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DECISION SUPPORT SYSTEM FOR SUSTAINABLE SITING AND MANAGEMENT OF NATIONAL FOOD BUFFET STOCK SYSTEMS IN GHANA

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DECLARATION

I hereby declare that this submission is my work towards the MPhil and that, to the best of my knowledge, it contains no material previously published by another person, nor material that has been accepted for the awarded of any other degree of the University, except where the acknowledgement has been made in the text.

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(Supervisor) Signature Date

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(Co-supervisor) Signature Date

DEDICATION

I dedicate this dissertation to my parents Mr & Mrs Buah and my siblings Bridget, Erica & Augustine. I also dedicate it to my colleagues and friends Marino, Bright, Nelly, Israel, Charlene, Dominica, Princess, Priscilla, and the Pinnacle Family for their immense support throughout the process.

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ABSTRACT

National Food Buffer Stock Company of Ghana (NAFCO), being the government's emergency food reserve and source of raw materials for agro-processing factories, is established to reduce post-harvest losses, and stabilize food supply and price. These stated aims are very broad, conflicting, and non-profit-oriented, making the buffer stock systems economically unsustainable. This research, therefore, develops a decision support system where decision-makers can stimulate various scenarios to allow them to design a sustainable national food buffer stock system that is fit for its purpose. The decision support system comprises a risk assessment conducted on the operations of NAFCO, pseudo-p-median model, goal programming model and inventory model. The efficacy of the decision support system was illustrated through a series of simulations, where six predicted optimal locations for siting NAFCO warehouses were identified with an average transportation cost of GHS 1.7924E+6. The optimal network design of NAFCO warehouses was to reduce the cost of transportation incurred by the respective stakeholders. The research also investigated the number of grains to be purchased during every quarter, if NAFCO was to stock their warehouses with 100,000 tonnes of grain in the year to reduce the cost of operation. An integrated approach coupled with readily available data was used in stimulating the models developed. Furthermore, the research provides NAFCO with the necessary actions to take to reduce the risk associated with the unit operation of transporting grains from the farm to the warehouses and from the warehouses to the markets and harbour since this operation had a risk profile number of 648. In conclusion, decisions must be taken to revamp the operations of NAFCO with the mindset of reducing cost by adopting decision support systems in sustainably siting and managing their operations.

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ARIMA-	Autoregressive Integrated Moving Averages
BSO-	Buffer Stock Operation
DSS-	Decision Support System
ECOWAS-	Economic Community of West African States
FMEA-	Failure Mode Effect Analysis
FRA-	Food Reserve Agency
GAMS-	General Algebraic Modelling System
GPRTU-	Ghana Private Road Transport Union
LBCs-	Licensed Buying Companies
MMNDP-	Multimodal Network Design Problem
NAFCO-	National Food Buffer Stock Company
PRMC-	Programme de Restructation des Marches Céléaliers
PFDS-	Public Food grain Distribution System
RPN-	Risk Priority Number
RNDP-	Road Network Design Problem
TNDPs-	Transit Network Design Problem
UN-	United Nations

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Grains are the most produced and consumed staple cereal around the world (Manandhar *et al.*, 2018). Annually, over two billion tonnes are produced to meet human food security and feed domestic animals (Jayas, 2012). In recent times, the grain sector has been considered a very vital part of the ecosystem due to its magnitude and importance to human survival (Ristic *et al.*, 2021).

Grains like other food crops are produced seasonally and consumed continuously throughout the year in most parts of the world (Manandhar *et al.*, 2018). According to United Nations (UN) in 2017, a survey indicated that 1.3 billion tonnes of food produced are lost worldwide (Njoki *et al.*, 2017). Most of these food losses are due to postharvest losses resulting from improper storage of the produce. The consequence of these losses in most developing countries is the economic implications on the smallholder farmers, whose incomes are reduced by 15 % (Njoki *et al.*, 2017). In addition, these food losses lead to food insecurity, which affects the actors along the food chain.

A continuous effort has been made to store grain in particular because they play an important role in the global food supply chain (Ristic *et al.*, 2021). The obvious reason for the storage of grains is to ensure the continuous supply of grains for consumption and cultivation throughout the year (Jayas, 2012). As such, in times of food scarcity, a country should be able to guarantee adequate food for its citizens (Gilbert, 2011).

However, in most developing countries there has been an inconsistency in the supply of agricultural produce as a result of a lack of storage facilities, good roads, and inadequate access to the market (Sugri *et al.*, 2021). Due to the above reasons, smallholder farmers usually sell their produce at low prices immediately after harvest for fear of their produce going bad (Hebebrand & Wedding, 2010). Most of these farmers take this action to meet the financial needs of their families and themselves (Armah *et al.*, 2019). Similarly, these farmers tend to buy the produce again at a high price during the lean season (Sugri *et al.*, 2021). This price variation also affects the consumers (Abokyi *et al.*, 2021).

This is evident in Bangladesh, where the year 2007 – 2008 saw a spike in food prices resulting in the poor suffering the most as they spent a much larger source of their income on food (Hebebrand & Wedding, 2010). Similarly, the demand for an increase in food as a result of population growth and urbanization in most developing countries implies that more people will be less involved in food production (Linderhof *et al.*, 2019).

Research has shown that based on experience, political and economic variations, every country has adopted various strategies to combat price volatility and food availability. Some countries have adopted buffer stocking that involves the physical stocking of grains in between planting seasons, whiles others have built monetary reserves to fund grain emergencies (Saini & Kozicka, 2014). Furthermore, some countries rely on the international food market to bridge the gap between demand and supply depending on production fluctuations (Ristic *et al.*, 2021). The goal of these various approaches is to ensure a cost-efficient, effective and reliable tool to smoothen out price fluctuation and variation between planting seasons (Saini & Kozicka, 2014).

Decisively, policymakers and governments in developing countries have also adopted several strategies to aid in addressing food insecurity and market failures through the establishment of buffer stock schemes (Dantwala, 2017; Pu & Zheng, 2018). Food buffer stock systems are approaches adopted by most countries and governments to smoothen out inter-seasonal fluctuations in crop production to stabilize prices on the market, protect consumers, provide food aid, and ensure national food security (Dantwala, 2017; Pu & Zheng, 2018). It is worth noting that, Sub- Saharan Africa is noted for the variation in prices of food commodities during every season when prices of food are low at harvest and high during the lean seasons (Abokyi *et al.*, 2020). By this, there is a variance in agricultural output markets leading to a rise and fall of the prices of the produce beyond the expectations of the consumer and the farmers in both the local and international markets. Market failures further lead to output price volatility (Abokyi *et al.*, 2021).

Governments usually stabilize the prices of commodities on the market through the buffer stock initiative by procuring excess production and storing them. The produce is released usually when there are price hikes hence depressing market prices (Pu & Zheng, 2018). A strong price mechanism ensures efficient movement of trade flow as well as the exchange of food products across deficit surplus regions. Furthermore, this allows for an effective design of a suitable market policy (Gitau & Meyer, 2018). In effect, the buffer stock operations have been adopted as a tool for ensuring food availability at the national level as well as fulfilling an interlinked objective of supporting food producers and food consumers (Saini & Kozicka, 2014).

In African countries, grains constitute a large share of the food requirements of most rural and urban households. Due to this reason and its storability, stabilization of the agricultural output process through buffer stock operation tends to focus on grains (Abokyi et al., 2018). In Mali, Programme de Restructation des Marches Céléaliers (PRMC), is a buffer stock operation, that has been established to integrate an emergency response system and market stabilization system (Galtier, 2018). This system ensures that food is made available to food insecure individuals through its comprehensive cereal market liberalization initiative (Abokyi *et al.*, 2020). Ethiopia's buffer stock reserve rather serves as an emergency reserve used to compensate for weak infrastructures and protects the destitute and powerless in times of shortage (Abokyi *et al.*, 2020). The Public Food Grain Distribution System (PFDS) has coexisted with the private exchange, focusing on security nets while permitting private traders to address rice cost volatility in Bangladesh. Zambia established its Food Reserve Agency (FRA) in 1996 to stabilize grain prices. During the years when there is a deficit in the production and availability of food on the market, FRA imports maize that is sold to consumers and large-scale mill operators at a cost lower than the market cost (Galtier, 2018). In 2008, Ghana suffered a drastic increase in the prices of grains by 50 -70 % due to the world food crisis. As a reaction to this, Ghana instituted the yield cost stabilization approach comprising the buffer stock operations (Abokyi *et al.*, 2018).

Ghana espoused the Buffer Stock Operation (BSO), known as the National Buffer Stock Programme in 2010 with the sole directive to provide market access as well as ensure the reduction in the prices of produce on the market (Abokyi *et al.*, 2020). National Food Buffer Stock Company (NAFCO) operations include purchasing, preservation, selling and distribution of food The grains are purchased from the farmers at the farm gates or designated market centres (Armah *et al.*, 2019).

However, most farmers would rather have their grains sold at designated market centres than farm gates because it is more lucrative. As a result of the low prices and the fall in prices, most farmers decide to cultivate alternate crops instead (Dantwala, 2017; Pu & Zheng, 2018). The implication of this required that policy orientation be initiated to provide standard remuneration for farmers (Abu *et al.*, 2016). Hence, NAFCO endeavours to provide lucrative prices to the farmers whose produce is bought to enhance their income (Abokyi *et al.*, 2020).

In Ghana, NAFCO serves as the main supplier of maize to public schools and hospitals as well as exporting some of the produce to neighbouring countries (Armah *et al.*, 2019). Maize, one of the staple foods among rice and soybeans being stocked by NAFCO, accounts for quite a significant share of poor households' budgets (Anokye & Oduro, 2015). NAFCO operations are envisioned to decrease the power of middlemen as most of the smallholders in Ghana lack the bargaining power to negotiate prices for their produce and resort to selling to unlicensed intermediaries. Additionally, NAFCO seeks through its activities to decrease the effect of the above challenge by providing lucrative prices to the farmers (Abokyi *et al.*, 2021).

NAFCO conducts buffer stock operations through planning, procurement, inventory, and operation programme (Anokye & Oduro, 2013). Figure 1 explains the supply chain theory of how produce gets to the final consumers from the farm. Buffer stock supply chain management integrates the key business process and people such as the government, farmers, NAFCO, and consumers (Sutopo *et al.*, 2010). NAFCO is the leading implementor of the buffer stock policy.

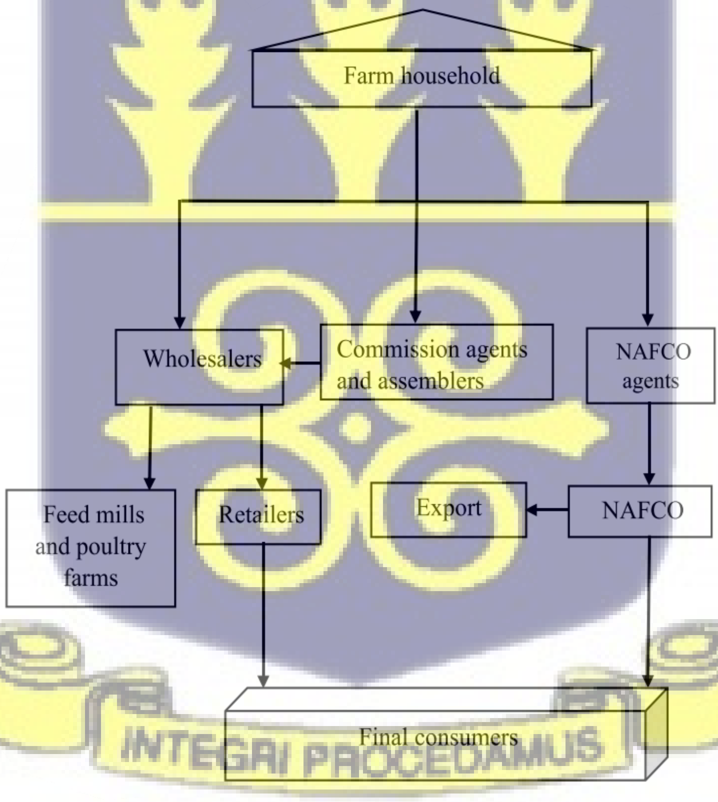

Figure 1.1:General overview of the grain supply chain in Ghana (Armah et al., 2019).

The farmers deliver their grains to Licensed Buying Companies (LBCs) at farm gates for favourable prices. The LBCs are authorized by NAFCO to buy grains for them at the floor price or base price. NAFCO has employed the services of about 73 LBCs (Angelucci & Pierre, 2014). These LBCs provide access to an efficient market devoid of the activities of unlicensed intermediaries. NAFCO pays a commission to the LBCs in addition to a fixed margin price entitled to them based on the drying, bagging, sacks, sewing, and transportation of the produce. The commission paid to the LBCs depends on the distance between the areas where the produce is obtained from. It is worth noting that the activities of the LBCs are contracted since the NAFCO does not have the logistics to procure the grains from remote areas (Abokyi *et al.*,2020). NAFCO then stores these cereals in their storage facilities in different regions in the country with district warehouses in Yendi, Techniman, Sunyani, and Nkawkaw holding operational and emergency reserves of maize, rice, and soya beans. These cereals are later re-sold at a ceiling cost devoid of interference from the government to the consumers (Angelucci & Pierre, 2014). Additionally, there has been evidence of Licensed Buying Companies (LBCs) cheating farmers by offering them lower prices than the agreed prices with NAFCO (Abokyi *et al.*, 2021). Furthermore, it's been noted that traders' associations under the leadership of "Market Queens" tend to store the produce and discharge them to the market during the lean season at higher prices to maximize profit. These released grains are usually restricted to member traders only. Hence, a possible reason why NAFCO does not sell to wholesalers but rather to other actors along the supply chain (Armah *et al.*, 2019). The challenge of NAFCO in these situations is deciding on running the business of NAFCO amidst the very broad, conflicting, and non-profit oriented, that make the buffer stock systems economically unsustainable. Food Buffer Stock systems, also rely heavily on insufficient government subventions (Armah *et al.*, 2019). The resulting financial unsustainability impairs the management of these systems thereby affecting their ability to achieve stated goals.

1.2 Problem with National Food Buffer Stock systems

Buffer stock schemes in most countries have been very unsustainable due to the challenges of the increase in the domestic production cost and low world prices (Pu & Zheng, 2018). Essien *et al.*, (2018) revealed that Ghana's grain storage facilities have not been optimally sited hence causing the farmers and other supply chain actors to spend an excessive amount of money on transporting their grains to these storage facilities. The improper siting of the warehouses and optimal management of the NAFCO warehouses are the major challenges impacting the sustainability of NAFCO in Ghana. The improper siting of the warehouses has led to the high cost of transporting the grains to the warehouses. In recent times, there have been issues of shortage of food in the country as institutions specifically the secondary schools that receive grains from NAFCO do not have enough food to feed their students. Thus, for NAFCO to achieve their goals, as well as optimize its operations, there is a need to have a system that helps in analysing the decision-making process after a careful risk assessment of the operations of NAFCO.

1.3. Objective

The objective of this study was to design a Decision Support System (DSS) for optimal siting and sustainable management of national food buffer stock systems to ensure the attainment of the system goals. With this DSS, decision-makers (bureaucrats, technocrats, opinion leaders, etc.) can simulate various scenarios to allow them to design a sustainable national food buffer stock system that is fit for purpose.

The specific objectives were to:

1. conduct an operational risk assessment on Ghana's National Food Buffer stock system.
2. design a scientific inventory control model and policy for the optimal management of the food buffer stock system.
3. simulate the optimal siting and management of an efficient food buffer stock system using Ministry of Food and Agriculture Food (MoFA) Production Data.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

Storage facilities reduce the deterioration of commodities. In developing countries, there have been issues of sustainability as the farmers do not have the storage capacity. As such, the grain storage facilities' capacity for the most part is measured based on the amassed capacity of the cluster of farmers it is meant to serve. Thus, the grain storage facilities that depend on a cluster of farmers, lead to unused capacity as the farmers do not have consistent output levels rendering them economically unsustainable (Essien *et al.*, 2018).

Most farmers do not have the resources to insure against adverse price shocks. As such, the government in these countries established price stabilization policies to help protect farmers and consumers (Anokye & Oduro, 2015). Most countries store up food produced to ensure price stabilization on the domestic market by making food available during the lean season. Similarly, these food stocks are also used to provide food access to vulnerable groups in the country during the event of a food shortage (Gilbert, 2011).

After the 2005 food crisis and price instability in West Africa, the governments in the ECOWAS sub-region decided to use market controls to limit price hikes through the construction of the Regional Food Reserve (Shear, 2015). The design of food reserves has been based on the choice of produce to be stored, the quantity of the produce, and the rules that trigger the use of the food reserves. Furthermore, the decision of the importance of the food and its nutritional value in the country is considered as well as the vulnerability to shortage or sharp price increases. All these factors and choices are subject to the decision of the stakeholders based on their objectives and propriety (Galtier, 2018). However, the goal of this research is to design a framework for analyzing the operational risk of existing systems of

Ghana's National Food Buffer Stock as well as designing tools for the optimal siting and management of the National Buffer Stock.

2.2 Risk Assessment in Agriculture

Risks are a significant part of agriculture; be it the pricing of the crops, government policies, yields or global markets, as they go a long way to affect the revenue generated (Klapper *et al.*, 2019). Risk management entails selecting the ideal solutions that limit the financial consequences of such uncertainty. Given the likelihood of the various agricultural risks occurring concurrently, several policy assessments have been initiated to address risks comprehensively (Komarek *et al.*, 2020).

In recent research, programs by the Centre of Resilience and the World Bank's forum for Agricultural Risk Management such as Platform on Agricultural management have been used in managing risk associated with agriculture (Komarek *et al.*, 2020). These initiatives focus on different risk sources such as financial, production, institution, market and human risk as they conceptualize, evaluate and manage the risk (Aven, 2016). Market risk arises as a result of price volatility and the unpredictable nature of food markets whereas financial risk focuses on the borrowed monies and the rising interest accumulated on the monies used in running the operation of the business. Similarly, production risk deals with the quality and quantity of goods and services rendered by the business while institutional risk stems from the uncertainty of policies and regulations initiated by the government which includes taxes. In addition, human risk touches on how human health and illness affect the day-to-day running of a business (Kahan, 2013). As such, risk is inseparable from our lives, therefore, the need to manage risk effectively. Decision-making is however paramount in managing the outcome of the risk identified. Good decision taken requires a handful of data and information on the causes, consequences and mitigation actions needed to tackle the risk identified (Kahan, 2013).

2.3 Decision Support System (DSS)

As humans, decision-making is an integral part of our lives. It involves having to choose between two or more alternatives to resolve a problem (Turki & Mounir, 2014). Decision Support Systems (DSS) are tools used to aid stakeholders of a system in making optimal decisions based on the information gathered. These systems help determine the uncertainties and risks associated with the process (Attadjei *et al.*, 2018). However, there is a growing demand for cost-effective solutions to lower the total costs of operation in a supply chain. This objective of finding cost-effective solutions has been hindered by boosting performance, as it is one of the most critical and significant issues facing supply chain players such as manufacturers, distributors, and retailers to stay competitive in today's market. On the other side, the recent global economic slump has forced many organizations, particularly in industrialized countries, to deal with many unfavourable events in their systems and supply chains. Although some businesses can mitigate the effects of operational risks and interruptions, many others are unable to handle unforeseen risks and experience considerable financial losses (Shishebori & Ghaderi, 2015).

This is a result of the poor management of information along the supply chain by suppliers, manufacturers, and customers leading to these uncertainties (Chang, 2014). Therefore, using a practical and effective model may help to solve the problem as well as improve and optimize each component of the supply chain to help businesses manage a variety of risks in their system (Shishebori & Ghaderi, 2015). Similarly, a more practical solution is needed to cut costs and boost productivity through optimization (Shishebori & Ghaderi, 2015; Teniwut & Hasyim, 2020).

Optimization of operations in recent years has seen an increase in profitability across all industries (Buhulaiga & Telukdarie, 2018). It has been pivotal in aiding decision-makers to make quick and adequate decisions in the most difficult times (Saksrisathaporn *et al.*, 2013).

As such, researchers have proposed that optimization models should be comprehensive enough to maximize the profit of all operations along the supply chain (Jarernsuk & Phruksaphanrat, 2019). Notwithstanding, the cost of a comprehensive optimization model can be affected by facility location problems including transportation costs and investment. As such, in agriculture, a handful of mathematical models have been developed to help deal with location problems that hinder optimization. These models applied in these cases are usually multi-faceted, hence, providing an optimal location solution for the siting of storage facilities and their corresponding routing decision (Essien *et al.*, 2018). The goal of these models is to reduce the cost of transportation by optimal siting locations of these storage facilities. This may vary based on the characteristics of the problem and the decision-makers demands in choosing these models (Rezaei *et al.*, 2018).

2.4 Location problem

Facility location plays a decisive role in the optimization and design of a supply chain (Weng *et al.*, 2011) as the location chosen for the construction of a facility can be very costly (Yu *et al.*, 2017). It is worth noting that proper facility location is key to attracting customers and generating profit (Yu *et al.*, 2017).

Facility location Decision Support Systems have been an effective tool used to facilitate the goals of minimizing transportation and maximizing the rate of returns on investment. As such, a combination of facility and network decision support models has aided in locating facilities. These DSS have played an important role in increasing competitiveness across all industries and services as business owners tend to introduce new and better services and products to the market that decrease expenses to endure the business market (Jafarnejad *et al.*, 2014).

Location problems may be divided into four main categories namely: warehouse location, network design, reliability location problem, and competitive facility location problem.

Effective mathematical modelling of facility location describes the problem and reduces its related cost (Jafarnejad *et al.*, 2014) since the high cost of transportation is incurred as a result of the poor siting of the facility (Yu & Zhang, 2018).

2.4.1 Network Design Location Problem

Network location problem aims at reducing the cost of the owner of the supply chain such that, the cost of setting up a chain of warehouses amongst customers to supply products from plants to warehouses is minimal. The network design problem focuses on expanding current facility capacity or developing a new facility; it is separated into three categories: Road Network Design Problem (RNDP), Transit Network Design Problem (TNDPs), and Multimodal Network Design Problem (MMNDP) (Jia *et al.*, 2019). The planning and development of a low-cost high-quality network design are critical for increasing competitiveness in the market (Kepaptsoglou *et al.*, 2009).

Two approaches have been adopted in solving the network location problem; they are heuristic and metaheuristic algorithms. The heuristic algorithm seeks to provide a feasible solution at an acceptable cost, particularly in terms of computing time and space; even though it does not guarantee feasibility or optimality. Metaheuristics algorithm improves heuristic algorithm through the incorporation of random algorithms into local search algorithms (Jia *et al.*, 2019). Despite the significant use of practical guidelines and experience in network design, research has suggested that empirical principles may not be sufficient for constructing an effective network location problem design and that enhancements may result in greater quality and more efficient services (Kepaptsoglou *et al.*, 2009).

Chen *et al.*, (2011) designed a bi-objective reliable network location problem model that expressly optimizes both supply-side and demand-side reliability metrics in the presence of demand uncertainty. This model includes a travel time reliability index on the demand-side measure that is more relevant to network consumers.

Furthermore, in Asia, an integrated network design model for the wheat supply chain takes into account the selection of the supplier, determining the amount of input, distribution of wheat, and production of its product. The research was aimed at significantly reducing the transportation cost and maximizing profit in a competitive market (Gholamian & Taghanzadeh, 2017)

2.4.2 Competitive Facility location problem

The competitive facility location problem involves the siting of new facilities in a competitive market to maximize profit and shares (Yu, 2020). This facility location problem considers the effect of the market on the siting of the facilities while other facility location problems earlier discussed ignore it. Various competitive facility locations have been developed for siting of facilities based on factors such as; the location of existing facilities, the performance of the firm, market size, demography, expansion, strategy, and budget of the firm (Yu, 2020).

When consumers have an option between competing facilities that offer exclusive services, present standards cannot adequately characterize customers' behaviour towards the facilities. To reflect client behaviour in the model, Yu, (2020) proposed the proportional rule as many real-world situations do not take into consideration the behaviour of the clients towards the facilities. This contradicts the assumption made in the majority of research conducted concerning the competitive facility location problem. They, therefore, developed a robust optimization model to address the unpredictability of client demands for the competitive facility location problem with the partially proportional rule using a mixed-integer optimization model.

Zhang *et al.*, (2016) dealt with competition and disruption in their model using the Stackelberg game approach where the two players make a decision. These players are the leader and the follower. The leader finds the facilities first, to begin with, and then the follower chooses their facility. Each player has precisely one move, that is, the leader will open N number of facilities then the follower will respond normally by ideally siting M number of facilities. This model assumes a binary preference with the customer having demand and seeking to choose only one operating facility nearest them at a given time. It is worth noting that when there are disruptions in the service being provided by a particular service provider or facility, the customer seeks to find another service provider hence causing a loss of revenue to the initial service provider. The problem with their research was that the model assumes that the leader knows the precise number of facilities to set up, but that is not the case in real life since the number of facilities to set up is dependent on capital constraints.

In dealing with competitiveness, which requires the leader and follower approach, Rahmani, (2016) proposed a mathematical bi-level mixed integer nonlinear programming model using a global optimization model called GMIN-aBB. The efficiency of this model was tested on randomly generated examples but had restrictions and proposed a combination of models such as Branch and bound and multi-parametric models in future research.

To further explain the concept of competitiveness, Drezner, (2014) stated in the review of research that the basic element running through all competitive location issues models is the presence of an interrelationship between four factors that is; purchasing power, distance, facility attractiveness, and market share with the primary three factors and the final being dependent.

Most research on facility siting assumes a particular approach to assessing market share and then using that strategy to locate the placement of new competitive facilities. Their review also focused on using the proximity and gravity approach for estimating market shares. Competitive location models for siting facilities are very viable in numerous scenarios where competing facility locations are desired. Location modellers have adopted the gravity approach as an effective approach in determining the market shares attracted by facilities.

2.4.3 Reliability location problem

Reliability is the probability of a system performing its intended goal with no hindrance (Chen *et al.,* 2011). A usual presumption made in the literature concerning facility location is that once a customer arrives at a service facility, customer engagement occurs. This implicitly presumes that the facilities are completely reliable. Most real-world service facilities, on the other hand, experience periodic disruptions rendering them momentarily unable to provide service and leading potential customers to seek service elsewhere (Berman *et al.*, 2009). Most research has combined other location problems with reliability to ensure the free flow of goods and services by these facilities. A typical example is the incorporation of reliability in network design problems under uncertainty by Chen *et al.,* (2011) in their research. Also, Essien *et al.,* (2018) combined warehouse location problems, firebox coverage location problems, and reliability in developing a decision support system for ideally placing storage facilities to decrease transportation costs in Ghana. Facility location problems including p-median and p-centre problems have been widely used to analyse and determine the locations of facilities (Hong *et al.*, 2012; Jafarnejad *et al.*, 2014). However, these models consider single objective functions instead of optimizing multiple conflicting objectives.

2.4.4 Warehouse Location Problem

Warehouse location plays an integral role in supply chain management since it is designed to primarily reduce the cost or distance of the customers to the warehouse. As a result, the warehouse facility's best location guarantees that costs are kept to a minimum while profits are maximized. (Singh *et al.*, 2018).

Many DSS models have been designed to consider the location of a single facility, planning based on a single period, demand, and cost of operation. However, most of these models turn out to be insufficient for practical application due to the number of assumptions, the nature of the problem being solved, and the needs of the decision-maker. Szczepański *et al.,* (2019) formulated and developed an algorithm taking into account the fixed cost of the facility operation, daily flow, and location of the warehouse as a response to the problem stated above. The research was carried out using the Flexism environment to implement a decision support system that is sensitive to disturbances such as the "what if" question.

Similarly, Gao, (2021) proposed a strategic and quantitative approach to handling location problems in the medical sector with different priority levels and different nonlinear functions at medical service centres. The goal of this research was to ensure that medical warehouses supply and distribute medical supplies to medical service centres using a fixed-point-based heuristic algorithm. Their results provide a flexible region for locating warehouses in disaster response but had limitations of being applied to a single facility location in disaster response.

Drezner *et al.,* (2003) considered a slightly different problem using a classic model that minimized overall transportation cost taking into account inventory and service cost of a given number of local warehouses and the ideal placement of a central warehouse. The entire inventory and transportation expenses were calculated based on the central warehouse location. The objective of the study was to integrate the location problem and inventory decision as very little research has been conducted on it.

2.5 Inventory problem

Inventory requires careful planning and coordination of the activities along the supply chain involving the movement of the produce and services from the suppliers to distributors to consumers (Beheshti, 2010). The goal of carrying out inventory is to aid reduce the physically impossible and economically impractical wait for each item to arrive where and when it is needed. Inventories are very necessary as they help to reduce uncertainty concerning supply and demand (Sani, 2014). Buffer stock serves as a part of the inventory that reserves produce against short-term shortages to dampen excessive fluctuations in goods and prices from the supplier. Generally, stocks are needed to balance the temporal deviations between demand and supply and between consumption and production (Gudehus & Kotzab, 2012). Depending on the demand and supply, two dynamic strategic decisions that are capacity allocation and facility location must be analyzed (María *et al.*, 2018).

However, supply chain network design models developed have dealt with issues related to location problems with most of the models overlooking tactical and operational decisions such as inventory control models. These models only consider the inventory control models after the issues of location of warehouse and plants have been resolved as well as the distribution centres allocated to consumers to minimize cost and maximize profit have been achieved (Araya-Sassi *et al.*, 2018).

Celik *et al.*, (2016) conducted research using a two-stage stochastic mixed-integer programming model to determine the pre-stocking levels for emergency supplies and location distribution centres for affected victims of disasters. Similarly, Araya-Sassi *et al.*, (2018) formulated an inventory control model for each warehouse with periodic anticipated safety stock, cycle stock and order amounts all reviewed. A well-structured inventory system can improve the performance of an organization and reduce operation costs (Beheshti, 2010). Existing research concerning mathematical modelling in facility location and inventory modelling deals with these problems as a single objective model concentrates on optimizing cost and a multi-objective model focuses on objectives such as total cost, the satisfaction of demand from customers, and environmental impact function (Jarernsuk & Phruksaphanrat, 2019).

This research tends to develop a decision support system that integrates inventory control models and goal programming models for the optimal siting and management of National Food Buffer Stock systems in developing countries. Goal programming models are used to optimize multiple conflicting objectives (Boonsothonsatit *et al.*, 2014) ensuring that the major stakeholder in the Buffer Stock supply chain is satisfied. The model is developed by considering the location of the new warehouse, transportation models, inventory models, and the addition of the export of the produce.

CHAPTER THREE

METHODOLOGY

3.1 Introduction

In Ghana, The National Food Buffer Stock Company (NAFCO) is mandated to operate the food reserves of the country by purchasing grains from local farms using Licensed Buying Companies (LBCs). The use of the LCBs is a result of the inadequate resources of NAFCO to procure the grains from remote areas in the countries. NAFCO stores the grains in different district warehouses across the country upon purchase (Abokyi *et al.*, 2021). The government, however, plays an important role in their operation by providing financial support to NAFCO. The government subventions are insufficient hence impeding the smooth operation and management of the system. This research, therefore, models the interactions between local farmers, Licensed Buying Companies and the National Food Buffer Stock Company as a network optimization problem as well as developing an inventory model to ensure NAFCO can store up food and sell it later to make a profit for the daily running of their organization. This is attained through the application of the following objectives:

1. Conduct an operational risk assessment on Ghana's National Buffer stock system.
2. Design a facility location model to optimally site National Food Buffer Stock facilities depending on pre-determined optimal service level.
3. Design a scientific inventory control model and policy for the optimal management of the food buffer stock system.

These objectives allowed for the application of a well-developed technique in a decision support system to determine the source of a problem and also proffer solutions.

3.2 Conduct an operational risk assessment on Ghana's National Buffer stock system

A risk assessment was performed on the operations of Ghana's National Food Buffer stock system using the Failure Mode Effect Analysis (FMEA). The FMEA as a risk assessment tool was used to scientifically examine all the possible means an operation or service could fail. For each of the failures, an estimate in terms of a numerical value ranging from 1 to 10 was attached to the occurrences of the failure, detection of the failure and severity of the failure. The occurrence of the failure indicated the recurrence of the failure, whiles, the severity of the failure indicated the gravity of the failure. Also, the detection of the failure indicated the ability to identify the failure before the service was rendered to the customers. Tables 3.1, 3.2 and 3.3 indicate the ranks in numerical value and their meaning assigned to the severity, occurrence and detection of the failure in the process and service.

Table 3.1: Severity process and services guidelines

Rank	Meaning
1	Minor: It is very severe likely that a minor failure will have an adverse effect on the service being rendered
2 - 3	Low: The nature of this failure will lead to a slight customer annoyance
4 - 6	Moderate: Moderate severity ranking causes customer dissatisfaction as the failure is noticeable
7 - 8	High: This failure leads to high customer dissatisfaction as a result of inoperative conveniences
9 - 10	Very high: This involves the failure to adhere to safety regulations as well as compliance with government regulations leading to failure of the process

NB: In this case, for the Failure Mode and Effect Analysis on the operation of the buffer stock company of Ghana, 9 – 10 is reserved for government compliance regulation and safety regulations with the operation.

Table 3.2: Occurrence process and service guidelines

Rank	Meaning
1	Remote possibility of occurrence of failure
2 – 5	Low possibility of occurrence of failure
6 - 7	Moderate possibility of occurrence of failure
8 - 9	High possibility of occurrence of failure
10	Very high possibility of occurrence of failure

Table 3.3: Detection process and service guidelines

Rank	Meaning
1	Very high: There is a very high possibility to detect a failure in a service hence issues in service are noticeable
2 - 5	High: There is a high possibility to detect a failure in a service
6 - 8	Moderate: There is a moderate possibility to detect a failure in a service hence issues in the delivery of service can be noticed and addressed
9	Low: The failure in service can easily go undetected
10	Very low: The failure in a service can go undetected hence leading to very high customer dissatisfaction

In order to determine the operations that needed a careful evaluation, the Risk Priority Number (RPN) was computed. The RPN is the product of the numerical value of the occurrence of failure, frequency of failure and severity of the failure.

$$RPN = Occurence\ of\ failure * frequency\ of\ failure * severity\ of\ failure$$

The operational risk assessment used in this research was to analyse the operations of the various stakeholder involved in the buffer stock operation. Thus, the activities of the farmers, license buying companies and NAFCO. Their activities ranged from transportation, postharvest handling, storage and sale of the grains. The established operations of the various stakeholders required the identification of the mode of failure, the cause of failure and the effects of the failure of the operations. The identified risk associated with the operations of the stakeholders with the highest Risk Priority Number (RPN) required a careful assessment of its issues.

Table 3.4 indicated an FMEA table containing the various supply chain operations of the various actors of Ghana's Buffer Stock system analyzed in this research which were obtained from interviewing the various actors along the supply chain as well as from literature.

Table 3.4: Operational risk assessment of the various operations of Ghana's National Buffer Stock System.

No	STEPS IN THE PROCESS	FAILURE MODE	FAILURE CAUSES	FAILURE EFFECTS	OCCURRENCE OF FAILURE (1-10)	DETECTION OF FAILURE (1-10)	SEVERITY OF FAILURE (1-10)	RISK PROFILE NUMBER (RPN)	MEASURES TO REDUCE OCCURRENCE OF FAILURE
1	TRANSPORTATION PROBLEM								
2	PRICE STABILIZATION AND FOOD RESERVES								
3	POSTHARVEST HANDLING								
4	PROBLEM WITH LICENSE BUYING COMPANIES								
5	PROBLEMS WITH FARMERS								

The risk assessment on transportation focused on the transportation of the grains from the farms to the warehouses, markets and harbours. This assessment analysed the possible failures associated with the transportation of the grains. Similarly, the price stabilization and food reserves assessment provided an insight into the failures associated with reducing food prices on the market, export of the grains and sale of the grains. In addition, postharvest handling risk assessment involved analysing the postharvest practices performed at the warehouse when the grains are received. A critical assessment was done on the failure causes and effects of this operation. The risk assessment concerning the operations of the license buying company involved the failures associated with market access, price margins on purchasing and selling of grains, financing storage, communication and contract. Finally, a risk assessment was conducted on the activities of the farmers. The mode of failure associated with the various operations was gathered from Ghana National Food Buffer Stock Company and literature.

To deal with these failures associated with the operations of the various stakeholders, there was a need to focus on location, transportation and inventory models since they formed an integral part of the failures identified with the risk assessment. The goal was to minimize the cost of transporting the grains from the farms to the warehouses, markets and harbour by optimally siting the warehouses for storing the grains. Similarly, to prevent the shortage and decrease operational costs, an inventory model was developed to tackle all the inventory issues of the NAFCO.

3.3 Design a facility location model to optimally site National Food Buffer Stock facilities

In order to determine the optimal location for siting the National Food Buffer stock warehouses, the roles the individual stakeholders play in the supply chain are described. A network model was developed to analyse the interactions of the stakeholders in the network for possible optimization. In this research, the network theory was modelled around the network of farmers, Licensed Buying Companies (LBCs) and the National Food Buffer Stock Company (NAFCO).

3.3.1 Farmers

Farmers produce enough grains to store and sell grains during the lean seasons. However, these farmers do not have the means to store the grains hence usually sell the grains at a reduced price to take care of their families. These grains are usually bought by aggregators usually known as middlemen and LBCs at farm gates and primary markets. Primary markets are small markets in the vicinity where the farmers produce and sell their grains.

3.3.2 Licensed Buying Company (LBCs)

LBCs are intermediary agents contracted by NAFCO to buy grains from farmers at farm gates and primary markets. Their services are contracted because NAFCO does not have the logistics to carry out procurement activities in remote areas.

3.3.3 National Food Buffer Stock Company (NAFCO)

NAFCO buys grains from LBCs to store up for emergency food reserves and price stabilization. NAFCO provides food produced to affected victims of natural disasters, therefore serving its emergency purpose. Contrary to this, NAFCO releases food produced to the markets to stabilize prices, especially during the lean seasons as there are normally price hikes on the market during that time. NAFCO stores these grains in their warehouses across the district in Ghana. Also, NAFCO exports some grains to make money.

Following the operational risk assessment, it was identified that there is an inherent failure with transportation of the grains from the farms to the warehouses, markets and harbours or ports as a result of the poor road networks and transportation routes. This objective, therefore, modelled the interaction between the farmers, LBCs and NAFCO.

3.3.4 Transportation Model

This model was utilized to compute the overall cost incurred by the individual stakeholders of the buffer stock system in accessing the grain storage warehouses. A separate transportation model was created for each stakeholder in the supply chain to compute the transportation cost incurred to use grain warehouses. A pseudo-p-median model was later used to design an optimal network that shows where to site the warehouse for NAFCO such that the total transportation cost of the various stakeholders was minimized (Essien *et al.*, 2018)

<u>Transportation model for farmers.</u>

Notation

W = Warehouses

F = Farming communities

$D_{W,F}$ = Distance between specific farming communities and warehouses, km

$A_{W,F}$

$=$ Amount of grains sent from a particular farming community to the warehouse, kg

$Cost_{W,F}$

$=$ Transportation cost per kilometre per kilogram of grain between the warehouse and farmer

$Site_W =$ Binary variable

$Y_{W,F} =$ Binary variable

Minimize

$$\sum_{W,F} D_{W,F} * Cost_{W,F} * A_{W,F} * Y_{W,F} \quad \text{Eqn. 3.1}$$

Subject to

$$\sum_W Y_{W,F} \geq 1 \text{ for all } F \quad \text{Eqn. 3.2}$$

$$\sum_F Y_{W,F} \geq Site_W \text{ for all } W \quad \text{Eqn. 3.3}$$

$$Site_W \geq Y_{W,F} \text{ for all } W \text{ and } F \quad \text{Eqn. 3.4}$$

$$Site_W = 1 \text{ for all warehouses} \quad \text{Eqn. 3.5}$$

$$Y_{W,F} \in \{0,1\} \quad \text{Eqn. 3.6}$$

$$Site_W \in \{0,1\} \quad \text{Eqn. 3.7}$$

The objective function (Equation 3.1) sought to reduce the overall transportation cost incurred by the farmers as they transport their grains to the warehouse. The cost of transportation was computed as the product of the distance from the farming communities to the warehouses ($D_{W,F}$), amount of grains being transported from that particular farming community to the grain warehouse ($A_{W,F}$) and the vehicular cost of transporting the grains per kilometre. Data on vehicular cost was obtained from research conducted by Essien *et al.*, (2018) where insight was shared on the Ghana Private Road Transport Union (GPRTU) vehicular cost of moving a kilogram of maize per kilometre.

The first constraint (equation 3.2) simply guaranteed that the model assigned at least one farming community to the warehouse to ensure that a farming community is considered wherever a warehouse is being sited. The second constraint (equation 3.3) essentially forced farmers in a particular farming community to be assigned to a district warehouse to store their grain production. The third constraint (equation 3.4) was provided to ensure that grains from a particular farming community are transported to the warehouse in the same vicinity. The fourth constraint (equation 3.5) specified the location of the warehouses in the model. The last two constraints (equations 3.6 & 3.7) are similar as they are both binary variables with a value of 0 and 1. If a warehouse is served by a particular farming community, then the value of $Y_{W,F}$ is 1 and 0 otherwise. The same applies with $Site_W$ a variable that has a value of 1 if particular farming has a warehouse.

Input Data.

Two main data were required for running this model. These two parameters were the transportation distance between the warehouses and the farms ($D_{W,F}$) as well as the number of grains produced by farmers in a specific farming community. The distance between the warehouses and the farms was obtained using a Google Distance Matrix API ®. The number of grains produced by a particular farming community was computed using the supplies tonnage of grains per community.

$S = (GBP * 0.7) - (H.P * PC)$ Eqn. 3.8,

Where,

$\mathrm{S} = \text{surplus grains per annum, kg}$

The $H.P$ = Human population of a district

PC = Per capita consumption per annum, kgs

GBP = Gross biological production

0.7

= 70 % of the gross biological production that is not lost to postharvest as estimated by

Ministry of Food and Agriculture

The human population of a district (H.P) and per capita grain consumption and gross biological production data were obtained from research conducted by Essien *et al.*, (2018) to decide the effectiveness of Ghana's network of grain storage facilities.

The transportation model developed for the various stakeholders is similar to the one developed for the farmers therefore, the objective function and the constraints are the same.

<u>Transportation of grains to the markets</u>

Notation

W = Warehouses

Mk = Markets

$D_{W,Mk}$ = Distance between specific market and district warehouses, km

$A_{W,Mk}$ = Amount of surplus grains available at the district warehouse to be sold at the specific market, kg

$Cost_{W,Mk}$ =

Transportation cost per kilometre per kilogram of grain between the district warehouse and specific market

$\text{Site}_{\text{W,Mk}}$ = Binary variable

$\text{Y}_{\text{W,Mk}}$ = Binary variable

Minimize

$$\sum_{W,Mk} D_{W,Mk} * \ Cost_{W,Mk} * A_{W,Mk} * \ Y_{W,Mk} \qquad \text{Eqn. 3.9}$$

Subject to

$$\sum_{W} Y_{W,Mk} \ \geq 1 \ for \ all \ Mk \qquad \text{Eqn. 3.10}$$

$$\sum_{F} Y_{W,Mk} \ \geq \ Site_{W} \ for \ all \ W \qquad \text{Eqn. 3.11}$$

$$Site_{W} \ \geq \ Y_{W,Mk} \ for \ all \ W \ and \ Mk \qquad \text{Eqn. 3.12}$$

$$Site_{W} \ = 1 \ for \ all \ warehouses \qquad \text{Eqn. 3.13}$$

$$Y_{W,Mk} \ \in \ \{0,1\} \qquad \text{Eqn. 3.14}$$

$$Site_{W} \ \in \ \{0,1\} \qquad \text{Eqn. 3.15}$$

Input Data

The parameter $A_{W,Mk}$, examined the number of surplus grains that the market traders of a specific market purchase from a particular district warehouse.

Transportation of grains by exporters at the harbours

Notation where applicable

W = Warehouses

Hb = Harbours

$\text{D}_{\text{W,Hb}}$ = Distance between specific harbours and district warehouses, km

$\text{A}_{\text{W,Hb}}$ = Amount of grains sent from a district warehouse to a specific harbour, kg

$\text{Cost}_{W,F} =$

Transportation cost per kilometre per kilogram of grain between the warehouse and specific harbour

$\text{Site}_W = \text{Binary variable}$

$Y_{W,Hb} = \text{Binary variable}$

Minimize

$$\sum_{W,Hb} D_{W,Hb} * \ Cost_{W,Hb} * A_{W,Hb} * \ Y_{W,Hb} \quad \text{Eqn. 3.16}$$

Subject to

$$\sum_{W} Y_{W,Hb} \geq 1 \ for \ all \ Hb \quad \text{Eqn. 3.17}$$

$$\sum_{F} Y_{W,Hb} \geq Site_W \ for \ all \ W \quad \text{Eqn. 3.18}$$

$$Site_W \geq Y_{W,Hb} \ for \ all \ W \ and \ Hb \quad \text{Eqn. 3.19}$$

$$Site_W = 1 \ for \ all \ warehouses \quad \text{Eqn. 3.20}$$

$$Y_{W,Hb} \in \{0,1\} \quad \text{Eqn. 3.21}$$

$$Site_W \in \{0,1\} \quad \text{Eqn. 3.22}$$

Input Data

The two major harbours in Ghana that were used were the Takoradi harbour and Tema harbour.

3.3.5 Pseudo P-median Models

In the earlier models, the cost of transportation incurred in conveying the grains from the farming communities to the district warehouse, markets and harbours was computed. This model, however, sought to optimally site the warehouses to reduce transportation costs incurred by the various stakeholders involved in the buffer stock system. This implicitly means that warehouses were sited at locations to reduce the cost of transportation to benefit a particular stakeholder provided they are under consideration.

Pseudo P-median model for the farmers.

Notation

$D_{i,j}$ – the distance between the district farming community and the district warehouse

$Y_{i,j}$ – Binary Variable

A_j – Capacity of the district warehouse, j

$Cost_{i,j}$ – Cost of transporting grains from district i to district j

$Site_i$ – Binary Variable

M – Number of warehouse site

Minimize

$$\sum_{i,j} D_{i,j} * y_{i,j} * A_j * Cost_{i,j} \quad \text{Eqn. 3.23}$$

Subject to

$$\sum_i y_{i,j} \geq 1 \; for \; all \; i \quad \text{Eqn. 3.24}$$

$$\sum_j y_{i,j} \geq 1 \; for \; all \; j \quad \text{Eqn. 3.25}$$

$$Site_i \geq y_{i,j} \; for \; all \; i \; and \; j \quad \text{Eqn. 3.26}$$

$$\sum_i Site_i = M \; for \; all \; i \quad \text{Eqn. 3.27}$$

$$y_{i,j} \in \{0,1\} \quad \text{Eqn. 3.28}$$

$$Site_i \in \{0,1\} \quad \text{Eqn. 3.29}$$

This model was developed to determine where to optimally site the grain warehouses to reduce the transportation cost of the farmer in transporting the grains from the farming communities to the grain storage warehouses. The objective function (Equation 3.23) sought to minimize this transportation cost incurred by the farmers by computing the product of the district between the farming community and the warehouse ($D_{i,j}$), the capacity of the district warehouse (A_j) and the cost of transporting the grains from the farming communities to the grain warehouses.

The first constraint (equation 3.24) simply ensured that the model assigns all farming communities to the warehouse in the design of the new optimal network. The second constraint (equation 3.25) performed a similar task to that of the first constraint ensuring that the grain warehouse is assigned to a farm community. The third constraint (equation 3.26) was provided to ensure that a farming community is assigned to a grain warehouse site only when the optimal location has been identified. The fourth constraint (equation 3.27) specified the optimal number of grain warehouse facilities to be sited in a district by the model. The last two constraints (equations 3.28 & 3.29) are similar as they are both binary variables with a value of 0 and 1. These constraints ($y_{i,j}, Site_i$) indicated the decision to optimally site a facility at a particular place when the value is 1 and 0 if otherwise.

Unlike the pseudo-p-median model for farmers that was used in choosing which farming community was assigned to a grain warehouse to reduce transportation costs, the model for the markets and harbours is different. This was because the model assumed that the storage capacity of the grain warehouses is enough to store the grains from the farming communities. However, the storage capacity of the markets and harbours were limited as a result of the number of traders and exporters in that district. In considering the commercial capacity of the markets and the harbours, a ratio of the source and destination of the capacities of these facilities was incorporated into the objective function.

Pseudo P-median model for the market traders.

Notation

W = District warehouses

Mk = Market

$D_{W,Mk}$ = the distance between specific district warehouses and markets

$Y_{W,Mk}$ = Binary Variable

A_W = Capacity from a particular district warehouse

C_{Mk} = Commerical capacity of a particular market

$Cost_{W,Mk}$ = Cost of conveying grains from the district warehouse to a market

$Site_W$ = Binary Variable

M = Number of warehouse site

Minimize

$$\sum_{W,Mk} D_{W,Mk} * y_{W,Mk} * Cost_{W,Mk} * \frac{1}{A_W * C_{Mk}} \quad \text{Eqn. 3.30}$$

Subject to

$$\sum_W y_{W,Mk} \geq 1 \; for\ all\ Mk \quad \text{Eqn. 3.31}$$

$$\sum_{Mk} y_{W,Mk} \geq Site_W \; for\ all\ W \quad \text{Eqn. 3.32}$$

$$Site_W \geq y_{W,Mk} \; for\ all\ W\ and\ Mk \quad \text{Eqn. 3.33}$$

$$\sum_W Site_W = M \quad \text{Eqn. 3.34}$$

$$y_{W,Mk} \in \{0,1\} \quad \text{Eqn. 3.35}$$

$$Site_W \in \{0,1\} \quad \text{Eqn. 3.36}$$

Pseudo P-median model for the exporters at the harbours.

Notation

W = District warehouses

Hb = Market

$D_{W,Hb}$ = the distance between specific district warehouses and markets

$Y_{W,Hb}$ = Binary Variable

A_W = Capacity from a particular district warehouse

C_{Hb} = Commerical capacity of a particular harbour

$Cost_{W,Hb}$ = Cost of conveying grains from the district warehouse to a harbour

$Site_W$ = Binary Variable

M = Number of warehouse site

Minimize

$$\sum_{W,Mk} D_{W,Hb} * y_{W,Hb} * Cost_{W,Hb} * \frac{1}{A_W * C_{Hb}} \quad \text{Eqn. 3.37}$$

Subject to

$$\sum_W y_{W,Hb} \geq 1 \; for \; all \; Hb \quad \text{Eqn. 3.38}$$

$$\sum_{Hb} y_{W,Hb} \geq Site_W \; for \; all \; W \quad \text{Eqn. 3.39}$$

$$Site_W \geq y_{W,Hb} \; for \; all \; W \; and \; Hb \quad \text{Eqn. 3.40}$$

$$\sum_W Site_W = M \quad \text{Eqn. 3.41}$$

$$y_{W,Hb} \in \{0,1\} \qquad \text{Eqn. 3.42}$$

$$Site_W \in \{0,1\} \qquad \text{Eqn. 3.43}$$

3.3.6 Goal Programming

The initial model was the transportation model that sought to reduce the transportation cost of the individual stakeholders in transporting the grain from the farming communities to the grain warehouse and from the grain warehouse to the markets and harbours. The Pseudo P-median model rather considered the optimal siting location of the grain warehouses to reduce the cost of transportation of the grains to the warehouse for the individual stakeholders. These two models had objective functions to minimize the individual cost for individual stakeholders with the assumption that the stakeholder had the financial capacity to set up individual warehouses for themselves. However, this is not the case as NAFCO had to set up warehouses to store the grains to serve as an emergency reserve and food reserve for price stabilization. NAFCO can do this due to its financial capacity and support from the government.

To optimally set up a grain warehouse, there was a need to incorporate the interests and opinions of the various stakeholders and policymakers together. Their opinions often revolved around the question, where do we site the grain warehouses? This is usually an intuition method as there is no mathematical support to their decision (Essien, *et al.*, 2018). A goal programming model was therefore developed to take into consideration all the opinions of the individual stakeholders mathematically in siting the grain warehouse facilities.

<u>Goal Programming</u>

Notation

W = Warehouse

Mk = Market

Hb = Harbour

Priority 1 = Priority level for the farmers

Priority 2

= Priority level for the market traders (NAFCO transporting grains to the market)

Priority 3 = Priority level for the exporters (NAFCO serving as exporters)

P1 = Positive deviational variable for farmers

P2 = Positive deviational variable for market traders

P3 = Positive deviational variable for exporters

N1 = Negative deviational variable for farmers

N2 = Negative deviational variable for market traders

N3 = Negative deviational variable for exporters

T1 = Minimum transportation cost for farmers

T2 = Minimum transportation cost for market traders

T3 = Minimum transportation cost for exporters

$D_{W,F}$ = the distance between the district farming community and the district warehouse

$D_{W,Mk}$ = the distance between specific district warehouses and markets

$D_{W,Hb}$ = the distance between specific district warehouses and markets

$Y1_{W,F}$ = Binary Variable

$Y2_{W,Mk}$ = Binary Variable

$Y3_{W,Hb}$ = Binary Variable

A_W = Capacity from a particular district warehouse

A_f = Capacity from a particular farming community

C_{Hb} = Commerical capacity of a particular harbour

C_{Mk} = Commerical capacity of a particular market

$X1_W$ = Binary Variable

$X2_W$ = Binary Variable

$X3_W$ = Binary Variable

Cost 11 = Total transportation cost the farmers in the new optimal network

Cost 22 = Total transportation cost the market traders in the new optimal network

Cost 33 = Total transportation cost the exporters in the new optimal network

$Site_W$ = Binary Variable

N = Number of warehouse to site

Minimize

$$\left(Priority\ 1 * \left(\frac{P1}{T1}\right)\right) + \left(Priority\ 2 * \left(\frac{P2}{T2}\right)\right) + \left(Priority\ 3 * \left(\frac{P3}{T3}\right)\right) \quad \text{Eqn. 3.44}$$

Subject to

$$T1 = \left(\sum_{W,F} D_{W,F} * Y1_{W,F} * A_f * Cost_{W,F}\right) + N1 - P1 \quad \text{Eqn. 3.45}$$

$$\sum_W Y1_{W,F} \geq 1 \quad \text{Eqn. 3.46}$$

$$\sum_F Y1_{W,F} \geq X1_W \quad \text{Eqn. 3.47}$$

$$Site_W = X1_W \quad \text{Eqn. 3.48}$$

$$Site_W \geq Y1_{W,F} \quad \text{Eqn. 3.49}$$

$$T2 = \left(\sum_{W,Mk} D_{W,Mk} * Y2_{W,Mk} * Cost_{W,Mk} * \frac{1}{A_{W*}C_{Mk}}\right) + N2 - P2 \quad \text{Eqn. 3.50}$$

$$\sum_{W} Y2_{W,Mk} \geq 1 \quad \text{Eqn. 3.51}$$

$$\sum_{Mk} Y2_{W,Mk} \geq X2_W \quad \text{Eqn. 3.52}$$

$$Site_W = X2_W \quad \text{Eqn. 3.53}$$

$$Site_W \geq Y2_{W,Mk} \quad \text{Eqn. 3.54}$$

$$T3 = \left(\sum_{W,Mk} D_{W,Hb} * Y3_{W,Hb} * Cost_{W,Hb} * \frac{1}{A_{W*}C_{Hb}}\right) + N3 - P3 \quad \text{Eqn. 3.55}$$

$$\sum_{W} Y3_{W,Hb} \geq 1 \quad \text{Eqn. 3.56}$$

$$\sum_{Mk} Y3_{W,Hb} \geq X3_W \quad \text{Eqn. 3.57}$$

$$Site_W = X3_W \quad \text{Eqn. 3.58}$$

$$Site_W \geq Y3_{W,Hb} \quad \text{Eqn. 3.59}$$

$$Cost\ 11 = \sum_{W,F} D_{W,F} * Y1_{W,F} * A_f * Cost_{W,F} \quad \text{Eqn. 3.60}$$

$$Cost\ 22 = \sum_{W,Mk} D_{W,Mk} * Y2_{W,Mk} * C_{Mk} * A_W * Cost_{W,Mk} \quad \text{Eqn. 3.61}$$

$$Cost\ 33 = \sum_{W,Hb} D_{W,Hb} * Y3_{W,Hb} * C_{Hb} * A_W * Cost_{W,Hb} \quad \text{Eqn. 3.62}$$

$$Site_W = M \quad \text{Eqn. 3.63}$$

The objective function (Equation 3.44) sought to minimize the transportation coefficient of all the stakeholders using priority levels. The priority levels were weights attached to the stakeholders to minimize the deviation from the target. Positive and negative deviational variables that are P1, P2, P3 and N1, N2, and N3, respectively were introduced into the objective function. The positive deviational variable controlled and measured the increase in the transportation cost beyond the attainable target of the final optimal network. The negative deviational variable controlled and measured the reduction levels if the final optimal network sought to reduce transportation costs. In prioritizing a stakeholder over the others, the priority variable of that stakeholder was higher. The transportation coefficient (T1, T2, T3) were already computed using the pseudo-p-median model already developed and earlier discussed in this chapter. The constraints as already discussed in this chapter essentially ensured that the grain warehouses were optimally sited such that the final location minimized the cost of transportation for the stakeholders.

3.3.7 Forecasting Model

With the constant change in grain surplus, the optimal network may be rendered redundant. This was a result of migration, urbanization and farmers choosing to grow lucrative crops (Essien, *et al.*,2018). A forecasting model, therefore, predicted the behaviour of the model with a constant change in surplus grain supply from various districts. For this research, a forecasting model developed using Autoregressive Integrated Moving Averages (ARIMA) developed by Essien *et al.*, (2018) was adopted and tested then used as inputs for the pseudo-p-median and transportation model developed.

3.4 Design a scientific inventory control model

"Sorry, we are out of this product", seems to be a common saying of most companies and shops in Ghana. This is a result of not placing an order to replenish inventories soon enough to avoid shortages. In this research, the National Food Buffer Company (NAFCO) cannot afford to run out of grains as it not only provides price stabilization but also serves as a food reserve for the government by supplying food to citizens during natural disasters. To achieve this, a deterministic multi-period inventory control model was developed to minimize the total cost of the Buffer Stock system in Ghana. This model took into consideration the following cost incurred during the operations of NAFCO.

1. Setup Cost

This cost takes into consideration the cost of providing machinery for the warehouse as well as hiring extra labour for loading and offloading ordering cost.

2. The unit cost of grain

This cost takes into consideration the cost of the sack of grains. The cost of the grain could decrease depending on the number of sacks of grains being bought.

3. Holding cost

This cost takes into consideration the actual cost of storing the grains when they arrive at the warehouse, processing and storage of the grains after processing.

4. Shortage cost

This takes into consideration the cost of not having grains in stock hence the government has to purchase grains from the market instead of purchasing from Buffer Stock Company.

It is worth noting that, this model considers no reserve supply of grains. This model essentially shows the user the least cost of production time such that inventory cost is minimized. The details of the model are explained below.

3.4.1 Inventory Model

Notation

x_t = number of grains stored during quarter t

y_t = binary variable

i_t = number of grains at the end of quarter t

d_t = demand for grains during quarter t

K_t = set up costs during quarter t

h_t = holding cost during quarter t

Minimize

$$\sum(K_t * y_t) + (h_t * i_t) \quad \text{Eqn. 3.64}$$

Subject to

$$i_t \geq 0 \quad \text{Eqn. 3.65}$$

$$M = 1000 \quad \text{Eqn. 3.66}$$

$$x_t \geq M * y_t \quad \text{Eqn. 3.67}$$

$$y_t \in \{0, 1\} \quad \text{Eqn. 3.68}$$

The objective function (Equation 3.64) sought to minimize the inventory cost of operating the buffer stock system. The cost was computed as the summation of the product of the holding cost and the inventory and set up cost at a particular quarter, time "t" in months. The first constraint (Equation 3.65) guaranteed that the inventory at any quarter, t, there is either zero or greater. The second constraint (Equation 3.66) ensured that equations attached to these constraints are not part of the optimal solution. The third constraint (Equation 3.67) ensured that there is no shortage of grains in the warehouses. The last constraint (Equation 3.68), which is a binary variable means that they change to either 1 or 0, depending on the situation at hand. For instance, if there is to be a set-up for the production during a quarter, t, then the value is 1 but 0 if otherwise.

In computing for the inventory (i_t) at a particular quarter, t, the number of grains and the demand are needed. That is;

Ending inventory = beginning inventory + production – demand, expressed in Eqn 3.69 below

Hence, $i_t = i_{t-1} + x_t - r_t$ Eqn. 3.69,

The unit cost of the grain was an irrelevant fixed cost for all the periods because all the inventory policies produced the same number of units of grains at the same time. Similarly, the shortage cost was also irrelevant as it was proposed in this research that NAFCO should set up their farms to have a constant supply of grains for its warehouses. All the models described so far in this chapter were programmed and solved using the General Algebraic Modelling System (GAMS®).

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Conduct an operational risk assessment on Ghana's National Food Buffer stock system

Table 4.1 outlined the operational risk associated with the operations of Ghana's Food buffer stock system. Table 4.1 assessed the failures, causes, effects, occurrence, severity and detection of the issues associated with the activities of the individual stakeholders of this supply chain. There were also proposed actions on how to reduce and mitigate the risks associated with these operations.

Table 4. 1: Operational risk assessment of Ghana's National Buffer Stock System

No.	STEPS IN THE PROCESS	FAILURE MODE	FAILURE CAUSES	FAILURE EFFECTS	OCCURRENCE OF FAILURE (1-10)	DETECTION OF FAILURE (1-10)	SEVERITY OF FAILURE (1-10)	RISK PROFILE NUMBER (RPN)	MEASURES TO REDUCE THE REPEAT OF A FAILURE
1	TRANSPORTATION PROBLEM								
a	Transportation of the produce to the warehouses, market and for export	Communication	Miscommunication between LBCs, NAFCO and the transportation agencies	Delay in the process of grain handling and storage, sale and export	6	5	2	60	Give the transportation agencies advance notice before the transportation of grains.
b	Transportation of the produce to the warehouses, market and ports	Damage during transportation due to poor packaging material	Lack of good packaging materials	Damage to the produce hence reducing the quantity available for storage, sale and export	7	5	8	280	Procurement of good packaging material for the storing and packaging of grains
c	Transportation of the produce to warehouses, market and harbour	Damage during transportation due to poor packing	Poor packing of the produce in the trucks during transportation	Damage to the produces hence reducing the quantity available for storage, sale and export	5	2	6	60	Educate the workers on the need to handle the grains with care and how to handle them
d	Transportation of the produce to the warehouses, market and harbour	Poor transportation route	Lack of knowledge on the best routes to use hence delays on the road	Delay of the process of produce handling, storage, sale and export	9	8	9	648	Adoption of transportation and network model in predicting the best route to use
e	Transportation of the produce to the warehouses,	Bad road network	The bad condition of the roads in the country	Damage to produce hence reducing the quantity available for	8	8	8	512	Construction and repairs of new and bad roads, respectively

No.	STEPS IN THE PROCESS	FAILURE MODE	FAILURE CAUSES	FAILURE EFFECTS	OCCURRENCE OF FAILURE (1-10)	DETECTION OF FAILURE (1-10)	SEVERITY OF FAILURE (1-10)	RISK PROFILE NUMBER (RPN)	MEASURES TO REDUCE THE REPEAT OF A FAILURE
	market and harbour			storage, sale and export					
f	Transportation of the produce to the warehouses, market and harbour	Damages as a result of loading and offloading of the product	Poor handling of the product during loading and offloading	Damage to the produces hence reducing the quantity available for storage, sale and export	5	2	6	60	Educate the workers on the need to handle the grains with care and how to handle them
2	PRICE STABILIZATION AND FOOD RESERVES								
a	Reducing food prices on the market	The surge in global prices of commodities	Increase in prices of natural resources such as gold and oil on the international market	Grains cannot be sold or both due to the high prices of the commodity	6	7	7	294	Take into consideration the changes in global market prices when buying and selling grains through a forecasting model
b	Reducing food prices on the market	Influence of the international bodies in terms of food supply (UN, AU)	Natural disasters lead to the UN and AU seeking food funds from other countries to support the affected countries	Reduce the food reserves or stock of the country	5	2	5	50	Make provisions for this unforeseen circumstance when purchasing grains
c	Reducing food prices on the market	High prices of goods and services due to government taxes and policies.	An increase in taxes and policies set up by the government makes it difficult to reduce prices as it affects the production and operational cost	Increase in operational and production cost	7	5	7	245	Government policies should consult all stakeholders Also, NAFCO should not depend on government subsidies but rather implement policies to run their operations
d	Reducing food prices on the market	Lack of financial support from Governmental agencies in running the Buffer stock company	NAFCO depends on the government to provide financial support hence changes in government or budget affect the operations of NAFCO	Operation and activities of NAFCO are affected	8	8	9	576	NAFCO should not depend on government subsidies but rather implement policies such as setting up their farms and exporting some of the produce to run their operations
e	Reducing food prices on the market	The setting of floor prices for buying food produce	Not accounting for local price differentials in the cost of production	Low price margins are given to the farmers and LBCs	6	6	5	180	NAFCO should take into consideration the production costs across all regions in the country before setting the farm gate prices
f	Reducing food prices on the market	Changes in prices as a result of the release of stored	Most market traders' associations store the grains and sell them at	Since they have access to the market, they tend to control the market	7	5	7	245	Release grains to the market for those who cannot afford the high prices. This will

No.	STEPS IN THE PROCESS	FAILURE MODE	FAILURE CAUSES	FAILURE EFFECTS	OCCURRENCE OF FAILURE (1-10)	DETECTION OF FAILURE (1-10)	SEVERITY OF FAILURE (1-10)	RISK PROFILE NUMBER (RPN)	MEASURES TO REDUCE THE REPEAT OF A FAILURE
		produce by other farmers and market association	a high price during the lean season						help stabilize the prices on the market
g	Reducing food prices on the market	The setting of the ceiling price for the sale of grains released to the market	The change in the economic situation of the country tends to affect the selling price of grains. This is usually set lower than the normal prices on the market hence affecting the profit margin	Profit margins of NAFCO are affected	6	5	6	180	The forecasting model can be used to integrate changes in the prices of grain for future purposes
h	Reducing food prices on the market	Having lower stock levels hence not being able to release the right quantity of grains to stabilize prices	Not getting adequate grains to purchase as a result of wrong inventory management or farmers changing crops	Low levels of grains in the warehouse to sell as well as used for emergency reserves	8	8	8	512	Keeping stock of grain in the warehouse to prevent the shortage of grains
i	Reducing food prices on the market	Wrong forecasting approach in stocking up the warehouses	Wrong inventory management system	Low levels of grains in the warehouse to sell as well as used for emergency reserves	9	8	8	576	Adopting an inventory model to keep track of grain in the warehouse
j	Export of the produce	Export rates are often high	Increase in foreign exchange	Reduction in sales	7	6	7	294	Negotiate with government and foreign agencies to help these taxes
k	Export of the produce	The export value of the grains is often reduced	Quality of the grains being produced and exported by the country	Lack of international competitiveness	7	5	6	210	Good handling, packaging and branding of the grains from NAFCO
l	Sale of the grains	Quality of the grains	Damaged grains as a result of postharvest handling	Loss of customers and revenue	7	6	8	336	NAFCO can employ good postharvest handling practices such as regular inspection of the grains
m	Sale of the grains	Quality of the services	Lack of a structured organizational plan	Loss of customers and revenue	5	6	5	150	A good organizational structure needed
n	Sale of grains	Quality of communication between clients and NAFCO	Lack of communication between management and employees	Loss of customers and revenue	5	5	4	100	Ensure good communication between stakeholders and employers of NAFCO
3	POSTHARVEST HANDLING								

No.	STEPS IN THE PROCESS	FAILURE MODE	FAILURE CAUSES	FAILURE EFFECTS	OCCURRENCE OF FAILURE (1-10)	DETECTION OF FAILURE (1-10)	SEVERITY OF FAILURE (1-10)	RISK PROFILE NUMBER (RPN)	MEASURES TO REDUCE THE REPEAT OF A FAILURE
a	Drying	Not getting the required temperature for drying of the grains	Climate change Lack of grain dryers	Having to store moist grains	6	5	7	210	Drying grains with dryers at the right temperature and humidity
b	Cleaning	Type of cleaning technology used	Lack of funds to acquire the right equipment for cleaning	Storing grains with foreign materials	6	5	7	210	Acquiring grain cleaners and winnowers to clean the grains
c	Weighing	Incorrect weight of the packaged grains	Filling the grains sacks with foreign materials to get the required weight for money	Low quantity and quality of grains	5	5	7	175	Checking the grains at the farmgate before purchasing them. Also, sanctioning farmers who engage in such activities
d	Grading	Grading technologies	Lack of an appropriate standard for grading grains	The quality of grains does not meet international standards	5	5	7	175	Acquire the right equipment and technologies in grading the grains
e	Packaging	Poor packaging of the grains	Lack of packaging materials and technology for packaging the grains	Deterioration of the grains	5	5	7	175	Invest more in packaging and branding of the grains
f	Storage	Poor environment for the storage of grains.	Lack of an appropriate temperature as well as the environment for the storage of grains.	Deterioration of the grains in the store.	7	6	8	336	Provide a conducive environment for the storage of grains.
g	Storage	Storage capacity of the warehouses	The capacity of the storage facilities is low	Not every grain can be purchased as a result of low storage capacity	7	6	8	336	Increase the storage capacity of the warehouses
4	PROBLEM WITH LICENSE BUYING COMPANIES								
a	Market Access	Emerging market expansion as a result of market competition	Competition from other LBCS	Loss of customers	5	5	5	125	Provide competitive prices for the grains they buy to have access to the market
b	Price margins	Lower buyer margins as a result of financing	Lack of credit for LBCs by banks and financial institutions	Loss of customers as a result of not being able to pay competitive prices	5	5	3	75	Source more credit to provide competitive prices to buy to have access to the market
c	Price margins	Lower selling price and commission from NAFCO	Lack of financial support from the government to NAFCO	LBCs can't offer competitive prices when buying produce	5	5	5	125	Sourcing of funds as well as implementing policies that help in the operations of NAFCO

No.	STEPS IN THE PROCESS	FAILURE MODE	FAILURE CAUSES	FAILURE EFFECTS	OCCURRENCE OF FAILURE (1-10)	DETECTION OF FAILURE (1-10)	SEVERITY OF FAILURE (1-10)	RISK PROFILE NUMBER (RPN)	MEASURES TO REDUCE THE REPEAT OF A FAILURE
d	Financing	High cost in financing their operations	Increase in taxes and inflation in the economy	LBCs cannot acquire the capital to operate	5	3	5	75	LBCs seek financial support with zero or low-interest rate
e	Storage	Most LBCS lack storage facilities for storing grains	The cost of running the storage facilities is not profitable as compared to the quantity of grains to be stored	Most of the grains get damaged if they are not properly stored and handled	6	7	5	210	LBCs should set up storage facilities for several satellite farming communities to store the produce. Also, they can ensure that the grains are dried properly before they are stored.
f	Contract	Breach of contract between LBCs and farmers as a result of the unfair influence of larger LBCs	The more bargaining power of larger LBCs makes it difficult for smaller LBCs to buy grains to meet their targets	Loss of customers	2	3	2	12	LBCs provide competitive prices for the grains
g	Communication	Non-agreed deadlines with the farmers	Miscommunication of deadlines between LBCs and farmers	Delay scheduled delivery of the grains as well as other postharvest activities at NAFCO warehouses	2	3	2	12	Ensure effective communication between the stakeholders
h	Buying of the grains	Lack of a farm gate as a result of the farmers cultivating other crops	Low price margins offered by LBCs	Low supply of grains for NAFCO warehouse	7	7	8	398	Provide competitive prices for grains
5	PROBLEMS WITH FARMERS								
a	Farming	Incorrect implementation of innovation	Lack of education for the farmers on the new technologies	Loss of capital	3	2	4	24	Provide training on new technology and implements to use in farming
b	Market Access	Emerging market expansion as a result of competition from other grain suppliers	Quality grains being provided by other farmers	Loss of customers	3	2	3	18	Provide quality grains for LBCs
c	Communication	Late responses to customer queries and wishes	Lack of managerial skills	Loss of customers	2	2	2	6	Effective communication with LBCs
d	Logistic	Lack of farm machinery to use on their farms as well	Inadequate farm machinery in certain areas of the country	Long time in farming as well as farming being	3	2	4	24	Provide support to the farmers by making available implements and

No.	STEPS IN THE PROCESS	FAILURE MODE	FAILURE CAUSES	FAILURE EFFECTS	OCCURRENCE OF FAILURE (1-10)	DETECTION OF FAILURE (1-10)	SEVERITY OF FAILURE (1-10)	RISK PROFILE NUMBER (RPN)	MEASURES TO REDUCE THE REPEAT OF A FAILURE
		as to convey their produce to the farm gates		made labour intensive					planting materials at subsidised prices.
e	Yield/ Production	Low yield as a result of poor farming technologies as well as natural disasters	Lack of education on new farming technologies	Loss of capital	5	3	6	90	Educate farmers on new planting technologies and climate change issues
f	Finance	Lack of finances/credit to use to purchase farm input	The inability of most farmers to provide documents to secure loans or capital for farming	Loss of customers	4	4	3	48	Help farmers acquire finance/credit to support their activities
g	Storage	Lack of improved storage facilities and technologies in storing their grains after harvest	Lack of education on the new storage techniques to use in storing their grains as well as the lack of storage facilities	Damage of grains Low yield	6	5	7	210	Acquire low-cost storage facilities or storage technology. Also, the government can support by providing satellite storage facilities for a cluster of farmers in farming communities
f	Postharvest handling	Lack of good postharvest technologies such as drying and cleaning	Lack Postharvest technologies	High postharvest losses	4	2	4	32	Educate the farmers on the availability and use of postharvest technologies and their importance

From Table 4.1, the Risk Priority Number (RPN) for each unit operation of the various stakeholders was a numeric assessment of the risk associated with the operation. The highest RPN of the various unit operation sections were highlighted as significant to the findings. The highest of all being 648 attributed to transporting the grains from the farms to the warehouses from the transportation problem operation. The five highest RPNs are from the various operations namely: transportation problems, price stabilization and food reserves, postharvest handling, a problem with license buying companies and problems with farmers. Subsequently, the highest RPN from each unit operation was observed along with its significance as well as recommended ways of tackling each of them.

The unit operation that required transporting of grains from the farms to the warehouse and from the warehouse to the markets and harbours had the highest RPN of 648. This was a result of poor transportation network routes leading to an increase in transportation costs as well as the delay of other operations. The recommended action proposed to reduce the RPN was to adopt a mathematical model that will help design a network route for transportation taking into consideration all the stakeholders to minimize the cost of transportation.

In addition, the operation of reducing the cost of grains on the market through price stabilization policies is hindered by the lack of financial support from the government. As such, the RPN value of this operation was 576, which was the second-highest. In order to ensure that NAFCO runs its operations devoid of government interference and subsidy, it is proposed that NAFCO implements policies such as setting up farms that will help it generate internal income to run its affairs.

Equally important, the price stabilization operation was also affected by the inventory control model. This failure has to do with not knowing when to buy grains and the quantity to buy them. This leads to a higher operation cost hence resulting in an RPN value of 576 same as the RPN value of depending on the government for funds to run its operation. The proposed action to reduce this was to incorporate an inventory model in determining when to stock up to prevent shortages.

Furthermore, with regards to postharvest handling as a unit operation in the buffer stock system, storage of the grains and warehouse capacity had the highest RPN value of 336. The failure associated with this operation was the poor storage environment and low capacity of the warehouses where the grains are stored hence leading to the deterioration of the grains. To deal with this failure, a conducive environment should be provided for the storage of the grains as well as building extra storage facilities to house the extra tonnage of grains purchased.

Similarly, in dealing with the farmers, it has to be ensured that they are given competitive prices for the grains they sell at the farm gate. This has not been the case hence resulting in this operation having the highest RPN value of 398 with regards to the problems LBCS face when dealing with the farmers. To ensure that the farmers do not cultivate other crops, it is advised that LBCs and NAFCO provide competitive prices to the farmers to address this failure.

Lastly, the farmers themselves have issues with storing their grains hence storage as a unit operation having an RPN value of 210. This is an issue for the farmers because they lack improved storage facilities and technological knowledge on storing their grains. This leads to deterioration of the grains hence resulting in low yields and causing financial loss to the farmer. To reduce the effect of this failure, it is proposed that farmers set up storage facilities or satellite storage facilities provided to a cluster of farmers in a farming community.

The main goal of this risk assessment process was to determine which of the areas in the operation of NAFCO needed more focus to deal with the issues of the operation. This meant concentrating more resources and energy on the risk associated with that operation to reduce its effect. As a result of this, a mathematical model was built to reduce the cost of transporting the grains from the farms to the warehouses and from the warehouses to the harbours and airports by optimally siting the NAFCO warehouses. Furthermore, an inventory control model was developed as they minimize the cost of setting up the warehouses as well as stocking them up.

4.2 Design a facility location model to optimally site National Food Buffer Stock facilities

Optimal location of National Food Buffer Stock Company Warehouse

In ascertaining the optimal locations to site the NAFCO warehouses, simulations were run with data on farm distance and capacities in the various districts of the country, market distance and capacities of maize producing districts and harbour distance and capacities for the export of the grains to design a network of warehouses over the country. The number of warehouses to be optimally sited by the model was indicated. To start with, the model was made to optimally predict four locations where the NAFCO warehouses were to the sited. This was done to compare the locations of the four existing NAFCO warehouses located at Yendi in the Northern Region, Techiman in the Brong Ahafo Region, Sunyani in the Brong Ahafo Region and Nkawkaw in the Eastern Region. The model optimally predicted the four locations with only one having the exact location as the existing location as shown in Table 4.2.

Table 4.2: Existing NAFCO warehouse location versus the four optimally predicted locations

Existing Location	Predicted Location
Yendi	Nadowli
Techiman	Techiman
Sunyani	Akropong
Nkawkaw	Donkorkrom

The predicted locations were Techiman in the Brong East Region, Nadowli in the Upper West Region, Akropong in the Eastern Region and Donkorkrom in the Eastern Region. The model used in this research was designed to minimize the total cost of transportation incurred by all the various stakeholders of the buffer stock system. Hence, there is a potential cost difference with this model having a total transportation network cost of GHS 2.6654 E+6 for the four optimally predicted NAFCO warehouses.

For this research, six optimal areas to site the NAFCO warehouses were to be determined by the model. Six optimal locations were simulated because NAFCO is planning to expand its storage capacity but the exact number to be added to the existing facilities was not disclosed. therefore, for this research, six optimal locations were used. The simulations showed these six optimal locations where the warehouses should be sited to decrease the transportation cost to all the individual stakeholders.

The location of the number of warehouses that the model was to predict optimally was mostly dependent on the resources available to NAFCO. These predicted optimal locations were Nadwoli in the Upper West Region, Winneba in the Central Region, Techiman in the Bono East Region, Agona in the Western Region, Donkorkrom and Somanya in the Eastern Region of Ghana as indicated in Figure 4.1 below. These warehouses were ideally suited to satisfy the individual stakeholders using the goal programming network design which resulted in an average overall cost of GHS 1.7924E+6 see above. Of the six optimally predicted locations, only one (Techiman) conforms to the existing location of NAFCO warehouses (see Table 4.2).

Table 4.3: Existing NAFCO warehouse location versus the six optimally predicted locations

Existing Location	Predicted Location
Yendi	Nadowli
Techiman	Techiman
Sunyani	Agona
Nkawkaw	Donkorkrom
	Winneba
	Somanya

Further simulations revealed the ideal market, harbours and farms assigned to these warehouses to reduce the cost to the individual stakeholders.

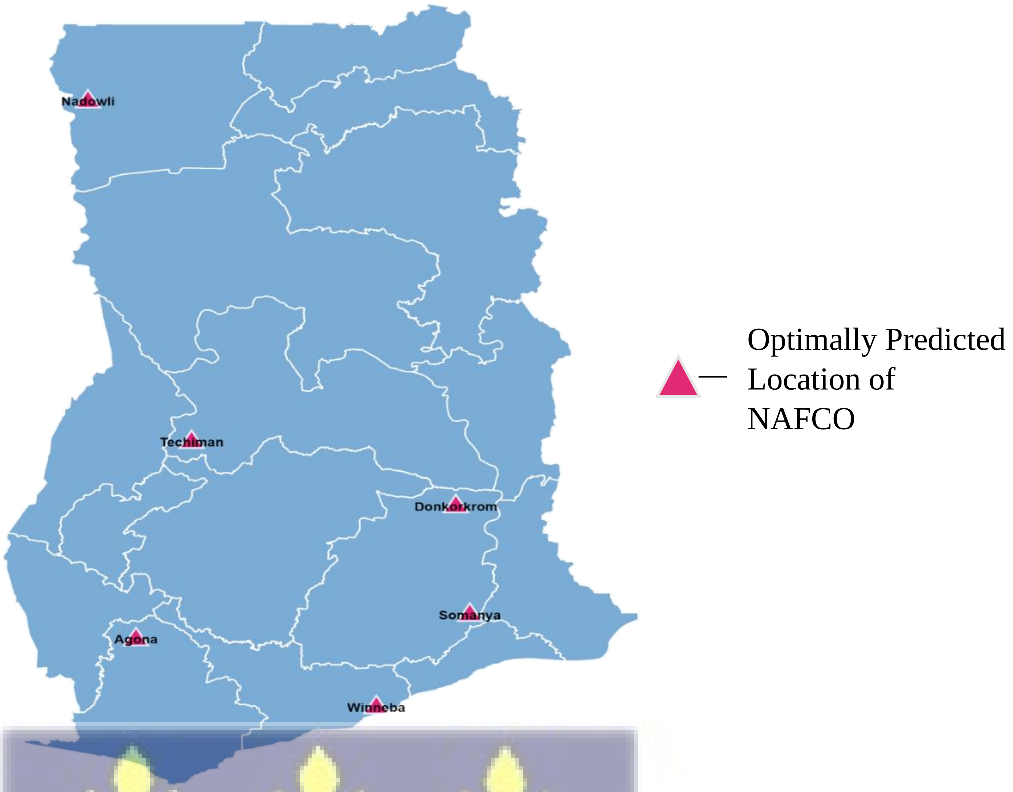

Figure 4.1: Optimal predicted locations of NAFCO warehouses

4.2.1 Transportation cost of transporting the grains from the optimally sited warehouses to the market

To reduce the cost of transporting from the NAFCO predicted optimal warehouses to the designated market, a pseudo-p-median model was used to assign the designated market to the predicted optimal warehouse (Agona, Techiman, Donkorkrom, Nadowli, Somanya and Winneba). These designated markets for the sale of the grains were Sunyani, Wenchi, Nkoranza, Techiman, Kintampo and Ejura- Sekyedumasi. Figure 4.2 indicates the relationship between the predicted optimal warehouses and the respective designated markets they are to serve. The average total transportation cost of transporting the grains from the predicted optimal warehouses to the designated markets was GHS 4.4578E+5.

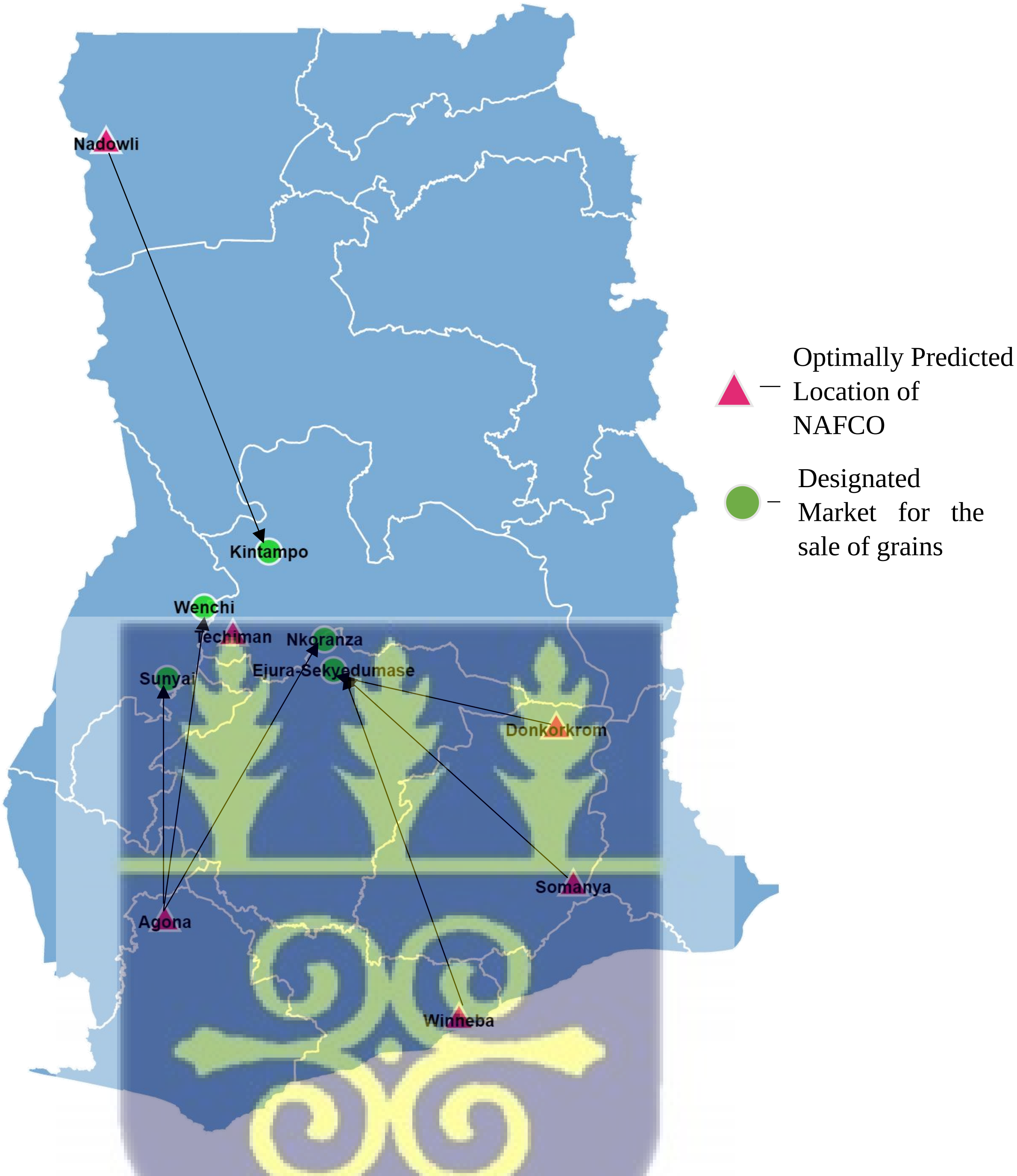

Figure 4.2: Optimal predicted warehouses and the respective maize markets they serve.

However, the government is looking at rehabilitating existing grain storage facilities to add up to the NAFCO warehouses. However, research by Essien *et al.*, (2018) compared the cost of transporting grains from the existing grain storage facilities to the markets and the cost of transporting the grains using optimal predicted locations from his model. From his findings, it was indicated that the total cost of transporting grains to the market from the existing grain storage facilities was 55 % higher as compared to the 23 % transport cost incurred using the optimal predicted location from his model. Furthermore, the total network design cost was GHS 8.3 E+07 as compared to GHS 4.4578E+5 obtained in this research. This disparity resulted from the different optimal locations predicted by both models.

4.2.2 Transportation cost of transporting the grains from the farms to the optimally sited warehouses

Transporting grains from the various farms across the different districts in the country is essential for NAFCO to operate. As such, these farms are optimally assigned to the predicted optimal warehouses using the pseudo-p-median to reduce the cost of transportation to the farmers as well as license-buying companies. The algorithm predicted an average transportation cost of GHS 1.256E+10 in conveying the grains from the district farms to the predicted optimally sited warehouses (Agona, Techiman, Donkorkrom, Nadowli, Somanya and Winneba). Table 4.2 provides the list of the district farms and their assigned warehouses as predicted by the model. On the contrary, the existing grain storage facilities that the government wants to adopt have an existing transportation cost of GHS 9.326 E+09 as compared to GHS 6.70 E+09 from the optimal location predicted by Essien *et al.*, (2018), which is a 26% improvement in the cost of transportation. This is on the high side, hence the government and NAFCO might need to reconsider this proposal of rehabilitating and adopting existing grain storage facilities.

Table 4.4: District farms and their respective predicted optimal warehouses they serve

PREDICTED WAREHOUSES	DISTRICT FARMS
Techiman	Agona Nkwanta, Daboase, Half Assini, Akatsi, Savelugu, Bole, Zabzugu, Tepa, Obuasi, New Adubiase Kumasi, Mamponteng, Sunyani, Dorma Ahenkro, Berekum,

	Bechem, Nkoranza, Techiman, Goaso, Drobo, Kintampo, Atebubu, Bongo
Agona	Axim, Asankragua, Enchi, Bibiani, Wiawso, Juabeso, Dunkwa-on-Offin, Foso, Denu, Jasikan, Ho, Bimbila, Gambaga, Salaga, Manso Nkwanta, Ejura, Mampong, Effiduase, Agona, Mankranso, Nkawie, Ejisu, Kuntenase, Ofinso, Konongo Odumase, Juaso, Kumasi, New Abirem, Mpraeso, Dodowa, Kenyasi, Wenchi, Sandema, Bawku
Nadowli	Keta, Damango, Gushiegu, Bekwai, Wa, Lawra, Tumu, Jirapa, Nadowli
Winneba	Sekondi, Twifu Praso, Abura-Dunkwa, Asikuma, Saltpond, Elmina, Ajumako, Winneba, Swedru, Sogakope, Tolon, Akim Oda, Asamankese, kade, Bolgatanga
Somanya	Cape Coast, Kadjebi, Nkwanta, Yendi, Saboba, Suhum, Nsawam, Akropong, Koforidua, Somanya, Kibi, Begoro, Atimpoku, Odumase Krobo, Tema, Ada, Navrongo
Donkorkrom	Tarkwa, Apam, Adidome, Kpandu, Hohoe, Kete Krachi, Tamale, Walewale, Donkorkrom, Amasaman, Accra, Kwame Danso, Zebila

4.2.3 Cost of transporting the grains from the optimally sited warehouses to the harbours

The pseudo-p-median model was used to determine the optimal assignment of the predicted optimal NAFCO warehouses (Agona, Techiman, Donkorkrom, Nadowli, Somanya and Winneba) to the respective harbours for the export of grains. This was done to reduce the cost of transporting the grains from the warehouses to the harbours. The optimal assignment of this network is illustrated in Figure 3. The average transportation cost for this optimal network is GHS 1.2011E+5. However, from research, the total cost of transporting the grains from existing grain storage facilities led to an increased cost of 33% as compared to a 20% cost increase of the predicted optimal location from research by Essien *et al.*, (2018). It is important to reiterate that the findings from that research and this research all saw a reduction in the cost of transportation with the optimal predicted locations even though the locations were different.

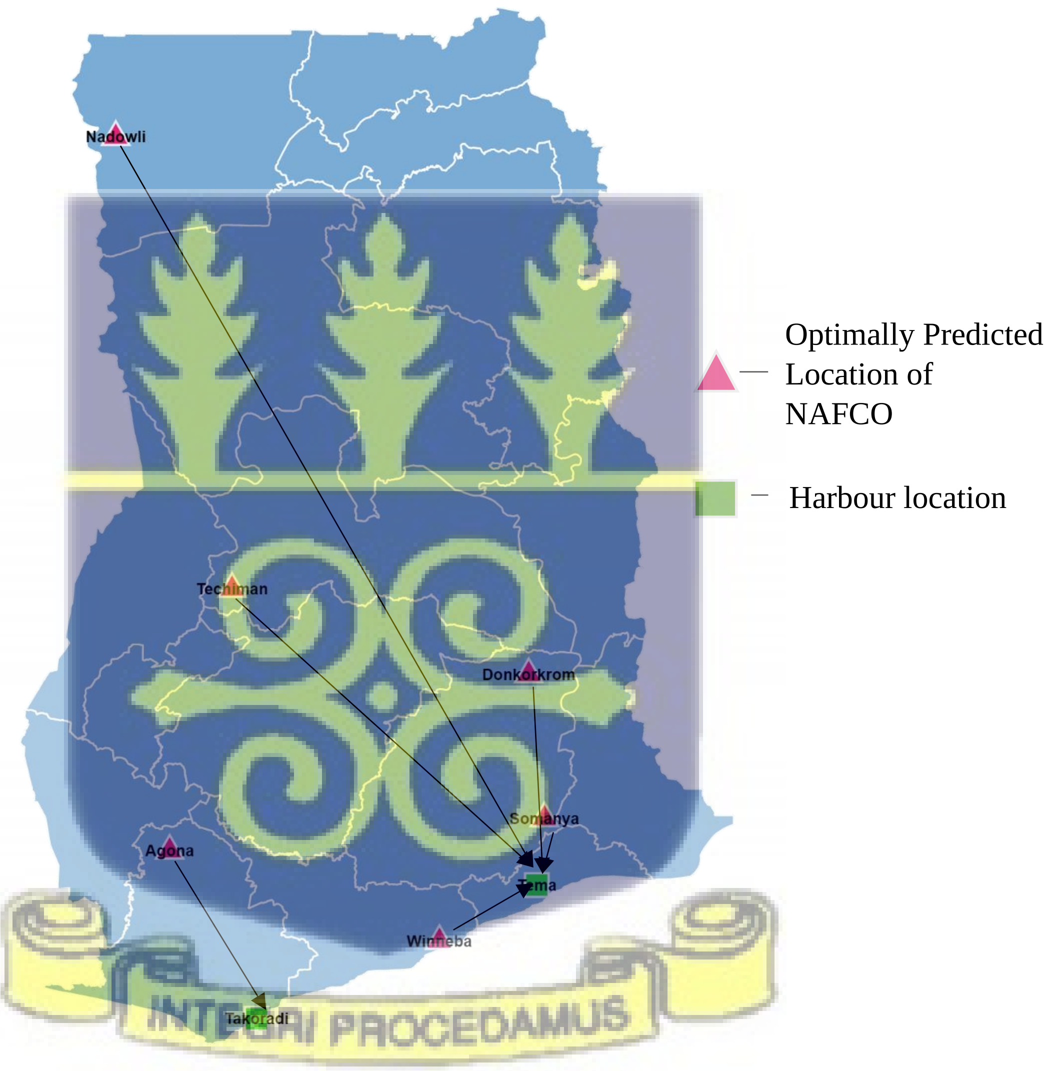

Figure 4.3: Optimal predicted location of NAFCO warehouses and the respective harbours they serve

4.3 Design of a scientific inventory control model

The inventory control model involves controlling the material flow and production operations of an organization. Inventory models are mostly adopted by an organization to prevent shortages as this will be the situation if the organization runs out of stocks and fails to meet the demand of the customers. This leads to the loss of customers. A stochastic inventory model programming approach was used in this research. This model was adopted to minimize the total cost of setting up and stocking up the warehouses. The stochastic inventory model allowed for the prediction of different possible outcomes under various conditions using random variables.

To keep track of the inventory, grains in the warehouses were periodically checked at a certain predetermined that is quarterly every year. The model adopted the quarterly approach of checking inventory since it was presumed that stocking up of NAFCO warehouses should be done every quarter. Thus, the model provided the number of grains available every quarter after having assigned numerical values to the setup cost, holding cost and demand for grains.

Based on the input given (setup cost, holding cost and demand for grains), the model predicts the optimal production quantity for each quarter as well as the grains available for each quarter to minimize the total cost of inventory.

According to the news by Graphics online (4th June, 2019), the National Buffer Stock warehouse has a capacity for 33,000 tonnes of grains. However, they are looking to add 50,000 tonnes capacity to it (Baneseh Mabel Aku, 2019). As such for this research, the annual demand for grains used in the simulation was 100,000 tonnes. This figure was used to allow for any excess grains that will be purchased by buffer stock beyond the 83,000 tonnages they were estimating.

For this research, dummy data was used for the simulations. The input variables used in evaluating the model were the number of grains needed at a particular quarter, the setup cost and the holding cost. Intending to minimize the inventory cost for the year, the output of the model was the number of grains available at a particular quarter, the total inventory cost and the supply or production of grains at a particular quarter.

A different set of data was used in evaluating the model to determine the number of grains to produce or purchase in a particular quarter to reduce the overall inventory cost based on the demand, setup cost and holding cost of that quarter. It was observed that to reduce the inventory cost, the setup cost and holding cost should be reduced.

Annual demand for the grains was 100,000 tonnes with a quarterly demand of 30,000 tonnes, 20,000 tonnes, 30,000 tonnes and 20,000 tonnes for the 1st, 2nd, 3rd and 4th quarters, respectively. GH₵ 2 million was allocated for setting up the production of the grains for every quarter and GH₵ 200,000 as holding cost for pre-storing, processing and storing of the grains every quarter. This model aimed to minimize the total inventory cost of NAFCO. To achieve this, the production amount per every quarter was determined along with the inventory. The model called for the production of 50,000 tonnes of grains during the 1st and 3rd quarters to meet the 100,000 tonnes demand. It was also observed from the model that, the inventory level at the 1st quarter was 20,000 tonnes and then dropped to 0 upon reaching the 2nd quarter hence the need for the production of 50,000 tonnes during the 3rd quarter. Similarly, the inventory level increased to 20,000 tonnes during the 3rd quarter and dropped to 0 again at the end of the last quarter. All this resulted in a total inventory cost of GH₵ 4.8 million as the optimal solution.

Figure 4.5 is a typical example of the data that was used in evaluating the model to predict the optimal solution to minimize inventory cost.

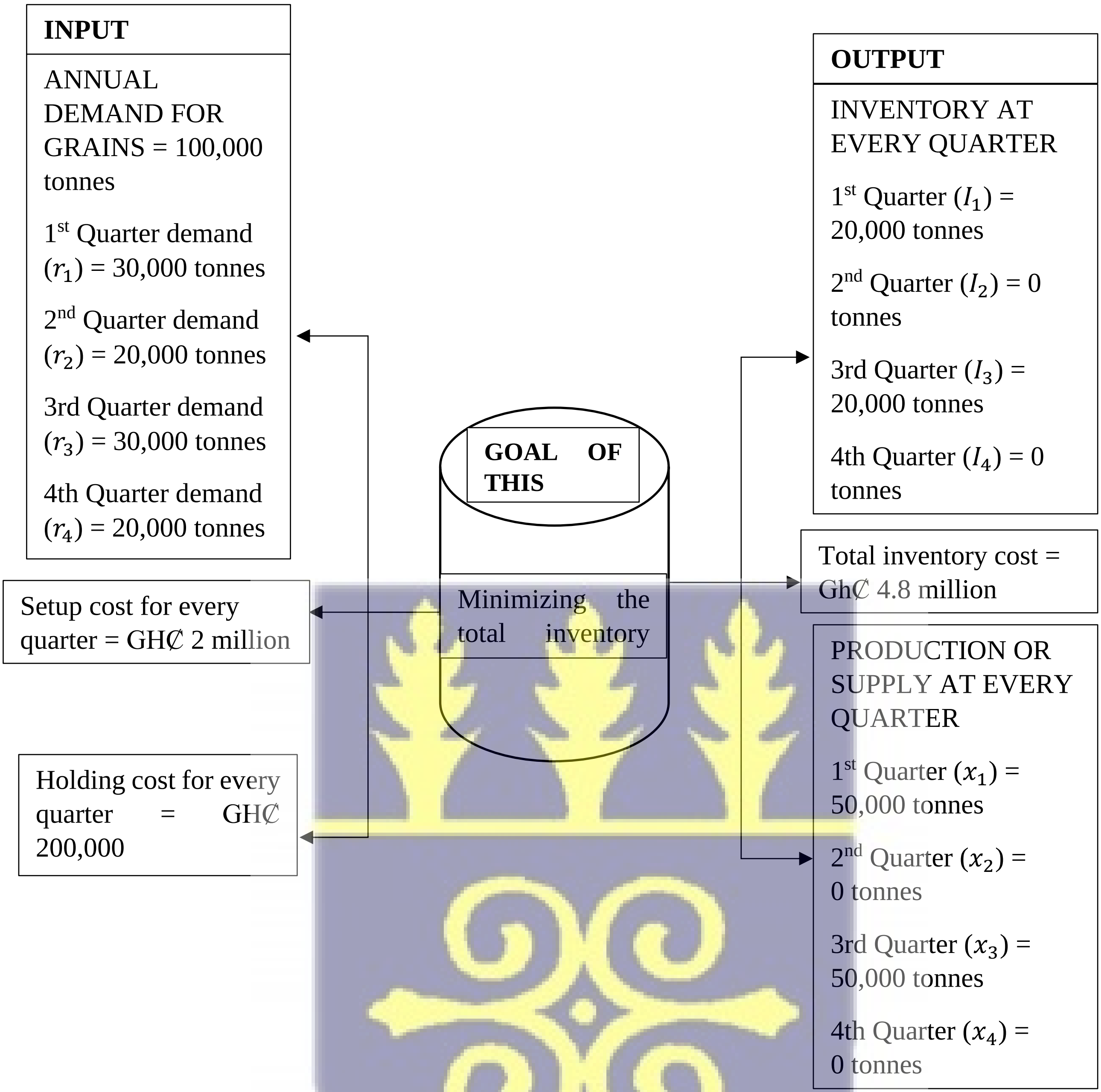

Figure 4.2: Simulation outcome of the inventory model

As such, to ensure that the operational cost of setting up and stocking up NAFCO warehouses is minimized, NAFCO has to spend GH₵ 4.8 million on the purchase of 100,000 tonnes of grains as well as taking into account the setup cost.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The proposed decision support system for the siting and managing of the National Food Buffer Stock System uses data on the grain production, the distance between stakeholders and the capacities of their facilities to optimally predict the locations and management of the warehouses. The key findings of this research were:

1. The simulations essentially showed the optimal locations, where the grains warehouses were to be sited to reduce transportation costs to the individual stakeholders. Similarly, the optimal network design ensured that all the stakeholders in the supply chain were satisfied. Six predicted optimal locations were stimulated by the model that is Agona, Techiman, Donkorkrom, Nadowli, Somanya and Winneba. The average total average cost incurred by NAFCO was GHS 1.7924E+6.
2. Furthermore, to ensure that there is no shortage of grains all year round, the simulation predicted the number of grains needed to be purchased and when to purchase them. This provides NAFCO with a way to track their inventory to ensure there are enough grains available to stabilize price hikes on the market as well as make grains available for emergency use. This results in the low cost of production for NAFCO.
3. Lastly, this will also reduce the risk assessment associated with the operations of NAFCO as indicated by the failure, mode and effect analysis conducted. Decision-makers in Ghana are thus urged to use the decision support systems instead of using human intuition as has always been the case.

5.2 Recommendation

1. Having predicted the optimal siting location of NAFCO warehouses, the implementers of these policies need to perform thorough risk assessments and planning before adopting this model.
2. Also, when implementing the inventory model, the implementers of the model need to critically consider the assumption and cost used to develop this model in this research to determine if they ideally suit their research or policies.
3. Ministry of Roads and Highways along with the Ministry of Food and Agriculture should consider constructing and rehabilitating roads leading to farming communities and not just focusing on cocoa roads.

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APPENDICES

Appendix A

CODES FOR GOAL PROGRAMMING MODEL FOR OPTIMALLY SITING NATIONAL BUFFER STOCK WAREHOUSES

```
*Goal programming model for sustainably siting
*National Buffer Stock systems in Ghana
GDXIN   C:\Users\Isaac\Documents\gamsdir\projdir\Data_actual.gdx
Sets
        warehouses
        airports
        markets
        harbours
        FarmJ
  ;
--- LOAD  warehouses = 2:warehouses
--- LOAD  airports = 3:airports
--- LOAD  markets = 4:markets
--- LOAD  harbours = 5:harbours
--- LOAD  FarmJ = 1:FarmJ
Display       warehouses, airports,  markets, harbours,FarmJ ;
```

```
Parameters

a(warehouses)  capacity of warehouses

b(markets)   demand at markets

c(airports)   demand at airports

d(harbours) demand at the harbour

e(FarmJ)  capacity of Farms

d1(warehouses,markets)
d2(warehouses,airports)
d3(warehouses,harbours)
d4(warehouses,FarmJ)   distance between farms
;
--- LOAD  a = 9:a
--- LOAD  b = 10:b
--- LOAD  c = 11:c
--- LOAD  d = 12:d
--- LOAD  e = 14:e
--- LOAD  d1 = 6:d1
--- LOAD  d2 = 7:d2
--- LOAD  d3 = 8:d3
--- LOAD  d4 = 13:d4
```

```
Positive variable  N1,N2,N3,N4,P1,P2,P3, P4;
Binary variable Site(warehouses), x1(warehouses),x2 (warehouses), x3(warehouses),x4(warehouses),y1(warehouses,markets),y2(warehouses,airports),y3(warehouses,harbours), y4(warehouses,FarmJ);
;
variable  z,K,cost11,cost22,cost33;

Scalars
Target1 /17.089/

Target2 /11.261/

Target3 /14.137/

Target4 /705/

*** This is the weight that will be attached to each stakeholder
weight1 /0.1/
weight2 /0.1/
weight3 /0.7/
weight4 /0.1/
;
*Goal.. K =E= P1+ P2 + P3;

Goal.. K =E= (weight1*(P1/Target1))+(weight2*(P2/Target2))+(weight3*(P3/Target3));

Pushit.. sum(warehouses,Site(warehouses))=e=6;
```

```
170  option optcr=0;

171

172  Model transport /all/ ;

173  Solve transport using MIP minimizing K ;

174

---- cost1  =E=  define cost  function for markets


cost1..  - N1 + P1 - 10.4995684647809*y1(Sekondi,Sunyani)

- 12.4295145034095*y1(Sekondi,Wenchi)

- 11.7287378754517*y1(Sekondi,Nkoranza)

- 11.5390452185932*y1(Sekondi,Techiman)

- 13.1953549271367*y1(Sekondi,Kintampo)

- 10.8116417333326*y1(Sekondi,Ejura-Sekyedumasi)

- 8.8554751475329*y1(Agona Nkwanta,Sunyani)

- 10.4267847765074*y1(Agona Nkwanta,Wenchi)

- 11.1944942268409*y1(Agona Nkwanta,Nkoranza)

- 10.4422516488573*y1(Agona Nkwanta,Techiman)

- 12.0985342700588*y1(Agona Nkwanta,Kintampo)

- 10.9478910641906*y1(Agona Nkwanta,Ejura-Sekyedumasi)
```

- 10.7394539665857*y1(Daboase,Sunyani)

- 11.9532919416173*y1(Daboase,Wenchi)

- 11.2525153136596*y1(Daboase,Nkoranza)

- 11.062822656801*y1(Daboase,Techiman)

- 12.7191052780025*y1(Daboase,Kintampo)

- 10.3354191715404*y1(Daboase,Ejura-Sekyedumasi)

- 8.44718763977492*y1(Tarkwa,Sunyani) - 10.0184972687494*y1(Tarkwa,Wenchi)
-

- 10.7862067190829*y1(Tarkwa,Nkoranza)

- 10.0339641410993*y1(Tarkwa,Techiman)

- 11.6902467623008*y1(Tarkwa,Kintampo)

- 8.47148498565556*y1(Tarkwa,Ejura-Sekyedumasi)

- 10.9513853313239*y1(Axim,Sunyani) - 12.5226949602984*y1(Axim,Wenchi)

- 13.2904044106319*y1(Axim,Nkoranza) - 12.5381618326483*y1(Axim,Techiman)

- 14.1944444538498*y1(Axim,Kintampo)

- 10.9324783665249*y1(Axim,Ejura-Sekyedumasi)

- 10.3609896225006*y1(Half Assini,Sunyani)

- 11.9322992514752*y1(Half Assini,Wenchi)

- 12.7000087018087*y1(Half Assini,Nkoranza)

- 11.947766123825*y1(Half Assini,Techiman)

- 13.6040758323686*y1(Half Assini,Kintampo)

- 12.4534055391583*y1(Half Assini,Ejura-Sekyedumasi)

- 8876.62525772004*y1(Asankragua,Sunyani)

- 11133.9259813686*y1(Asankragua,Wenchi)

- 12236.7965205891*y1(Asankragua,Nkoranza)

- 11156.1452699825*y1(Asankragua,Techiman)

- 13535.5158857182*y1(Asankragua,Kintampo)

- 10701.9534368803*y1(Asankragua,Ejura-Sekyedumasi)

- 28208.9014571337*y1(Enchi,Sunyani) - 34884.2850809608*y1(Enchi,Wenchi)

- 38145.7397288001*y1(Enchi,Nkoranza)

- 34949.9928857705*y1(Enchi,Techiman)

- 41986.3666736747*y1(Enchi,Kintampo)

- 37098.0972507135*y1(Enchi,Ejura-Sekyedumasi)

- 4755.89876324401*y1(Bibiani,Sunyani)

- 6857.87919263085*y1(Bibiani,Wenchi)

---- supply_A =G= observe supply limit at plant warehouses

Supply_A(Sunyani).. y1(Sekondi,Sunyani) + y1(Agona Nkwanta,Sunyani)

+ y1(Daboase,Sunyani) + y1(Tarkwa,Sunyani) + y1(Axim,Sunyani)

+ y1(Half Assini,Sunyani) + y1(Asankragua,Sunyani) + y1(Enchi,Sunyani)

+ y1(Bibiani,Sunyani) + y1(Wiawso,Sunyani) + y1(Juabeso,Sunyani)

+ y1(Dunkwa-on-Offin,Sunyani) + y1(Twifu Praso,Sunyani) + y1(Foso,Sunyani)

+ y1(Abura-Dunkwa,Sunyani) + y1(Asikuma,Sunyani) + y1(Saltpond,Sunyani)

+ y1(Elmina,Sunyani) + y1(Ajumako,Sunyani) + y1(Winneba,Sunyani)

+ y1(Apam,Sunyani) + y1(Cape Coast,Sunyani) + y1(Swedru,Sunyani)

+ y1(Adidome,Sunyani) + y1(Sogakope,Sunyani) + y1(Akatsi,Sunyani)

+ y1(Keta,Sunyani) + y1(Denu,Sunyani) + y1(Kpandu,Sunyani)

+ y1(Hohoe,Sunyani) + y1(Jasikan,Sunyani) + y1(Kadjebi,Sunyani)

+ y1(Nkwanta,Sunyani) + y1(Kete Krachi,Sunyani) + y1(Ho,Sunyani)

+ y1(Damango,Sunyani) + y1(Yendi,Sunyani) + y1(Bimbila,Sunyani)

+ y1(Gushiegu,Sunyani) + y1(Gambaga,Sunyani) + y1(Savelugu,Sunyani)

+ y1(Salaga,Sunyani) + y1(Tamale,Sunyani) + y1(Bole,Sunyani)

supply1(Wenchi).. y1(Sekondi,Wenchi) + y1(Agona Nkwanta,Wenchi)

+ y1(Daboase,Wenchi) + y1(Tarkwa,Wenchi) + y1(Axim,Wenchi)

+ y1(Half Assini,Wenchi) + y1(Asankragua,Wenchi) + y1(Enchi,Wenchi)

+ y1(Bibiani,Wenchi) + y1(Wiawso,Wenchi) + y1(Juabeso,Wenchi)

+ y1(Dunkwa-on-Offin,Wenchi) + y1(Twifu Praso,Wenchi) + y1(Foso,Wenchi)

+ y1(Abura-Dunkwa,Wenchi) + y1(Asikuma,Wenchi) + y1(Saltpond,Wenchi)

+ y1(Elmina,Wenchi) + y1(Ajumako,Wenchi) + y1(Winneba,Wenchi)

+ y1(Apam,Wenchi) + y1(Cape Coast,Wenchi) + y1(Swedru,Wenchi)

+ y1(Adidome,Wenchi) + y1(Sogakope,Wenchi) + y1(Akatsi,Wenchi)

+ y1(Keta,Wenchi) + y1(Denu,Wenchi) + y1(Kpandu,Wenchi) + y1(Hohoe,Wenchi)

+ y1(Jasikan,Wenchi) + y1(Kadjebi,Wenchi) + y1(Nkwanta,Wenchi)

+ y1(Kete Krachi,Wenchi) + y1(Ho,Wenchi) + y1(Damango,Wenchi)

+ y1(Yendi,Wenchi) + y1(Bimbila,Wenchi) + y1(Gushiegu,Wenchi)

+ y1(Gambaga,Wenchi) + y1(Savelugu,Wenchi) + y1(Salaga,Wenchi)

+ y1(Tamale,Wenchi) + y1(Bole,Wenchi) + y1(Saboba,Wenchi)

+ y1(Tolon,Wenchi) + y1(Walewale,Wenchi) + y1(Zabzugu,Wenchi)

---- final_cost1 =E= this will be the final total transportation cost of produ
ct 1 after the optimisation

final_cost1.. 10.4995684647809*y1(Sekondi,Sunyani)

+ 12.4295145034095*y1(Sekondi,Wenchi)

+ 11.7287378754517*y1(Sekondi,Nkoranza)

+ 11.5390452185932*y1(Sekondi,Techiman)

+ 13.1953549271367*y1(Sekondi,Kintampo)

+ 10.8116417333326*y1(Sekondi,Ejura-Sekyedumasi)

+ 8.8554751475329*y1(Agona Nkwanta,Sunyani)

+ 10.4267847765074*y1(Agona Nkwanta,Wenchi)

+ 11.1944942268409*y1(Agona Nkwanta,Nkoranza)

+ 10.4422516488573*y1(Agona Nkwanta,Techiman)

+ 12.0985342700588*y1(Agona Nkwanta,Kintampo)

+ 10.9478910641906*y1(Agona Nkwanta,Ejura-Sekyedumasi)

+ 10.7394539665857*y1(Daboase,Sunyani)

Model Statistics SOLVE transport Using MIP From line 173

MODEL STATISTICS

BLOCKS OF EQUATIONS 26 SINGLE EQUATIONS 14,765

BLOCKS OF VARIABLES 22 SINGLE VARIABLES 14,313

NON ZERO ELEMENTS 72,143 DISCRETE VARIABLES 14,300

GENERATION TIME = 0.500 SECONDS

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EXECUTION TIME = 0.500 SECONDS

10 MB 25.1.3 r4e34d435fbd WEX-WEI

GAMS 25.1.3 r4e34d435fbd Released Oct 30, 2018 WEX-WEI x86 64bit/MS Windows 02/24/22 14:09:56 Page 7

G e n e r a l A l g e b r a i c M o d e l i n g S y s t e m

Solution Report SOLVE transport Using MIP From line 173

S O L V E S U M M A R Y

MODEL transport OBJECTIVE K

TYPE MIP DIRECTION MINIMIZE

SOLVER CBC FROM LINE 173

**** SOLVER STATUS 1 Normal Completion

**** MODEL STATUS 1 Optimal

**** OBJECTIVE VALUE 1792426.4733

Appendix B

CODES FOR INVENTORY CONTROL MODEL

DETERMINISTIC MULTI-PERIODIC INVENTORY CONTROL MODEL

```
* ASSUMPTION
*No shortage cost
Unit cost of the grain is an irrelevant fixed cost
*/
8
18
20
GDXIN   C:\Users\Isaac\Documents\gamsdir\projdir\InvSheet.gdx
22
23  set Periods ;
24
--- LOAD  Periods = 1:Periods
26  display Periods;
27
28  Parameter
29  d(Periods)     ;
30  scalar
31  C1
32  C2
33  M ;
34
--- LOAD  d = 4:d
--- LOAD  C1 = 2:C1
--- LOAD  C2 = 3:C2
--- LOAD  M = 5:M
36
38
```

```
VARIABLES   L;
POSITIVE VARIABLES  Pdtn(Periods), Inv(Periods);
BINARY VARIABLES  y(Periods);
EQUATIONS  OBJ,E1,E2;

OBJ.. L=E=sum (Periods,C1*y(Periods))+ sum(Periods,C2*Inv(Periods));

E1(Periods)..  Pdtn(Periods)+ Inv(Periods-1)- Inv(Periods)=e=d(Periods);
E2(Periods)..          Pdtn(Periods)=l=y(Periods)* M;


MODEL InventoryProblem /All/;
SOLVE InventoryProblem USING MIP minimizing L;
```

EQUATIONS

---- OBJ =E=

OBJ.. L - 0.2*Inv(x1) - 0.2*Inv(x2) - 0.2*Inv(x3) - 0.2*Inv(x4) - 2*y(x1)

- 2*y(x2) - 2*y(x3) - 2*y(x4) =E= 0 ; (LHS = 0)

---- E1 =E=

E1(x1).. Pdtn(x1) - Inv(x1) =E= 3 ; (LHS = 0, INFES = 3 ****)

E1(x2).. Pdtn(x2) + Inv(x1) - Inv(x2) =E= 2 ; (LHS = 0, INFES = 2 ****)

E1(x3).. Pdtn(x3) + Inv(x2) - Inv(x3) =E= 3 ; (LHS = 0, INFES = 3 ****)

MODEL STATISTICS

BLOCKS OF EQUATIONS	3	SINGLE EQUATIONS	9
BLOCKS OF VARIABLES	4	SINGLE VARIABLES	13
NON-ZERO ELEMENTS	28	DISCRETE VARIABLES	4

GENERATION TIME = 0.234 SECONDS

4 MB 25.1.3 r4e34d435fbd WEX-WEI

EXECUTION TIME = 0.234 SECONDS

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General Algebraic Modeling System

Solution Report SOLVE InventoryProblem Using MIP From line 51

SOLVE SUMMARY

MODEL InventoryProblem OBJECTIVE L

TYPE MIP DIRECTION MINIMIZE

SOLVER CBC FROM LINE 51

**** SOLVER STATUS 1 Normal Completion

**** MODEL STATUS 8 Integer Solution

**** OBJECTIVE VALUE 4.8000