and from these the ranges were developed. This method was used to anticipate that a country with a smaller population is also incorporated when affected by the worst possible eventuality.

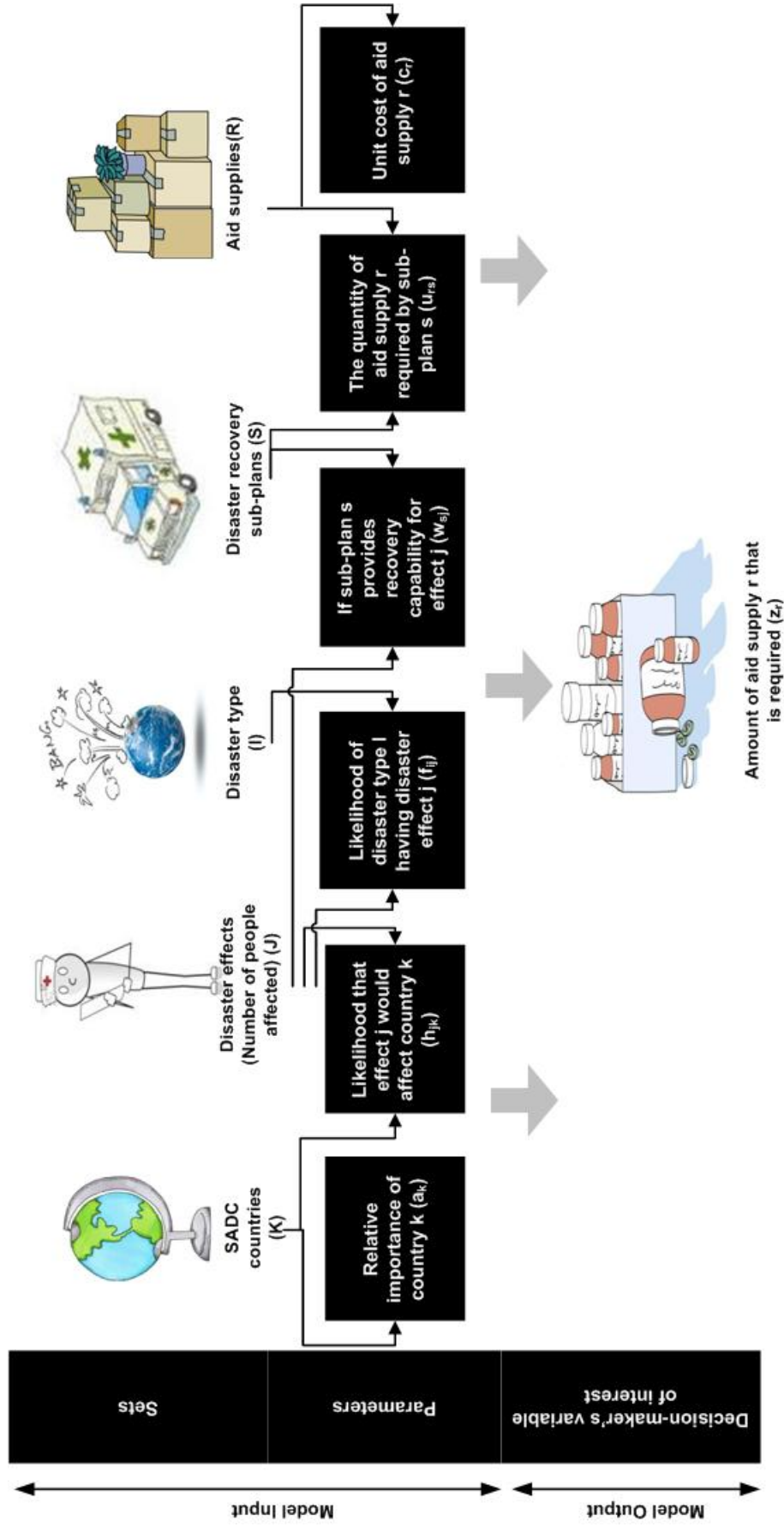


Figure 4.1: Overview of the DRP for the SADC countries

The ranges are depicted in Table 4.1; disaster effect 1 will only include between 1 and 39 people affected, whereas the worst possible effect, effect 10, will include between 505 000 and 15 000 000 people affected.

Table 4.1: Disaster effects  $J$

Effect ( $J$ )	Range (No of people affected)
1	1 - 39
2	40 - 99
3	100 - 299
4	300 - 899
5	900 - 2 999
6	3 000 - 9 999
7	10 000 - 23 999
8	24 000 - 101 999
9	102 000 - 504 999
10	505 000 - 15 000 000

The set of sub-plans  $S$ , was determined by cross referencing aid supplies with disaster types. As presented in Table 4.2, different supplies are required for different disasters. Some disasters do however require the same aid supplies such as: an epidemic, flood, miscellaneous accident, transport accident, insect infestation, storm and an earthquake will require all the defined aid supplies. This approach was followed to ensure that no unnecessary inventory is kept in the pre-positioned warehouse. Subsequently, the table presents 5 different aid supply combinations. Taking into consideration that there are 10 effects, each possible combination thus provides 10 different options. This means that 50 sub-plans are identified to provide relief. The first ten sub-plans provide relief for the first combination of supplies, the next 10, for the second combination, and in the same manner for all 50 sub-plans.

## Parameters

With reference to the parameters, the probability  $f_{ij}$  was determined by analysing disaster types  $i$  in relation to disaster effects  $j$ . This analysis provides a method to determine the frequency of a disaster type in relation to its unique consequence. This is shown in Table 4.3. From this table it was possible to determine  $f_{ij}$ , by dividing each frequency value by the total of 475 disasters that have occurred in the SADC in the past 30 years. The result is seen in Table 4.4 which summarises the likelihood of disaster type  $i$  having disaster effect  $j$ . Similarly,  $h_{jk}$  was developed by cross referencing disaster effect  $j$  with country  $k$ ; the same steps were followed with the parameter  $f_{ij}$ . These values can be viewed in more detail in Appendix C in Table A.3 and Table A.4.

The next parameter  $a_k$ , provides each country  $k$  with a given weight according to importance criteria: total population, disaster frequency, the Gross Domestic Product (GDP) of each country, the number of people affected, and the number of people killed by disasters over the last 30 years. Each criteria gives an obvious overview of how susceptible a country is to a possible disaster. The Analytical Hierarchy Process (AHP) is applied to determine the comparable

Table 4.2: Aid supply  $R$  required by disaster type  $I$ 

$I$	$R$																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Drought					x	x	x			x	x	x	x	x	x		
Epidemic	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Flood	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Mass movement wet <sup>1</sup>		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Industrial accident		x	x	x	x	x	x		x			x	x	x	x		x
Miscellaneous accident <sup>2</sup>	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Transport accident	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Insect infestation	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Storm	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Earthquake	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Wildfire		x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Extreme temperatures <sup>3</sup>		x	x	x	x	x	x	x	x	x	x	x	x	x	x		

Table 4.3: Frequency of disaster type  $i$  having disaster effect  $j$ 

$J$	$I$												Total
	1	2	3	4	5	6	7	8	9	10	11	12	
1	0	2	5	0	0	1	0	0	4	1	36	1	50
2	0	2	4	0	0	1	0	0	5	0	33	0	45
3	0	0	12	0	3	4	0	1	4	3	22	0	49
4	0	3	25	0	4	1	0	0	2	7	5	0	47
5	0	3	15	0	11	1	0	1	1	8	0	4	44
6	0	2	13	0	19	0	0	0	1	11	0	2	48
7	1	1	16	0	26	0	0	0	1	3	0	0	48
8	6	1	9	0	25	0	0	0	0	7	1	0	49
9	17	0	2	0	18	0	0	0	0	10	0	0	47
10	31	0	0	0	9	0	0	0	0	8	0	0	48
Total	55	14	101	0	115	8	0	2	18	58	97	7	475

weight of each country, which is an effective tool used to make decisions when multiple criteria are considered [34].

First, the criteria are weighed against each other according to an importance factor between 1 and 10, 1 being completely irrelevant and 10 absolutely mandatory. To illustrate this method, disaster frequency  $i$  is compared with population size  $j$ . If, for example,  $x_{ij} = 9$ , then criteria  $i$  is 9 times more important than criteria  $j$ . Then for consistency, it is necessary that  $x_{ji} = \frac{1}{9}$  [34]. Correspondingly, each criteria is compared with the next (Table A.5).

The following step is to “normalise” Table A.5 to obtain the final weight of each criteria.

<sup>1</sup>Refers to quantities of rock or stone falling freely from a cliff face. It is caused by undercutting, weathering or permafrost degradation [11].

<sup>2</sup>Includes technological accidents of a non-industrial or transport nature [11].

<sup>3</sup>Refers to winter storms that cause damage to buildings, infrastructure and traffic inflicted by snow and ice [11].

Table 4.4: Probability of disaster type  $i$  having disaster effect  $j$  ( $f_{ij}$ )

$J$	$I$												Total
	1	2	3	4	5	6	7	8	9	10	11	12	
1	0	0.0042	0.0105	0	0	0.0021	0	0	0.0084	0.0021	0.0758	0.0021	0.1053
2	0	0.0042	0.0084	0	0	0.0021	0	0	0.0105	0	0.0695	0	0.0947
3	0	0	0.0253	0	0.0063	0.0084	0	0.0021	0.0084	0.0063	0.0463	0	0.1032
4	0	0.0063	0.0526	0	0.0084	0.0021	0	0	0.0042	0.0147	0.0105	0	0.0989
5	0	0.0063	0.0316	0	0.0232	0.0021	0	0.0021	0.0021	0.0168	0	0.0084	0.0926
6	0	0.0042	0.0274	0	0.0400	0	0	0	0.0021	0.0232	0	0.0042	0.1011
7	0.0021	0.0021	0.0337	0	0.0547	0	0	0	0.0021	0.0063	0	0	0.1011
8	0.0126	0.0021	0.0189	0	0.0526	0	0	0	0	0.0147	0.0021	0	0.1032
9	0.0358	0	0.0042	0	0.0379	0	0	0	0	0.0211	0	0	0.0989
10	0.0653	0	0	0	0.0189	0	0	0	0	0.0168	0	0	0.1011
Total	0.1158	0.0295	0.2126	0	0.2421	0.0168	0	0.0042	0.0379	0.1221	0.2042	0.0147	1

Each  $x_{ij}$  value is divided by the total in column  $j$  and presented in Table A.6. In this normalised table, the average value of every row is calculated, yielding the weight of each criteria. These weights indicate that the GDP of a country is the most important criteria, followed by disaster frequency, number of people affected, number of deaths and population size.

The AHP is completed by listing the population, disaster frequency, number of people affected, GDP and the number of deaths for each SADC country, presented as a fraction of the total (Table A.7). The respective weights are multiplied using matrix multiplication. The sum of the multiplication per country yields the weight of the specific country. Figure 4.2 illustrates this method. The various country weights shown in Table 4.5 indicate that Seychelles is considered to be the most important country, being the most susceptible to a disaster, whereas Botswana is the least important country.

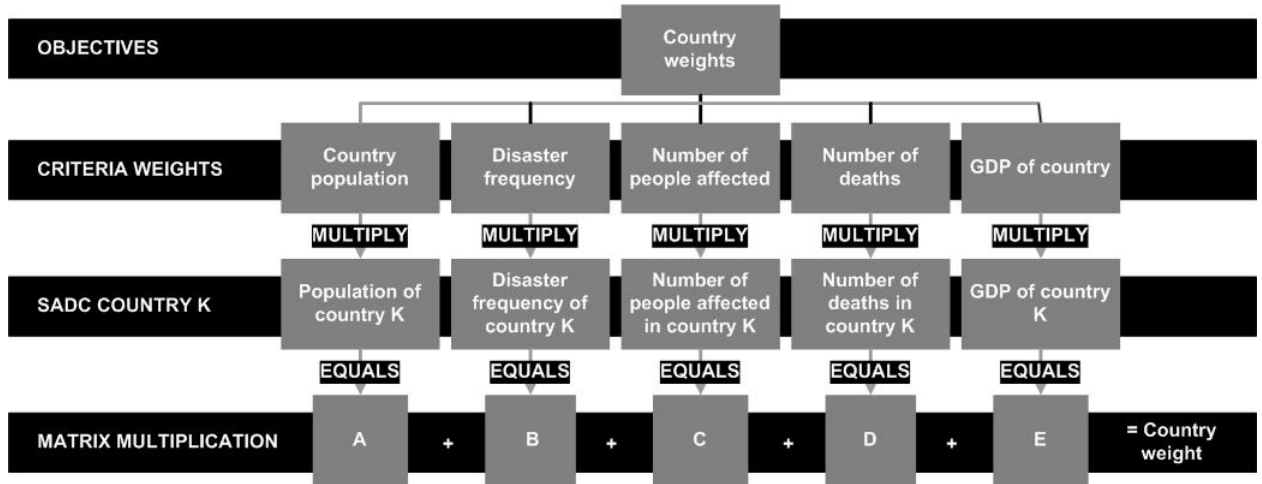


Figure 4.2: AHP to determine country weights

The parameter  $u_{rs}$ , the quantity of aid supply  $r$  required per sub-plan  $s$ , was calculated to supply relief for 30 days which according to Kovacs and Spens [19], allows sufficient time for the recovery phase to be planned. As previously mentioned, there are 50 sub-plans, each having

Table 4.5: Country importance weights

Country ( $K$ )	Weight ( $a_k$ )
Angola	0.0379
Botswana	0.0172
Congo	0.0306
Lesotho	0.0960
Madagascar	0.0481
Malawi	0.0809
Mauritius	0.0207
Mozambique	0.1206
Namibia	0.0254
Seychelles	0.1734
South Africa	0.0972
Swaziland	0.0589
Tanzania	0.0681
Zambia	0.0425
Zimbabwe	0.0825

different amounts and types of aid supplies, providing relief for one or many disasters. Table A.8, outlines these sub-plans.

The cost of the aid supplies,  $c_r$ , were determined per unit in South African Rands (ZAR) and is presented in Table 4.6. The table also specifies the number of persons that can utilise one unit. An estimate of the delivery charges is included in the unit costs, which makes it possible to apply the model to any SADC country. All this data was obtained from the appropriate suppliers.

As mentioned above, all 50 sub-plans provide relief for one or more effect. A matrix is therefore developed, in which each cell indicates that sub-plan  $s$  provides recovery capability for disaster effect  $j$ . Each cell represents a binary value,  $w_{sj}$  [8]. These values are shown in Table A.9.

#### 4.1.2 Model Results

The model was tested by keeping the defined parameters constant and varying the budget limit. The decision variable of interest to the decision-maker is  $z_r$ , giving an indication of the amount and types of aid supplies to be kept in a pre-positioned facility. Table 4.7 reflects the outcome of 4 different budgets. According to Kovacs and Spens [19] an estimated annual budget for relief agencies amounts to ZAR 7 280 000. The budget is therefore alternated between ZAR 1 000 000, ZAR 7 500 000, ZAR 10 000 000 and ZAR 10 500 000, to indicate how the model output changes between two extremes and two realistic estimates.

Table 4.7 displays interesting results, considering that the quantity of each item does not necessarily increase as the budget increases. Furthermore, when observing the values of the food supplies for example, the quantity of units increase as the budget increases, whereas with the water supplies, the quantities initially increase, but thereafter remain constant as the budget

Table 4.6: Unit cost of aid supplies ( $c_r$ )

Item $r$	Unit cost (ZAR)	No of people
Mosquito nets	45.76	1
Waterproof ponchos	9.60	1
Waterproof ground mats	45.76	1
Children's activity pack	40	10
Durable plastic box	286.00	10
Collapsible water containers	34.32	1
Water purifying equipment	194.48	10
Ten-person tent	57.20	10
Thermal fleece blankets	228.80	1
Cooking equipment	686.40	10
Gel stove	686.40	10
Toolkit	171.60	10
First aid kit	114.82	10
Food supplies	24.60	1
Water	3594.00	110
Portable toilet	2662.00	20
Waste bin	588.00	120

increases. The results evidently provide an approach to satisfy total recovery for any SADC country rather than simply increasing inventory when the budget increases. This means that the pre-positioned facilities will not be over-stocked with unnecessary types and quantities of aid supplies.

Table 4.7: Model results

No	Item	ZAR 1 000 000	ZAR 7 500 000	ZAR 10 000 000	ZAR 10 500 000
1	Mosquito nets	0	1	1	1
2	Waterproof ponchos	2	2	2	2
3	Waterproof ground mats	0	0	0	0
4	Children's activity pack	0	0	0	0
5	Durable plastic box	1	1	1	1
6	Collapsible water containers	182	200	200	200
7	Water purifying equipment	921	1 010	1 010	1 010
8	Ten-person tent	0	1	1	1
9	Thermal	55	60	60	60
10	Cooking equipment	1 861	2 040	2 040	2 040
11	Gel stove	0	0	0	0
12	Toolkit	1	1	1	1
13	First aid kit	10	10	10	10
14	Food supplies	2 513	263 062	364 688	385 014
15	Water	55	60	60	60
16	Portable toilet	5	6	6	6
17	Waste bin	187	204	204	204

### 4.1.3 Cost-benefit Analysis

To draw further conclusions from the varying budget a Cost-benefit Analysis (CBA) is performed. This is a standard method utilised to determine and compare the costs and benefits of an intended investment. The measured cost and benefits are weighed against each other to establish criteria for decision making.

The costs of each item identified in Table 4.7 are incorporated in the budget compiled to fund the inventory kept in the pre-positioning facilities, whereas the benefits include the objective values of the model which represent the total recovery capability of the sub-plans chosen. The budgets are selected randomly for testing purposes, from the lowest possible value to the highest possible extreme. Figure 4.3 below indicates the results of the CBA.

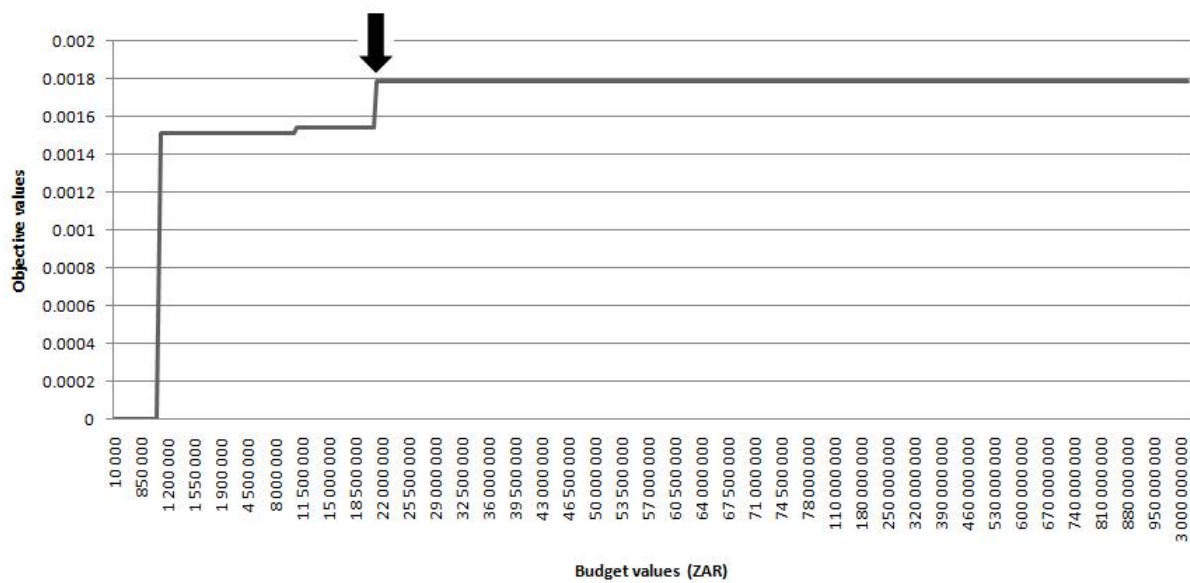


Figure 4.3: Cost-benefit Analysis

The CBA interpretation shows that as the budget increases, the objective value also increases. The benefits do however reach a limit, which means that by reaching a certain budget the objective value will no longer increase, thus reaching a saturated limit. In other words, the decision-maker should not have to invest more than ZAR 21 500 000 for the pre-positioning of aid supplies, as any larger investment will become increasingly irrelevant.

## 4.2 The Stochastic Inventory Model

### 4.2.1 Pre-processing Procedure

For the purpose of the second model it was necessary to identify disaster scenarios or more simply stated, disaster impacts. To effectively analyse a scenario, all the possible characteristics of a disaster have to be considered, which comprises disaster types and effects. Therefore, for each individual disaster type and each related effect a probability is determined, which is multiplied to obtain a disaster scenario. Figure 4.4 illustrates this method.

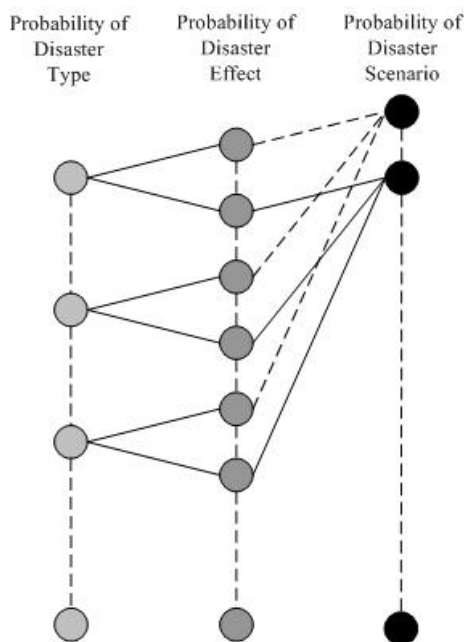


Figure 4.4: Determining scenario probabilities

Predicting a disaster is challenging and in most cases impossible, however, a probability can be determined to estimate the likelihood of a such an event. The approach used to determine these probabilities was to observe the number of times the identified disasters had occurred in the SADC in the past 30 years. The total number of occurrences of each disaster is then divided by the overall total of all the SADC disasters, highlighted in Table 4.8. A distinct difference when compared with the DRP, is that the stochastic model considers the probability that no disaster will take place. Table 4.8 displays these probabilities.

In addition to identifying the frequency of each disaster occurrence it is important to understand all the disaster impacts. Therefore, the number of times a disaster inflicted a specific effect is determined, shown in Table 4.9. Effects 2-11 are similar to those defined in Table 4.1 and effect 1 now represents no disaster effects. From this table the probable effect of a defined disaster can be determined by dividing each value with the associated totals highlighted in Table 4.9. The probabilities are presented in Table 4.10.

Table 4.8: Probability of a disaster occurrence

No	Disaster	Total	Probability
1	Drought	70	0.01341
2	Earthquake	17	0.00326
3	Epidemic	154	0.02950
4	Extreme temperature	2	0.00038
5	Flood	168	0.03218
6	Industrial Accident	26	0.00498
7	Insect infestation	5	0.00096
8	Mass movement wet	4	0.00077
9	Miscellaneous accident	28	0.00536
10	Storm	100	0.01916
11	Transport accident	298	0.05709
12	Wildfire	12	0.00230
13	No disaster	4336	0.83065
Total		5220	1

Table 4.9: Disaster frequency / Disaster effect

Effect	Disaster Type											
	1	2	3	4	5	6	7	8	9	10	11	12
1	15	3	53	2	53	18	5	2	10	42	201	5
2	0	2	5	0	0	1	0	0	4	1	36	1
3	0	2	4	0	0	1	0	0	5	0	33	0
4	0	0	12	0	3	4	0	1	4	3	22	0
5	0	3	25	0	4	1	0	0	2	7	5	0
6	0	3	15	0	11	1	0	1	1	8	0	4
7	0	2	13	0	19	0	0	0	1	11	0	2
8	1	1	16	0	26	0	0	0	1	3	0	0
9	6	1	9	0	25	0	0	0	0	7	1	0
10	17	0	2	0	18	0	0	0	0	10	0	0
11	31	0	0	0	9	0	0	0	0	8	0	0
Total	70	17	154	2	168	26	5	4	28	100	298	12

Referring back to Figure 4.4, the probability of a disaster scenario is obtained by multiplying the probability of each similar disaster effect by the probability of every disaster type and adding these values. Table 4.11 shows the related probabilities, which represent the parameter  $q_k$ .

Table 4.10: Probability of a disaster type having a defined effect

Effect	Disaster Type											
	1	2	3	4	5	6	7	8	9	10	11	12
1	0.2143	0.1765	0.3442	1	0.3155	0.6923	1	0.5000	0.3571	0.4200	0.6745	0.4167
2	0	0.1176	0.0325	0	0	0.0385	0	0	0.1429	0.0100	0.1208	0.0833
3	0	0.1176	0.0260	0	0	0.0385	0	0	0.1786	0	0.1107	0
4	0	0	0.0779	0	0.0179	0.1538	0	0.2500	0.1429	0.0300	0.0738	0
5	0	0.1765	0.1623	0	0.0238	0.0385	0	0	0.0714	0.0700	0.0168	0
6	0	0.1765	0.0974	0	0.0655	0.0385	0	0.2500	0.0357	0.0800	0	0.3333
7	0	0.1176	0.0844	0	0.1131	0	0	0	0.0357	0.1100	0	0.1667
8	0.0143	0.0588	0.1039	0	0.1548	0	0	0	0.0357	0.0300	0	0.0000
9	0.0857	0.0588	0.0584	0	0.1488	0	0	0	0	0.0700	0.0034	0
10	0.2429	0	0.0130	0	0.1071	0	0	0	0	0.1000	0	0
11	0.4429	0	0	0	0.0536	0	0	0	0	0.0800	0	0

To determine the parameter  $x_{ik}$ , the total expected demand for aid supply  $i$  for demand scenario  $k$ , it should be noted that the types of aid supplies are identical to the supplies defined in the DRP model. The quantities of these supplies, however, are determined by establishing the required demand for every possible disaster scenario. The total supply of all the items will also be sufficient for a period of 30 days. These quantities are reflected in more detail in Table 4.12. The unit ordering costs  $c_i$  of each item, corresponds with the selected unit costs of the DRP defined in Table 4.6.

Table 4.11: Probability of a scenario ( $q_k$ )

Scenario $k$	Probability
1 (No Effect)	0.9090
2	0.0096
3	0.0086
4	0.0094
5	0.0090
6	0.0084
7	0.0092
8	0.0092
9	0.0094
10	0.0090
11	0.0092
Total	1

Table 4.12: Aid supply  $i$  required by scenario  $k$  ( $x_{ik}$ )

Scenario $K$	Aid supply $I$								
	1	2	3	4	5	6	7	8	9
1	0	0	0	0	0	0	0	0	0
2	40	40	40	4	4	40	4	4	40
3	100	100	100	10	10	100	10	10	100
4	300	300	300	30	30	300	30	30	300
5	900	900	900	90	90	900	90	90	900
6	3 000	3 000	3 000	300	300	3 000	300	300	3000
7	10 000	10 000	10 000	1 000	1 000	10 000	1 000	1 000	10 000
8	23 000	23 000	23 000	2 300	2 300	23 000	2 300	2 300	23 000
9	102 000	102 000	102 000	10 200	10 200	102 000	10 200	10 200	102 000
10	505 000	505 000	505 000	50 500	50 500	505 000	50 500	50 500	505 000
11	15 000 000	15 000 000	15 000 000	1 500 000	1 500 000	15 000 000	1 500 000	1 500 000	15 000 000

Scenario $K$	Aid supply $I$								
	10	11	12	13	14	15	16	17	
1	0	0	0	0	0	0	0	0	
2	4	4	4	4	1200	11	2	1	
3	10	10	10	10	3 000	27	5	1	
4	30	30	30	30	9 000	82	15	3	
5	90	90	90	90	27 000	245	45	8	
6	300	300	300	300	90 000	818	150	25	
7	1 000	1 000	1 000	1 000	300 000	2 727	500	83	
8	2 300	2 300	2 300	2 300	690 000	6 273	1 150	192	
9	10 200	10 200	10 200	10 200	3 060 000	27 818	5 100	850	
10	50 500	50 500	50 500	50 500	15 150 000	137 727	25 250	4 208	
11	1 500 000	1 500 000	1 500 000	1 500 000	450 000 000	4 090 909	750 000	125 000	

The final parameters to be considered is the holding cost  $h_i$  and shortage cost  $s_i$ . To emphasize the significance of these costs, Kovacs and Spens [19] raise the following question:

*How to balance the costs of shortages and/or holding inventory with human suffering, and should they be balanced?*

Due to the complications arising when determining these costs for humanitarian organisations, the assumption is made that when any shortages are present, it simply means that there is an insufficient quantity of relief supplies for disaster victims, resulting in the loss of one or many lives. Therefore, the shortage cost is determined as follows:

Shortage cost = (Monetary value of human life  $\times$  Probability that item  $i$  will be required)  $\times$  Number of persons that can utilise one unit

It might seem insensitive and inhumane to place a monetary value on human life, but to estimate the value of a treatment or solution to save a life, it is necessary to determine such value [9]. In addition, by not assigning a selected monetary value to human life in relation to the shortage costs associated with humanitarian organisations, could be considered careless if just any random value is selected.

The monetary value of a life for the purpose of this model is determined by using the fatal injury cost per person from the National Department of Transport in South Africa [12]. The estimated value is ZAR 529 459.

The probability that an aid supply will be required is simply the sum of the probabilities of the disasters in which the aid supply is demanded. The supplies required for each disaster was determined in Table 4.2.

Holding cost comprises the cost of carrying one unit of inventory for one time period and usually includes storage and insurance cost, taxes on inventory, labour cost and cost due to the eventuality of spoilage, theft, or obsolescence [34]. Unlike supply and distribution cost, not all humanitarian relief chains will have substantial inventory cost, in that some relief organizations will maintain and operate their own supply warehouses [5]. The holding costs will therefore depend entirely on the decision-maker's personal preference and demand. Factors such as the size of the warehouse, number of staff and insurance rates need to be considered. Because of the implications involved in determining these factors the holding costs will be computed in a similar manner as the shortage costs:

$$\text{Holding cost} = (\text{Monetary value of human life} \times \text{Probability that item } i \text{ will not be required}) \times \text{Number of persons that can utilise one unit}$$

The probability that an item is not required will then equal the sum of the probabilities of the disasters in which the aid supply is not required and the probability that no disaster will occur. The holding and shortage costs are depicted in Table 4.13.

Table 4.13: Holding and shortage cost per aid supply (ZAR)

No	Item	No of persons	Shortage Cost	Holding Cost
1	Mosquito nets	1	78100.23	451358.48
2	Waterproof ponchos	1	82563.10	446895.61
3	Waterproof ground mats	1	82563.10	446895.61
4	Children's activity pack	10	825631.01	4468956.05
5	Durable plastic box	10	896631.22	4397955.84
6	Collapsible water containers	1	89663.12	439795.58
7	Water purifying equipment	10	896631.22	4397955.84
8	Ten-person tent	10	799259.50	4495327.56
9	Thermal fleece blankets	1	82563.10	446895.61
10	Cooking equipment	10	870259.71	4424327.35
11	Gel stove	10	870259.71	4424327.35
12	Toolkit	10	896631.22	4397955.84
13	First aid kit	10	896631.22	4397955.84
14	Food supplies	1	89663.12	439795.58
15	Water	110	9862943.40	48377514.24
16	Portable toilet	20	1594461.85	8994712.27
17	Waste bin	120	9883229.18	53651815.53

## 4.2.2 Model Results

In the first instance, the stochastic inventory model is tested by using the defined parameters addressed above and the holding and shortage costs as identified in Table 4.13. The graph in

Figure 4.5 illustrates the resulting quantities and types of aid supplies required. The results show that as the scenario effects worsen, the quantity of aid supplies do not increase accordingly. The model is concerned with the minimum cost of inventory kept, therefore attempts to provide sufficient relief but not at the expense of unnecessary costs. To view the individual values of each aid supply refer to Table B.1 in Appendix B.

To further test the functionality of the model, a sensitivity analysis is conducted. The method utilised is to alternate the holding and shortage costs, whilst the other parameters are kept constant. The shortage costs are alternated with 10 consecutive progressive ranges of values, shown in Table B.2, while the holding cost remains constant. Thereafter, the holding costs are alternated with 10 consecutive progressive ranges of values, presented in Table B.3, while the shortage cost remains constant. Figure 4.6 illustrates how the overall cost given by the objective function gradually increases with each progressive range. The values 1-10 in the graph represent the increasing ranges depicted in Table B.2 and Table B.3. The graph illustrates that when the holding costs are kept constant the total cost is at a minimum as long as the shortage cost is kept at the lowest possible value, and the same result is shown when the holding cost is kept at a minimum. From this graph it can be concluded that the model will provide the lowest overall cost if holding and shortage costs are kept as low as possible.

The model evidently provides a means to determine the quantities and types of aid supplies to be kept in a pre-positioned facility at the lowest possible cost. The model identifies the required inventory to keep for one year and should be revisited annually with updated data to provide relief for the subsequent year.

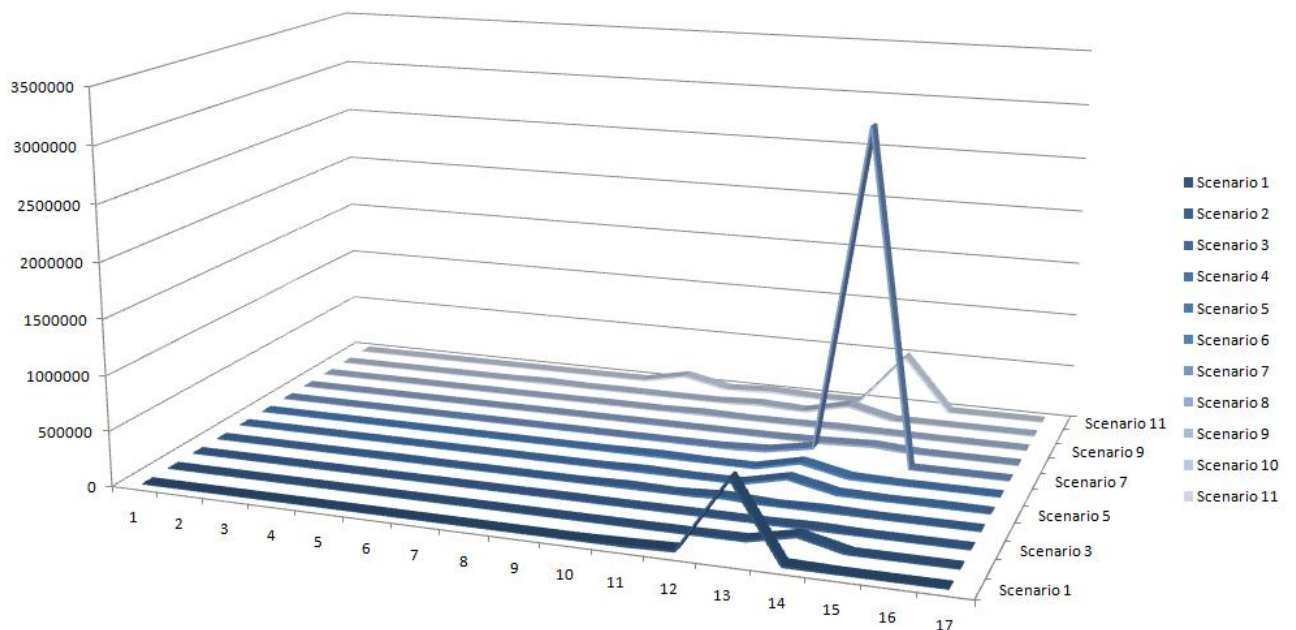


Figure 4.5: Model results: Quantities and types of aid supplies

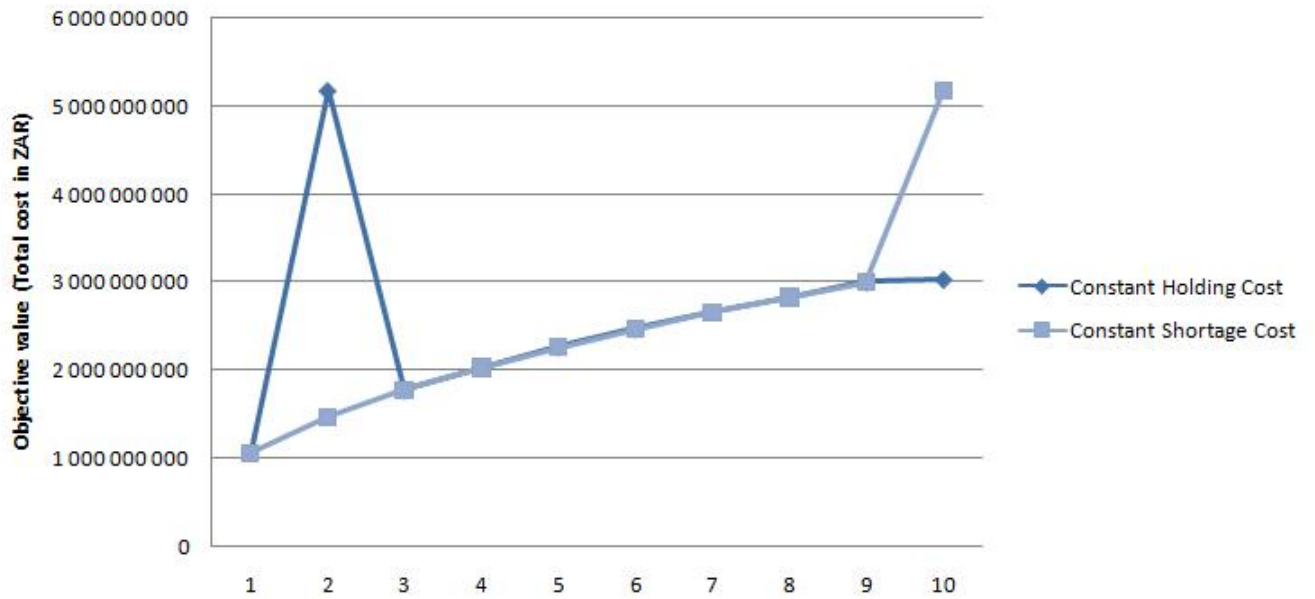


Figure 4.6: Effect of alternating holding and shortage costs

### 4.3 Conclusion

Both models provide meaningful results, but with different perspectives and for this reason comparing the results would be impractical. The DRP is concerned with the total recovery capability and the stochastic inventory model aims to minimise the overall costs. Therefore, instead of selecting one model for the purpose of this project, both should be acknowledged, enabling the decision-maker to either focus on total recovery or minimise cost, depending on the desired objective.

This chapter shows that the models provide interesting and useful results which give the decision-maker various options and the assurance that inventory for disaster relief can be effectively pre-positioned in the SADC countries. However, the models can easily be adapted to be suitable for other countries in the world. The next chapter concludes this report by addressing possible future work and recommendations.

# Chapter 5

## Future Work

### 5.1 Managerial Implications and Recommendations

The aid sector lacks operational knowledge and is not up to date with the latest methods and techniques available to solve disaster relief complexities [19]. Even though this project presents an appropriate method for disaster preparedness, it will not achieve its full potential if the other phases in the disaster operations life cycle are not properly planned and managed. All four phases need to be well collaborated and coordinated to complete a successful life cycle. A humanitarian organisation can be well prepared for a disaster, but severe implications will arise if the response and recovery phase are not properly managed.

Another implication to be considered is that, although a pre-positioned facility can be effectively stocked with the correct amounts and types of aid supplies, the logistics involved with receiving the items from suppliers and transporting these supplies to disaster affected areas is a vital managerial responsibility. The inventory for disaster relief must be kept up to date, with reference to the quantity and types of aid supplies. Some countries have poor infrastructure and therefore transport and pre-positioning need to be well pre-prepared. The final consideration is the prevention of crime, such as theft, which is a concern in certain countries within the SADC. Consequently a pre-positioned facility should be fully equipped with security measures.

A closer look at humanitarian logistics thus shows that risk management, crisis management, continuity planning and project management form an important part of the logistics process. For a successful recovery from a disaster, organisations need to incorporate these managerial processes into the disaster operations life cycle (Figure 1.1), which will lead to an increasing assurance that lives will be saved.

Future studies can complement this work by perhaps applying operational research methods to the other phases in the disaster operations life cycle. Future research developments can be made to both the models by gathering data from other countries and applying the models to such preselected regions.

In the stochastic inventory model, the difficulty of determining holding and shortage costs for humanitarian organisations was overcome by assigning a monetary value to human life and incorporating the value as part of the holding and shortage costs. To improve on this approach and increase the functionality and reliability of the model, it can be converted into its dual composition structure.

Due to the useful results provided by both models, the implementation thereof will effectively

assist and guide decision-makers with inventory decisions for disaster relief. With adequate marketing, both models can be implemented by humanitarian organisations.

## 5.2 Conclusion

The aim of this project is to show how mathematical modelling can be utilised to provide strategic decision support for selecting the required amount and types of aid supplies to be kept in inventory in a pre-positioning facility within the SADC countries.

The models address the concerns of feasibility, consistency and completeness. The objective of the DRP model was to maximise the total value of the coverage provided by the set of selected sub-plans, subject to the model constraints. Whereas, the stochastic inventory model minimises the total costs incurred when accumulating and storing relief supplies.

From a decision-maker's point of view, both models can serve as a handy guideline to assist with planning of types and quantities of aid supplies that should be kept so that lives are saved and not destroyed due to insufficient preparedness. The results of the models indicate that workable solutions have been identified, which have unveiled the possibility to increase the use of operational research methods to enhance disaster relief decision making.

In conclusion, this project challenges the fatal effects of disasters by providing instruments to overcome some of the difficulties of disaster management. Swani Vivekananda [29] cautions:

“If you think about disaster, you will get it. Brood about death and you hasten your demise. Think positively and masterfully, with confidence and faith, and life becomes more secure, more fraught with action, richer in achievement and experience.”

Disasters cause a great deal of suffering, but through careful planning, evaluation and the implementation of the models contained in this project, it is possible to achieve the aim of improving disaster preparedness through keeping aid supplies in pre-positioned facilities in the SADC, at reasonable and affordable cost structures.

# Bibliography

- [1] Altay, N. and Green, W. G. (2006). OR/MS research in disaster operations management. *European Journal of Operations Research*, 175:475–493.
- [2] Anderson, F. (2010). Survival needs. Available online from <http://www.waterencyclopedia.com/St-Ts/Survival-Needs.html> / (Retrieved 3 May 2010).
- [3] ARC (2010). American Red Cross. Available online from <http://www.redcrossstore.org/> (Retrieved 3 May 2010).
- [4] Arminas, D. (2005). Supply lessons of tsunami aid. *Supply Management*, 10(2):14.
- [5] Beamon, B. M. and Balcik, B. (2008). Performance measurement in humanitarian relief chains. *International Journal of Public Sector Management*, 21:4–25.
- [6] Beamon, B. M. and Kotleba, S. (2006b). Inventory modelling for complex emergencies in humanitarian relief operations. *International Journal of Logistics: Research and Applications*, 9(1):1–18.
- [7] Blecken, A., Danne, C., Dangelmaier, W., Rottkemper, B., and Hellingrath, B. (2010). Proceedings of the 43rd Hawaii International Conference on System Sciences. In *Optimal Stock Relocation under Uncertainty in Post-disaster Humanitarian Operations*.
- [8] Bryson, K.-M. N., Millar, H., Joseph, A., and Mobolurin, A. (2002). Using formal MS/OR modeling to support disaster recovery planning. *European Journal of Operations Research*, 141:679–688.
- [9] Card, W. I. and Mooney, G. H. (1977). What is the monetary value of a human life? *British Medical Journal*, 2:1627–1629.
- [10] Ciottone, G. R. (2006). *Disaster Medicine*. Elsevier Mosby, 3rd edition.
- [11] CRED (2009). Country profiles. Technical report, Centre for Research on the Epidemiology of Disasters. Available online from <http://www.emdat.be/disaster-profiles/> (Retrieved 12 March 2010).
- [12] De Beer, E. J. H. and Van Niekerk, E. (2004). The estimation of unit costs of road traffic accidents in South Africa. Technical report, National Department of Transport.
- [13] Duran, S., Gutierrez, M. A., and Keskinocak, P. (2009). Pre-positioning of Emergency Items Worldwide for CARE International. *INFORMS*. Doi: 10.1287.

- [14] Eccles, D. W. and Groth, P. (2006). Wolves, bees, and football: Enhancing coordination in sociotechnological problem solving systems through the study of human and animal groups. *Computers in Human Behavior*, pages 2778–2790.
- [15] Hills, A. (1998). Seduced by recovery: The consequences of misunderstanding disaster. *Journal of Contingencies and Crisis Management*, 6(3):162–170.
- [16] IFRC (2009). *Disaster reduction programme 2001 - 2008*. International Federation of Red Cross and Red Crescent Societies. Available online from <http://www.ifrc.org/Docs/pubs/disasters/resources/reducing-risks/dr-programme-en.pdf> / (Retrieved 12 March 2010).
- [17] JoJo Tanks (2010). JoJo Tanks. Available online from <http://www.jojotanks.co.za/> (Retrieved 3 May 2010).
- [18] Karlin, S. and Fabens, A. (1960). The (s,S) inventory model under Markovian demand process. *Mathematical Methods in the Social Sciences*, (Chapter 8):159–175.
- [19] Kovacs, G. and Spens, K. M. (2007). Humanitarian logistics in disaster relief operations. *International Journal of Physical Distribution and Logistics Management*, 37(2):99–114.
- [20] Leichenko, R. M. and O’Brien, K. L. (2002). The dynamics of rural vulnerability to global change: The case of Southern Africa. *Mitigation and Adaption Strategies for Global Change*, 7:1–18.
- [21] Mete, H. O. and Zabinsky, Z. B. (2009). Stochastic optimization of medical supply location and distribution in disaster management. *International Journal of Production Economics*. Doi: 10.1016/j.ijpe.2009.10.004.
- [22] Oxfam (2010). Oxfam. Available online from <http://www.oxfam.org.au/refugee/public/resources/education/docs/EdKit-L4-T5.pdf> (Retrieved 21 August 2010).
- [23] Rawls, C. G. and Turnquist, M. A. (2009). Pre-positioning of emergency supplies for disaster response. *Transportation Research, Part B*. Doi: 10.1016/j.trb.2009.08.003.
- [24] SADC (2009). *Southern African Development Community*. Available online from <http://www.sadc.int/> (Retrieved 1 May 2010).
- [25] Samii, R. and Wassenhove, L. V. (2002). IFRC Choreographer of Disaster Management - Hurricane Mitch. Technical report, INSEAD Case Study No.06/ 2002 - 5039.
- [26] Sen, S. and Higle, J. L. (1999). An Introductory Tutorial on Stochastic Linear Programming Models. *Institute for Operations Research and the Management Sciences*, 29:33–61.
- [27] ShelterBox (2010). *ShelterBox*. Available online from <http://www.shelterbox.org//> (Retrieved 3 May 2010).
- [28] Taskin, S. and Lodree, E. J. J. (2009). Inventory decisions for emergency supplies based on hurricane count predictions. *International Journal of Production Economics*, doi: 10.1016/j.ijpe.2009.10.008:1–10.

- [29] Think Exist (2010). *Think exist*. Available online from <http://www.thinkexist.com/> (Retrieved 22 March 2010).
- [30] Tomasini, R. and Wassenhove, L. V. (2009). *Humanitarian Logistics*. Palgrave Macmillan.
- [31] Turoff, M. (2002). Past and future emergency response information systems. *Communications of the ACM*, 45:29–33.
- [32] WFP (2010). *World Food Programme*. Available online from <http://www.wfp.org/nutrition/WFP-foodbasket/> (Retrieved 3 May 2010).
- [33] Whybark, D. (2007). Issues in managing disaster relief inventories. *International Journal of Production Economics*, 108:228–235.
- [34] Winston, W. L. (2004). *Introduction to probability models*, volume 2. Curt Hinrichs, 4th edition.

## Appendix A

# Disaster Recovery Plan (DRP) Model Data

Table A.1: Summary of SADC disasters

Country	Disaster	Type	No. of events	Average no. killed per event	Average no. affected per event
Angola	Drought	Drought	6	10	435 000
		Epidemic	Unspecified	1	-
	Flood	Bacterial infectious diseases	14	318	8010
		Viral infectious diseases	2	185	333
		Unspecified	5	5	21803
		General Flood	18	17	49 648
	Mass movement wet	Landslide	1	13	-
	Industrial accident	Chemical spill	1	5	100
	Miscellaneous accident	Collapse	2	16	-
		Explosion	1	22	17
		Fire	1	61	87
	Transport accident	Air	18	41	4
		Rail	1	300	147
		Road	16	23	20
Water		2	101	-	
Botswana	Drought	Drought	3	-	379 100
		Epidemic	Unspecified	1	470
	Flood	Bacterial infectious diseases	1	2	15
		Parasitic infectious diseases	1	183	14 618
		Flash flood	1	20	5 500
		General flood	5	2	32 080
	Insect infestation	Locust	1	-	-
	Storm	Local storm	1	-	400
Congo	Drought	Drought	1	-	-
		Earthquake	1	6	1 505
	Epidemic	Bacterial infectious diseases	5	35	849
		Viral infectious diseases	5	42	6
	Flood	Unspecified	1	2	42 000
		General flood	6	1	20 250
	Miscellaneous accident	Other	1	142	-
	Transport accident	Air	2	18	-
		Rail	4	49	33
		Road	3	16	10
Water		2	367	-	
Lesotho	Drought	Drought	4	-	451 625
		Epidemic	Unspecified	1	28
	Flood	Bacterial infectious diseases	1	28	1 834
		Unspecified	1	18	100 000
		General flood	2	11	40 000
	Storm	Unspecified	5	1	450
		Local storm	1	-	4500
	Transport accident	Road	1	40	60

Country	Disaster	Type	No. of events	Average no. killed per event	Average no. affected per event
Madagascar	Drought	Drought	5	40	559 058
		Epidemic	Unspecified	1	121
	Bacterial infectious diseases		1	860	15 173
	Viral infectious diseases		3	230	7 732
	Flood		Unspecified	2	-
		General flood	3	15	27 662
		Storm surge/coastal flood	1	7	33 000
	Insect infestation	Locust	1	-	-
	Storm	Tropical cyclone	36	52	163 154
	Miscellaneous accident	Collapse	1	14	5
	Transport accident	Air	1	34	5
		Road	1	45	38
		Water	4	34	4
Malawi	Drought	Drought	6	83	3 279 784
	Earthquake	Earthquake	3	4	23 612
	Epidemic	Unspecified	2	88	-
		Bacterial infectious diseases	10	143	5155
	Flood	Unspecified	9	2	42 932
		Flash flood	4	120	84 812
		General flood	9	1	73 122
		Storm surge/coastal flood	2	34	259 250
	Storm	Unspecified	1	11	8
	Miscellaneous accident	Other	1	11	-
	Transport accident	Rail	2	15	122
		Road	10	21	28
		Water	1	24	-
Mauritius	Drought	Drought	1	-	-
	Epidemic	Viral infectious diseases	1	-	2 553
	Storm	Tropical cyclone	12	1	4 101
	Transport accident	Air	1	159	-
Mozambique	Drought	Drought	10	10 007	1 129 750
	Earthquake	Earthquake	1	4	1 476
	Epidemic	Unspecified	1	11	1 810
		Bacterial infectious diseases	19	147	17 156
		Parasitic infectious diseases	1	-	16 773
		Viral infectious diseases	1	43	466
	Flood	Unspecified	4	6	203 384
		General flood	15	65	416 554
		Storm surge/coastal flood	2	42	324 665
	Insect infestation	Unspecified	1	-	-
	Mass movement wet	Landslide	1	87	2 500
	Storm	Unspecified	4	4	1 279
		Tropical cyclone	11	46	315 382
	Wildfire	Unspecified	1	49	3 023
	Industrial accident	Collapse	1	12	-
		Fire	1	-	200
	Miscellaneous accident	Explosion	1	117	450
	Transport accident	Air	2	39	-
		Rail	5	92	108
		Road	6	21	10
		Water	6	25	8 338

Country	Disaster	Type	No. of events	Average no. killed per event	Average no. affected per event
Namibia	Drought	Drought	6	-	130 533
		Epidemic	Bacterial infectious diseases	3	10
	Parasitic infectious diseases		2	117	6 049
	Viral infectious diseases		1	10	47
	Flood		Unspecified	1	-
		Flash flood	1	2	12 000
		General flood	8	18	58 225
	Transport accident	Road	1	20	-
		Water	1	19	9
Seychelles	Earthquake	Earthquake	1	3	4 830
	Epidemic	Viral infectious diseases	1	-	5 461
	Flood	Unspecified	1	5	1 237
	Storm	Tropical cyclone	1	-	6 800
	Transport accident	Water	1	-	-
South Africa	Drought	Drought	6	-	2 911 667
	Earthquake	Earthquake	6	10	75
	Epidemic	Unspecified	2	6	213
		Bacterial infectious diseases	4	81	27 990
		Viral infectious diseases	1	1	-
	Extreme temperature	Cold wave	2	26	-
	Flood	Unspecified	4	26	13 462
		Flash flood	5	45	1 722
		General flood	16	46	11 043
	Mass movement wet	Landslide	1	34	-
	Storm	Unspecified	6	9	261
		Local storm	13	6	9 685
		Tropical cyclone	1	64	500 000
	Wildfire	Bush fire	1	34	25
		Forest fire	2	16	800
		Grassland fire	6	11	959
	Industrial accident	Collapse	1	104	-
		Explosion	8	26	185
		Fire	4	55	59
		Other	3	84	19
	Miscellaneous accident	Collapse	2	51	236
		Fire	6	9	1 424
		Other	2	42	105
	Transport accident	Air	3	22	-
		Rail	13	15	109
		Road	86	21	18
		Water	10	21	59
Swaziland	Drought	Drought	5	100	326 000
	Epidemic	Bacterial infectious diseases	2	31	1 839
		Parasitic infectious diseases	1	80	-
	Flood	General flood	2	-	137 250
	Storm	Unspecified	2	1	3 843
		Tropical cyclone	1	53	623 500
	Wildfire	Forest fire	1	2	1 500
	Transport	Road	2	26	30

Country	Disaster	Type	No. of events	Average no. killed per event	Average no. affected per event
Tanzania	Drought	Drought	6	-	1 327 333
	Earthquake	Earthquake	4	1	2 123
		Tsunami	1	10	-
	Epidemic	Unspecified	4	61	264
		Bacterial infectious diseases	17	306	17 4 909
		Parasitic infectious diseases	1	590	4 853
		Viral infectious diseases	4	32	245
	Flood	Unspecified	9	21	45 701
		Flash flood	3	22	1 600
		General flood	14	24	20 177
	Insect infestation	Locust	1	-	-
	Mass movement wet	Landslide	1	13	150
	Storm	Local storm	3	-	427
		Tropical cyclone	1	4	2 500
	Wildfire	Grassland fire	1	-	-
	Industrial accident	Chemical spill	1	100	-
		Other	1	42	-
	Miscellaneous accident	Explosion	2	30	9 703
		Fire	2	26	34
		Other	2	20	8
	Transport accident	Air	1	12	-
Rail		5	73	96	
Road		37	23	26	
Water		13	94	4	
Zambia	Drought	Drought	5	-	834 641
	Epidemic	Unspecified	2	197	5 725
		Bacterial infectious diseases	13	55	4 098
		Viral infectious diseases	2	68	334
		Unspecified	2	3	958 950
	Flood	General flood	12	5	267 290
		Locust	1	-	-
	Industrial accident	Collapse	1	10	-
	Miscellaneous accident	Explosion	1	46	-
		Other	2	5	400
		Collapse	1	15	79
		Other	1	-	150
	Transport accident	Air	2	21	-
		Rail	2	26	75
Road		7	33	16	
Water		5	97	1	
Zimbabwe	Drought	Drought	5	-	2 771 000
	Epidemic	Unspecified	2	36	5 051
		Bacterial infectious diseases	14	347	7 863
		Parasitic infectious diseases	1	1 311	500 000
		Viral infectious diseases	1	50	1 200
		Unspecified	1	13	30 000
	Flood	General flood	6	23	50 463
		Tropical cyclone	2	4	-
	Industrial accident	Collapse	1	20	1
	Miscellaneous accident	Other	3	14	100
	Transport accident	Rail	3	32	100
		Road	21	30	62

Table A.2: Sets defined

Set	No	Definition
SADC country ( $K$ )	1	Angola
	2	Botswana
	3	The Democratic Republic of Congo
	4	Lesotho
	5	Madagascar
	6	Malawi
	7	Mauritius
	8	Mozambique
	9	Namibia
	10	Seychelles
	11	South Africa
	12	Swaziland
	13	Tanzania
	14	Zambia
	15	Zimbabwe
Aid supply ( $R$ )	1	Mosquito nets
	2	Waterproof ponchos
	3	Waterproof ground mats
	4	Children's activity pack
	5	Durable plastic box
	6	Collapsible water containers
	7	Water purifying equipment
	8	Ten-person tent
	9	Thermal fleece blankets
	10	Cooking equipment
	11	Gel stove
	12	Toolkit
	13	First aid kit
	14	Food supplies
	15	Water
	16	Portable toilet
	17	Waste bin
Disaster type ( $I$ )	1	Drought
	2	Epidemic
	3	Flood
	4	Mass movement wet
	5	Industrial accident
	6	Miscellaneous accident
	7	Transport accident
	8	Insect infestation
	9	Storm
	10	Earthquake
	11	Wildfire
	12	Extreme temperatures

Table A.3: Frequency of country  $k$  having disaster effect  $j$

$J$	$I$										Total
	1	2	3	4	5	6	7	8	9	10	
1	6	7	5	4	2	0	4	8	4	1	41
2	1	0	0	1	0	3	3	1	1	1	11
3	6	1	1	2	2	2	2	3	0	0	19
4	0	1	1	0	3	1	0	2	4	0	12
5	4	0	0	2	0	2	6	8	6	9	37
6	7	2	2	4	2	3	6	4	4	7	41
7	0	0	1	1	4	2	0	1	0	0	9
8	2	3	5	4	5	11	3	6	11	9	59
9	1	2	2	0	1	1	3	3	4	0	17
10	0	0	0	0	1	3	0	0	0	0	4
11	9	9	15	10	8	8	7	5	2	3	76
12	0	1	0	0	5	1	0	0	3	2	12
13	5	12	8	11	7	6	5	4	5	4	67
14	4	2	4	3	1	5	6	0	1	8	34
15	5	5	5	5	3	1	3	3	2	4	36
Total	50	45	49	47	44	49	48	48	47	48	475

Table A.4: Probability of country  $k$  having disaster effect  $j$  ( $h_{jk}$ )

$J$	$I$										Total
	1	2	3	4	5	6	7	8	9	10	
1	0.0126	0.0147	0.0105	0.0084	0.0042	0	0.0084	0.0168	0.0084	0.0021	0.0863
2	0.0021	0	0	0.0021	0	0.0063	0.0063	0.0021	0.0021	0.0021	0.0232
3	0.0126	0.0021	0.0021	0.0042	0.0042	0.0042	0.0042	0.0063	0	0	0.0400
4	0	0.0021	0.0021	0	0.0063	0.0021	0	0.0042	0.0084	0	0.0253
5	0.0084	0	0	0.0042	0	0.0042	0.0126	0.0168	0.0126	0.0189	0.0779
6	0.0147	0.0042	0.0042	0.0084	0.0042	0.0063	0.0126	0.0084	0.0084	0.0147	0.0863
7	0	0	0.0021	0.0021	0.0084	0.0042	0	0.0021	0	0	0.0189
8	0.0042	0.0063	0.0105	0.0084	0.0105	0.0232	0.0063	0.0126	0.0232	0.0189	0.1242
9	0.0021	0.0042	0.0042	0	0.0021	0.0021	0.0063	0.0063	0.0084	0	0.0358
10	0	0	0	0	0.0021	0.0063	0	0	0	0	0.0084
11	0.0189	0.0189	0.0316	0.0211	0.0168	0.0168	0.0147	0.0105	0.0042	0.0063	0.1600
12	0	0.0021	0	0	0.0105	0.0021	0	0	0.0063	0.0042	0.0253
13	0.0105	0.0253	0.0168	0.0232	0.0147	0.0126	0.0105	0.0084	0.0105	0.0084	0.1411
14	0.0084	0.0042	0.0084	0.0063	0.0021	0.0105	0.0126	0	0.0021	0.0168	0.0716
15	0.0105	0.0105	0.0105	0.0105	0.0063	0.0021	0.0063	0.0063	0.0042	0.0084	0.0758
Total	0.1053	0.0947	0.1032	0.0989	0.0926	0.1032	0.1011	0.1011	0.0989	0.1011	1.0000

Table A.5: Country criteria

No	Criteria	Population size	Disaster frequency	No affected	No of deaths	GDP
1	Population size	1	0.1111	0.1429	0.2	0.1250
2	Disaster frequency	9	1	3	7	0.5
3	No affected	0.3333	1	5	0.1111	
4	No of deaths	5	0.1429	0.2	1	0.1111
5	GDP	8	2	9	9	1
Total		30	3.5873	13.3429	22.2	1.8472

Table A.6: Normalised matrix

Criteria	Population size	Disaster frequency	No of people affected	No of deaths	GDP	Average
Population size	0.0333	0.0310	0.0107	0.0090	0.0677	0.0303
Disaster frequency	0.3000	0.2788	0.2248	0.3153	0.2707	0.2779
No affected	0.2333	0.0929	0.0749	0.2252	0.0602	0.1373
No of deaths	0.1667	0.0398	0.0150	0.0450	0.0602	0.0653
GDP	0.2667	0.5575	0.6745	0.4054	0.5414	0.4891
Total						1

Table A.7: Determining country weights

No	Country	Total Country Population	Fraction of Total	Disaster frequency	Fraction of total	No of people affected	Fraction of total
1	Angola	13 068 000	0.048	87	0.099	3 640 167	0.031
2	Botswana	2 029 307	0.007	14	0.016	1 340 496	0.012
3	Congo	70 916 439	0.259	31	0.035	169 444	0.001
4	Lesotho	1 919 552	0.007	16	0.018	1 997 007	0.017
5	Madagascar	21 281 844	0.078	59	0.067	8 662 933	0.075
6	Malawi	15 447 500	0.057	59	0.067	21 699 356	0.188
7	Mauritius	1 294 104	0.005	16	0.018	51 869	0
8	Mozambique	22 061 451	0.081	94	0.106	22 867 395	0.198
9	Namibia	2 128 471	0.008	23	0.026	1 270 165	0.011
10	Seychelles	88 340	0	5	0.006	18328	0
11	South Africa	49 109 107	0.180	213	0.241	18 471 294	0.160
12	Swaziland	1 354 051	0.005	16	0.018	2 549 921	0.022
13	Tanzania	41 892 895	0.153	133	0.151	8 786 227	0.076
14	Zambia	19 056 923	0.070	58	0.066	9 364 523	0.081
15	Zimbabwe	11 651 858	0.043	59	0.067	14 809 291	0.128
	Total	273 299 842	1	883	1	115 698 416	1

No	Country	No of deaths	Fraction of total	GDP in US Dollars (Billion)	Total GDP ÷ GDP per country	Weight of GDP
1	Angola	6 952	0.047	84.90	5.5507	0.003445712
2	Botswana	686	0.005	13.40	35.1681	0.021831412
3	Congo	1 187	0.008	11.70	40.2780	0.025003498
4	Lesotho	137	0.001	1.62	290.8969	0.180580816
5	Madagascar	3 996	0.027	9.46	49.8153	0.030923988
6	Malawi	2 989	0.020	4.27	110.3637	0.068510755
7	Mauritius	171	0.001	9.32	50.5636	0.031388511
8	Mozambique	105 565	0.718	9.85	47.8429	0.029699586
9	Namibia	461	0.003	8.84	53.3092	0.033092865
10	Seychelles	8	0	0.83	565.7299	0.351189583
11	South Africa	5 150	0.035	276	1.7074	0.001059931
12	Swaziland	750	0.005	2.84	165.9342	0.103007367
13	Tanzania	9 499	0.065	20.50	22.9880	0.014270289
14	Zambia	2 190	0.015	14.30	32.9548	0.020457407
15	Zimbabwe	7 235	0.049	3.42	137.7933	0.085538281
Total		146 976	1	471.253	1610.896	1

Table A.8: Number of aid supplies  $r$  required by sub-plan  $s$  ( $u_{rs}$ )

$S$	$R$								
	1	2	3	4	5	6	7	8	9
1	0	0	0	0	4	40	4	0	0
2	0	0	0	0	10	100	10	0	0
3	0	0	0	0	30	300	30	0	0
4	0	0	0	0	90	900	90	0	0
5	0	0	0	0	300	3 000	300	0	0
6	0	0	0	0	1 000	10 000	1 000	0	0
7	0	0	0	0	2 300	23 000	2 300	0	0
8	0	0	0	0	10 200	102 000	10 200	0	0
9	0	0	0	0	50 500	505 000	50 500	0	0
10	0	0	0	0	1 500 000	15 000 000	1 500 000	0	0
11	40	40	40	4	4	40	4	4	4
12	100	100	100	10	10	100	10	10	100
13	300	300	300	30	30	300	30	30	300
14	900	900	900	90	90	900	90	90	900
15	3 000	3 000	3 000	300	300	3 000	300	300	3 000
16	10 000	10 000	10 000	1 000	1 000	10 000	1 000	1 000	10 000
17	23 000	23 000	23 000	2 300	2 300	23 000	2 300	2 300	23 000
18	102 000	102 000	102 000	10 200	10 200	102 000	10 200	10 200	102 000
19	505 000	505 000	505 000	50 500	50 500	505 000	50 500	50 500	505 000
20	15 000 000	15 000 000	15 000 000	1 500 000	1 500 000	15 000 000	1 500 000	1 500 000	15 000 000
21	0	40	40	4	4	40	4	4	40
22	0	100	100	10	10	100	10	10	100
23	0	300	300	30	30	300	30	30	300
24	0	900	900	90	90	900	90	90	900
25	0	3 000	3 000	300	300	3 000	300	300	3 000
26	0	10 000	10 000	1 000	1 000	10 000	1 000	1 000	10 000
27	0	23 000	23 000	2 300	2 300	23 000	2 300	2 300	23 000
28	0	102 000	102 000	10 200	10 200	102 000	10 200	10 200	102 000
29	0	505 000	505 000	50 500	50 500	505 000	50 500	50 500	505 000
30	0	15 000 000	15 000 000	1 500 000	1 500 000	15 000 000			
31	0	40	40	4	4	40	4	0	40
32	0	100	100	10	10	100	10	0	100
33	0	300	300	30	30	300	30	0	300
34	0	900	900	90	90	900	90	0	900
35	0	3 000	3 000	300	300	3 000	300	0	3 000
36	0	10 000	10 000	1 000	1 000	10 000	1 000	0	10 000
37	0	23 000	23 000	2 300	2 300	23 000	2 300	0	23 000
38	0	102 000	102 000	10 200	10 200	102 000	10 200	0	102 000
39	0	505 000	505 000	50 500	50 500	505 000	50 500	0	505 000
40	0	15 000 000	15 000 000	1 500 000	1 500 000	15 000 000	1 500 000	0	15 000 000
41	0	40	40	4	4	40	4	4	40
42	0	100	100	10	10	100	10	10	100
43	0	300	300	30	30	300	30	30	300
44	0	900	900	90	90	900	90	90	900
45	0	3 000	3 000	300	300	3 000	300	300	3 000
46	0	10 000	10 000	1 000	1 000	10 000	1 000	1 000	10 000
47	0	23 000	23 000	2 300	2 300	23 000	2 300	2 300	23 000
48	0	102 000	102 000	10 200	10 200	102 000	10 200	10 200	102 000
49	0	505 000	505 000	50 500	50 500	505 000	50 500	50 500	505 000
50	0	15 000 000	15 000 000	1 500 000	1 500 000	15 000 000	1 500 000	1 500 000	15 000 000

<i>R</i>								
<i>S</i>	10	11	12	13	14	15	16	17
1	4	4	4	4	1 200	11	0	0
2	10	10	10	10	3 000	27	0	0
3	30	30	30	30	9 000	82	0	0
4	90	90	90	90	9000	82	0	0
5	300	300	300	300	90 000	818	0	0
6	1 000	1 000	1 000	1 000	300 000	2 727	0	0
7	2 300	2 300	2 300	2 300	690 000	6 273	0	0
8	102 000	102 000	102 000	102 000	3 060 000	27 818	0	0
9	50 500	50 500	50 500	50 500	15 150 000	137 727	0	0
10	1 500 000	1 500 000	1 500 000	1 500 000	450 000 000	4 090 909	0	0
11	4	4	4	4	1 200	11	2	1
12	10	10	10	10	3 000	27	5	1
13	30	30	30	30	9 000	82	15	3
14	90	90	90	90	27 000	245	45	8
15	300	300	300	300	90 000	818	150	25
16	1 000	1 000	1 000	1 000	300 000	2 727	500	83
17	2 300	2 300	2 300	2 300	690 000	6 273	1 150	192
18	10 200	10 200	10 200	10 200	3 060 000	27818	5 100	850
19	50 500	50 500	50 500	50 500	15 150 000	137 727	25 250	4 208
20	1 500 000	1 500 000	1 500 000	1 500 000	450 000 000	4 090 909	750 000	125 000
21	4	4	4	4	1 200	11	2	1
22	10	10	10	10	3 000	27	5	1
23	30	30	30	30	9 000	82	15	3
24	90	90	90	90	27 000	245	45	8
25	300	300	300	300	90 000	818	150	25
26	1 000	1 000	1 000	1 000	300 000	2 727	500	83
27	2 300	2 300	2 300	2 300	690 000	6 273	1 150	192
28	10 200	10 200	10 200	10 200	3 060 000	27818	5 100	850
29	50 500	50 500	50 500	50 500	15 150 000	137 727	25 250	4 208
30	1 500 000	1 500 000	1 500 000	1 500 000	450 000 000	4 090 909	750 000	125 000
31	0	0	4	4	1 200	11	2	1
32	0	0	10	10	3 000	27	5	1
33	0	0	30	30	9 000	82	15	3
34	0	0	90	90	27 000	245	45	8
35	0	0	300	300	90 000	818	150	25
36	0	0	1 000	1 000	300 000	2 727	500	83
37	0	0	2 300	2 300	690 000	6 273	1 150	192
38	0	0	10 200	10 200	3 060 000	27818	5 100	850
39	0	0	50 500	50 500	15 150 000	137 727	25 250	4 208
40	0	0	1 500 000	1 500 000	450 000 000	4 090 909	750 000	125 000
41	4	4	4	4	1 200	11	0	0
42	10	10	10	10	3 000	27	0	0
43	30	30	30	30	9 000	82	0	0
44	90	90	90	90	27 000	245	0	0
45	300	300	300	300	90 000	818	0	0
46	1 000	1 000	1 000	1 000	300 000	2 727	0	0
47	2 300	2 300	2 300	2 300	690 000	6 273	0	0
48	10 200	10 200	10 200	10 200	3 060 000	27818	0	0
49	50 500	50 500	50 500	50 500	15 150 000	137 727	0	0
50	1 500 000	1 500 000	1 500 000	1 500 000	450 000 000	4 090 909	0	0

Table A.9: Sub-plan  $s$  providing recovery capability for disaster effect  $j$  ( $w_{sj}$ )

		$S$																								
$J$		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	0	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1
3	0	0	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	0	0	1	1	1
4	0	0	0	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	0	0	0	1	1
5	0	0	0	1	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	0	0	0	0	1
6	0	0	0	0	1	1	1	1	1	1	1	0	0	0	0	1	1	1	1	1	1	0	0	0	0	0
7	0	0	0	0	0	1	1	1	1	1	1	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0
8	0	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0
9	0	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0
10	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0

		$S$																												
$J$		26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50				
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			
2	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1	1	1			
3	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1	1			
4	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	0	0	0	1	1	1	1	1	1	1	1			
5	1	1	1	1	1	1	0	0	0	0	1	1	1	1	1	1	0	0	0	0	1	1	1	1	1	1	1			
6	1	1	1	1	1	1	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0	1	1	1	1	1	1			
7	0	1	1	1	1	1	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	1			
8	0	0	1	1	1	1	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	1	1	1	1			
9	0	0	0	1	1	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	1			
10	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1			

## Appendix B

# Stochastic Inventory Model Data

Table B.1: Model results

Aid Supply $I$	Scenario $K$										
	1	2	3	4	5	6	7	8	9	10	11
1	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	40	40	40	4	4
3	40	4	4	40	4	4	4	4	1 200	11	2
4	1	100	100	100	10	10	100	10	10	100	10
5	10	10	10	3 000	27	5	1	300	300	300	30
6	30	300	30	30	300	30	30	30	30	9 000	82
7	15	3	900	900	900	90	90	900	90	90	900
8	90	90	90	90	0	245	45	8	3 000	3 000	3 000
9	300	300	3 000	300	300	3 000	300	300	300	300	90 000
10	818	150	25	10 000	10 000	10 000	1 000	1 000	10 000	1 000	1 000
11	10 000	1 000	1 000	1 000	1 000	0	2 727	500	83	23 000	23 000
12	23 000	2 300	2 300	23 000	2 300	2 300	23 000	2 300	2 300	2 300	2 300
13	690 000	6 273	1 150	192	102 000	102 000	102 000	10 200	10 200	102 000	10 200
14	10 200	102 000	10 200	10 200	10 200	10 200	3 060 000	27 818	5 100	850	50 5000
15	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	4 208	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0

Table B.2: Constant holding cost  $h_i$  and varied shortage cost  $s_i$

No	Item	$h_i$	Shortage Cost (ZAR)									
			1	2	3	4	5	6	7	8	9	10
1	Mosquito nets	451358.48	78100.23	156200.46	234300.69	312400.92	390501.15	468601.38	546701.61	624801.84	702902.08	781002.31
2	Waterproof ponchos	446895.61	82563.10	165126.20	247689.30	330252.40	412815.50	495378.61	577941.71	660504.81	743067.91	825631.01
3	Waterproof ground mats	446895.61	82563.10	165126.20	247689.30	330252.40	412815.50	495378.61	577941.71	660504.81	743067.91	825631.01
4	Children's activity pack	446895.61	82563.10	165126.20	247689.30	330252.40	412815.50	495378.61	577941.71	660504.81	743067.91	825631.01
5	Durable plastic box	439795.58	89663.12	179326.24	268989.37	358652.49	448315.61	537978.73	627641.85	717304.97	806968.10	896631.22
6	Collapsible water containers	439795.58	89663.12	179326.24	268989.37	358652.49	448315.61	537978.73	627641.85	717304.97	806968.10	896631.22
7	Water purifying equipment	439795.58	89663.12	179326.24	268989.37	358652.49	448315.61	537978.73	627641.85	717304.97	806968.10	896631.22
8	Ten-person tent	449532.76	79925.95	159851.90	239777.85	319703.80	399629.75	479555.70	559481.65	639407.60	719333.55	799259.50
9	Thermal fleece blankets	446895.61	82563.10	165126.20	247689.30	330252.40	412815.50	495378.61	577941.71	660504.81	743067.91	825631.01
10	Cooking equipment	442432.73	87025.97	174051.94	261077.91	348103.88	435129.86	522155.83	609181.80	696207.77	783233.74	870259.71
11	Gel stove	442432.73	87025.97	174051.94	261077.91	348103.88	435129.86	522155.83	609181.80	696207.77	783233.74	870259.71
12	Toolkit	439795.58	89663.12	179326.24	268989.37	358652.49	448315.61	537978.73	627641.85	717304.97	806968.10	896631.22
13	First aid kit	439795.58	89663.12	179326.24	268989.37	358652.49	448315.61	537978.73	627641.85	717304.97	806968.10	896631.22
14	Food supplies	439795.58	89663.12	179326.24	268989.37	358652.49	448315.61	537978.73	627641.85	717304.97	806968.10	896631.22
15	Water	439795.58	89663.12	179326.24	268989.37	358652.49	448315.61	537978.73	627641.85	717304.97	806968.10	896631.22
16	Portable toilet	449735.61	79723.09	159446.18	239169.28	318892.37	398615.46	478338.55	558061.65	637784.74	717507.83	797230.92
17	Waste bin	447098.46	82360.24	164720.49	247080.73	329440.97	411801.22	494161.46	576521.70	658881.95	741242.19	823602.43

Table B.3: Constant shortage cost  $s_i$  and varied holding cost  $h_i$

No	Item	$s_i$	Holding Cost (ZAR)									
			1	2	3	4	5	6	7	8	9	10
1	Mosquito nets	78100.23	451358.48	902716.95	1354075.43	1805433.90	2256792.38	2708150.85	3159509.33	3610867.80	4062226.28	4513584.75
2	Waterproof ponchos	82563.10	446895.61	893791.21	1340686.82	1787582.42	2234478.03	2681373.63	3128269.24	3575164.84	4022060.45	4468956.05
3	Waterproof ground mats	82563.10	446895.61	893791.21	1340686.82	1787582.42	2234478.03	2681373.63	3128269.24	3575164.84	4022060.45	4468956.05
4	Children's activity pack	82563.10	446895.61	893791.21	1340686.82	1787582.42	2234478.03	2681373.63	3128269.24	3575164.84	4022060.45	4468956.05
5	Durable plastic box	89663.12	439795.58	879591.17	1319386.75	1759182.34	2198977.92	2638773.50	3078569.09	3518364.67	3958160.26	4397955.84
6	Collapsible water containers	89663.12	439795.58	879591.17	1319386.75	1759182.34	2198977.92	2638773.50	3078569.09	3518364.67	3958160.26	4397955.84
7	Water purifying equipment	89663.12	439795.58	879591.17	1319386.75	1759182.34	2198977.92	2638773.50	3078569.09	3518364.67	3958160.26	4397955.84
8	Ten-person tent	79925.95	449532.76	899065.51	1348598.27	1798131.02	2247663.78	2697196.53	3146729.29	3596262.05	4045794.80	4495327.56
9	Thermal fleece blankets	82563.10	446895.61	893791.21	1340686.82	1787582.42	2234478.03	2681373.63	3128269.24	3575164.84	4022060.45	4468956.05
10	Cooking equipment	87025.97	442432.73	884865.47	1327298.20	1769730.94	2212163.67	2654596.41	3097029.14	3539461.88	3981894.61	4424327.35
11	Gel stove	87025.97	442432.73	884865.47	1327298.20	1769730.94	2212163.67	2654596.41	3097029.14	3539461.88	3981894.61	4424327.35
12	Toolkit	89663.12	439795.58	879591.17	1319386.75	1759182.34	2198977.92	2638773.50	3078569.09	3518364.67	3958160.26	4397955.84
13	First aid kit	89663.12	439795.58	879591.17	1319386.75	1759182.34	2198977.92	2638773.50	3078569.09	3518364.67	3958160.26	4397955.84
14	Food supplies	89663.12	439795.58	879591.17	1319386.75	1759182.34	2198977.92	2638773.50	3078569.09	3518364.67	3958160.26	4397955.84
15	Water	89663.12	439795.58	879591.17	1319386.75	1759182.34	2198977.92	2638773.50	3078569.09	3518364.67	3958160.26	4397955.84
16	Portable toilet	79723.09	449735.61	899471.23	1349206.84	1798942.45	2248678.07	2698413.68	3148149.29	3597884.91	4047620.52	4497356.13
17	Waste bin	82360.24	447098.46	894196.93	1341295.39	1788393.85	2235492.31	2682590.78	3129689.24	3576787.70	4023886.16	4470984.63

## Appendix C

# Disaster Recovery Plan (DRP) *LINGO* Model

Model:

!The model must provide a generic approach to determine the types and amount of aid supplies required for a defined any disaster within the SADC countries;

Title: A generic inventory model for disaster relief;

sets:

countries/1..15/:a;  
subplans/1..50/:y;  
effects/1..10/:g,p;  
supplies/1..17/:c,z;  
disasters/1..12/;  
recovery(subplans, effects):w;  
quantity(supplies, subplans):u;  
country(effects, countries):h;  
disaster(disasters, effects):f;  
endsets

data:

a=0.0379	0.0172	0.0306	0.0960	0.0481	0.0809	0.0207	0.1206
0.0254	0.1734	0.0972	0.0589	0.0681	0.0425	0.0825;	
f=0.0000	0.0023	0.0057	0.0000	0.0000	0.0011	0.0000	0.0000
0.0045	0.0011	0.0408	0.0011				
0.0000	0.0023	0.0045	0.0000	0.0000	0.0011	0.0000	0.0000
0.0057	0.0000	0.0374	0.0000				
0.0000	0.0000	0.0136	0.0000	0.0034	0.0045	0.0000	0.0011
0.0045	0.0034	0.0249	0.0000				
0.0000	0.0034	0.0283	0.0000	0.0045	0.0011	0.0000	0.0000
0.0023	0.0079	0.0057	0.0000				
0.0000	0.0034	0.0170	0.0000	0.0125	0.0011	0.0000	0.0011
0.0011	0.0091	0.0000	0.0045				
0.0000	0.0023	0.0147	0.0000	0.0215	0.0000	0.0000	0.0000
0.0011	0.0125	0.0000	0.0023				
0.0011	0.0011	0.0181	0.0000	0.0294	0.0000	0.0000	0.0000
0.0011	0.0034	0.0000	0.0000				
0.0068	0.0011	0.0102	0.0000	0.0283	0.0000	0.0000	0.0000
0.0000	0.0079	0.0011	0.0000				
0.0193	0.0000	0.0023	0.0000	0.0204	0.0000	0.0000	0.0000
0.0000	0.0113	0.0000	0.0000				
0.0351	0.0000	0.0000	0.0000	0.0102	0.0000	0.0000	0.0000
0.0000	0.0091	0.0000	0.0000;				
h=0.0068	0.0079	0.0057	0.0045	0.0023	0.0000	0.0045	0.0091
0.0045	0.0011						
0.0011	0.0000	0.0000	0.0011	0.0000	0.0034	0.0034	0.0011
0.0011	0.0011						
0.0068	0.0011	0.0011	0.0023	0.0023	0.0023	0.0023	0.0034
0.0000	0.0000						
0.0000	0.0011	0.0011	0.0000	0.0034	0.0011	0.0000	0.0023
0.0045	0.0000						
0.0045	0.0000	0.0000	0.0023	0.0000	0.0023	0.0068	0.0091
0.0068	0.0102						
0.0079	0.0023	0.0023	0.0045	0.0023	0.0034	0.0068	0.0045
0.0045	0.0079						
0.0000	0.0000	0.0011	0.0011	0.0045	0.0023	0.0000	0.0011
0.0000	0.0000						
0.0023	0.0034	0.0057	0.0045	0.0057	0.0125	0.0034	0.0068
0.0125	0.0102						
0.0011	0.0023	0.0023	0.0000	0.0011	0.0011	0.0034	0.0034
0.0045	0.0000						
0.0000	0.0000	0.0000	0.0000	0.0011	0.0034	0.0000	0.0000
0.0000	0.0000						
0.0102	0.0102	0.0170	0.0113	0.0091	0.0091	0.0079	0.0057
0.0023	0.0034						
0.0000	0.0011	0.0000	0.0000	0.0057	0.0011	0.0000	0.0000
0.0034	0.0023						
0.0057	0.0136	0.0091	0.0125	0.0079	0.0068	0.0057	0.0045

0.0045	0.0057	0.0023	0.0045	0.0045	0.0034	0.0011	0.0057	0.0068	0.0000
0.0057	0.0011	0.0091	0.0057	0.0057	0.0034	0.0011	0.0034	0.0034	0.0034
	0.0023	0.0045;							

c=45.76	9.6	45.76	40	286	34.32	194.48	1944.8	57.2	228.8	686.4	171.6
	114.82	24.6	3594	2662	588;						

u=0	0	0	0	4	40	4	0	0	4	4	4	4	1200	11
	0	0												
0	0	0	0	10	100	10	0	0	10	10	10	10	3000	27
	0	0												
0	0	0	0	30	300	30	0	0	30	30	30	30	9000	82
	0	0												
0	0	0	0	90	900	90	0	0	90	90	90	90	27000	245
	0	0												
0	0	0	0	300	3000	300	0	0	300	300	300	300	90000	818
	0	0												
0	0	0	0	1000	10000	1000	0	0	1000	1000	1000	1000	300000	
	2727	0	0											
0	0	0	0	2300	23000	2300	0	0	2300	2300	2300	2300	690000	
	6273	0	0											
0	0	0	0	10200	102000	10200	0	0	10200	10200	10200	10200	10200	
	3060000	27818	0	0										
0	0	0	0	50500	505000	50500	0	0	50500	50500	50500	50500	50500	
	15150000	137727	0	0										
0	0	0	0	1500000	15000000	1500000	0	0	1500000	1500000	1500000	1500000	1500000	
	1500000	1500000	1500000	450000000	4090909	0	0	1500000						
40	40	40	4	4	40	4	4	40	4	4	4	4	1200	11
	2	1												
100	100	100	10	10	100	10	10	100	10	10	10	10	3000	27
	5	1												
300	300	300	30	30	300	30	30	300	30	30	30	30	9000	82
	15	3												
900	900	900	90	90	900	90	90	900	90	90	90	90	27000	245
	45	8												
3000	3000	3000	300	300	3000	300	300	3000	300	300	300	300	90000	818
	150	25												
10000	10000	10000	1000	1000	10000	1000	1000	10000	1000	1000	1000	1000	300000	
	2727	500	83											
23000	23000	23000	2300	2300	23000	2300	2300	23000	2300	2300	2300	2300	690000	
	6273	1150	192											
102000	102000	102000	102000	102000	10200	10200	102000	10200	10200	102000	102000	102000	10200	
	10200	10200	10200	3060000	27818	5100	850							
505000	505000	505000	505000	505000	50500	50500	505000	50500	50500	505000	505000	505000	50500	
	50500	50500	50500	15150000	137727	25250	4208							
15000000	15000000	15000000	15000000	15000000	1500000	1500000	1500000	15000000	15000000	15000000	15000000	15000000	45000000	
	1500000	15000000	1500000	1500000	1500000	1500000	1500000	1500000	1500000	1500000	1500000	1500000	45000000	
0	40	40	4	4	40	4	4	40	4	4	4	4	1200	11
	2	1												
0	100	100	10	10	100	10	10	100	10	10	10	10	3000	27
	5	1												
0	300	300	30	30	300	30	30	300	30	30	30	30	9000	82
	15	3												
0	900	900	90	90	900	90	90	900	90	90	90	90	27000	245
	45	8												
0	3000	3000	300	300	3000	300	300	3000	300	300	300	300	90000	818
	150	25												
0	10000	10000	1000	1000	10000	1000	1000	10000	1000	1000	1000	1000	300000	
	2727	500	83											
0	23000	23000	2300	2300	23000	2300	2300	23000	2300	2300	2300	2300	690000	
	6273	1150	192											
0	102000	102000	102000	10200	10200	102000	10200	10200	10200	102000	102000	102000	10200	
	10200	10200	3060000	27818	5100	850								
0	505000	505000	505000	50500	50500	505000	50500	50500	50500	505000	505000	505000	50500	
	50500	50500	15150000	137727	25250	4208								

0	15000000	15000000	1500000	1500000	15000000	1500000	1500000	15000000	1500000	1500000	450000000	1500000	1500000	
	15000000	1500000	1500000	1500000	1500000	1500000	1500000	1500000	1500000	1500000	450000000	4090909		
	750000	125000												
0	40	40	4	4	40	4	0	40	0	0	4	4	1200	11
	2	1												
0	100	100	10	10	100	10	0	100	0	0	10	10	3000	27
	5	1												
0	300	300	30	30	300	30	0	300	0	0	30	30	9000	82
	15	3												
0	900	900	90	90	900	90	0	900	0	0	90	90	27000	245
	45	8												
0	3000	3000	300	300	3000	300	0	3000	0	0	300	300	90000	818
	150	25												
0	10000	10000	1000	1000	10000	1000	0	10000	0	0	1000	1000	300000	
	2727	500	83											
0	23000	23000	2300	2300	23000	2300	0	23000	0	0	2300	2300	690000	
	6273	1150	192											
0	102000		102000		10200	10200	102000		10200	0	102000		0	0
	10200	10200	3060000		27818	5100	850							
0	505000		505000		50500	50500	505000		50500	0	505000		0	0
	50500	50500	15150000		137727		25250	4208						
0	15000000		15000000		1500000		1500000		15000000		1500000		0	
	15000000	0	0		1500000		1500000		450000000		4090909		750000	
	125000													
0	40	40	4	4	40	4	4	40	4	4	4	4	1200	11
	0	0												
0	100	100	10	10	100	10	10	100	10	10	10	10	3000	27
	0	0												
0	300	300	30	30	300	30	30	300	30	30	30	30	9000	82
	0	0												
0	900	900	90	90	900	90	90	900	90	90	90	90	27000	245
	0	0												
0	3000	3000	300	300	3000	300	300	3000	300	300	300	300	90000	818
	0	0												
0	10000	10000	1000	1000	10000	1000	1000	10000	1000	1000	1000	1000	300000	
	2727	0	0											
0	23000	23000	2300	2300	23000	2300	2300	23000	2300	2300	2300	2300	690000	
	6273	0	0											
0	102000		102000		10200	10200	102000		10200	10200	102000		10200	10200
	10200	10200	3060000		27818	0	0							
0	505000		505000		50500	50500	505000		50500	50500	505000		50500	50500
	50500	50500	15150000		137727		0	0						
0	15000000		15000000		1500000		1500000		15000000		1500000		1500000	
	15000000	0	0		1500000		1500000		1500000		450000000		4090909	
	0	0;												
w=1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0	1	1	1	1	1	1	1	1	0	1	1	1	1	1
	1	1	1	1	1	0	1	1	1	1	1	1	1	1
	1	0	1	1	1	1	1	1	1	1	1	0	1	1
	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0	0	1	1	1	1	1	1	1	0	0	1	1	1	1
	1	1	1	1	1	0	0	1	1	1	1	1	1	1
	1	0	0	1	1	1	1	1	1	1	1	0	0	1
	1	1	1	1	1	1	1	1	1	1	1	1	1	1
0	0	0	1	1	1	1	1	1	0	0	0	0	1	1
	1	1	1	1	1	0	0	0	1	1	1	1	1	1
	1	0	0	0	0	1	1	1	1	1	1	0	0	0
	0	1	1	1	1	1	1	1	1	1	1	1	1	1
0	0	0	0	0	1	1	1	1	0	0	0	0	0	0
	1	1	1	1	1	0	0	0	0	1	1	1	1	1
	1	0	0	0	0	1	1	1	1	1	1	0	0	0
	0	1	1	1	1	1	1	1	1	1	1	1	1	1
0	0	0	0	0	1	1	1	1	1	0	0	0	0	0
	1	1	1	1	1	0	0	0	0	0	1	1	1	1

	1	0	0	0	0	0	1	1	1	1	1	0	0	0
0	0	0	1	1	1	1	1	1	1	0	0	0	0	0
	0	1	1	1	1	0	0	0	0	0	0	1	1	1
	1	0	0	0	0	0	0	1	1	1	1	0	0	0
0	0	0	0	1	1	1	1	1	1	0	0	0	0	0
	0	0	1	1	1	0	0	0	0	0	0	0	1	1
	1	0	0	0	0	0	0	0	1	1	1	0	0	0
	0	0	0	0	1	1	1	1	1	0	0	0	0	0
0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
	0	0	0	1	1	0	0	0	0	0	0	0	0	1
	1	0	0	0	0	0	0	0	0	1	1	0	0	0
0	0	0	0	0	0	1	1	1	1	0	0	0	0	0
	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	0	0	0	0	1	0	0	0	0	0	0	0	0	0
	1	0	0	0	0	0	0	0	0	0	1	0	0	0
	0	0	0	0	0	0	0	0	0	0	0	1	0	0

B=4000000000;

enddata

max=@sum(recovery(s,j):w(s,j)\*g(j)\*p(j)\*y(s));

@sum(supplies(r):c(r)\*z(r))<=B;

@for(effects(j):@sum(subplans(s):y(s))<=1);

@for(supplies(r):@sum(subplans(s):u(r,s)\*y(s)-z(r))<=0);

@for(effects(j):@sum(disasters(i):f(i,j))=p(j));

@for(effects(j):@sum(countries(k):a(k)\*h(j,k))=g(j));

@for(supplies(r):@gin(z(r)));

@for(subplans(s):@bin(y(s)));

end

## Appendix D

# Stochastic Inventory *LINGO* Model

Model:!stochastic;

Title:Inventory;

sets:

supplies/1..17/:c,h,s;

scenario/1..11/:r;

inventory(supplies,scenario):x,u,v,q;

endsets

data:

c=45.76 9.6 45.76 40 286 34.32 194.48 1944.8 57.2 228.8 686.4 171.6 114.816 24.5968 3594  
2662 588;

x=0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0													
40	40	40	4	4	40	4	4	40	4	4	4	4	1200	11
	2	1												
100	100	100	10	10	100	10	10	100	10	10	10	10	3000	27
	5	1												
300	300	300	30	30	300	30	30	300	30	30	30	30	9000	82
	15	3												
900	900	900	90	90	900	90	90	900	90	90	90	90	27000	245
	45	8												
3000	3000	3000	300	300	3000	300	300	3000	300	300	300	300	90000	818
	150	25												
10000	10000	10000	1000	1000	10000	1000	1000	10000	1000	1000	1000	1000	300000	
	2727	500	83											
23000	23000	23000	2300	2300	23000	2300	2300	23000	2300	2300	2300	2300	690000	
	6273	1150	192											
102000	102000	102000	102000	102000	102000	102000	102000	102000	102000	102000	102000	102000	102000	10200
	10200	10200	10200	3060000	27818	5100	850							
505000	505000	505000	505000	505000	505000	505000	505000	505000	505000	505000	505000	505000	505000	50500
	50500	50500	50500	15150000	137727	25250	4208							
15000000	15000000	15000000	15000000	15000000	15000000	15000000	15000000	15000000	15000000	15000000	15000000	15000000	15000000	1500000
	1500000	15000000	15000000	15000000	15000000	15000000	15000000	15000000	15000000	15000000	15000000	15000000	450000000	
	4090909	750000	125000;											

r=0.909003831

0.009578544

0.00862069

0.009386973

0.009003831

0.008429119

0.009195402

0.009195402

0.009386973

0.009003831

0.009195402;

h=451358.48 446895.61 446895.61 446895.61 439795.58 439795.58 439795.58  
449532.76 446895.61 442432.73 442432.73 439795.58 439795.58 439795.58  
439795.58 449735.61 447098.46;

s=781002.31 825631.01 825631.01 825631.01 896631.22 896631.22 896631.22  
799259.50 825631.01 870259.71 870259.71 896631.22 896631.22 896631.22  
896631.22 797230.92 823602.43;

enddata

min=@sum(inventory(i,k):r(k)\*(c(i)\*q(i,k)+h(i)\*v(i,k)+s(i)\*u(i,k)));

@for(inventory(i,k):(q(i,k)+(v(i,k)\*u(i,k))-v(i,k))=x(i,k));

@for(inventory(i,k):(q(i,k))>=0);

@for(inventory(i,k):(v(i,k))>=0);

```
@for (inventory(i,k) : (u(i,k)) >= 0);
```

```
end
```