KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

DEPARTMENT OF MATHEMATICS

TOPIC: THE OPTIMAL PRODUCTION-TRANSPORTATION PROBLEM OF LATEX FOAM GHANA LTD.

BY

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DECLARATION

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

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To the family of Mr. Joseph and Madam Anna (**Anna Store**) D**/SO II**.

I REALLY APPRECIATE YOUR KINDNESS

ABSTRACT

Manufacturing firms are tasked to produce to meet market demand at a minimum cost. Production and transportation are the major components of total cost to such firms. Coordinating production and distribution functions of such firms is seen as a step towards cost optimization. Latex Foam Ghana. Ltd. was incorporated in March, 1969 to produce quality foam products for the bedding and furniture Industry. In this thesis, we assume that the customers' monthly demand for high density mattress as well as the monthly production capacities of each plant is known. We consider the problem of finding an optimal monthly production program for each plant as well as the optimal monthly transportation of products to customers for which the sum of the production and transportation costs is minimized. We solve the production and transportation planning problems sequentially each by the transportation model for the available data from Latex Foam Ghana Ltd for the 2012 operation year. As a result we get a complete solution consisting of production and transportation plans. The study revealed that with the introduction this model, management could reduce production and transportation cost by 43% and 38% respectively. The model is useful for annual budget planning and financial planning. The proposed model solution has demonstrated improvement in cost optimization as compared to the rule-of-thumb based planning.

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LIST OF ABBREVIATIONS

A/R	**ASHANTI REGION**
ACC PLT	**ACCRA PLANT**
ACC WHS	**ACCRA WAREHOUSE**
AUG	**AUGUST**
B/R	**BRONG –AHAFO REGION**
C/R	**CENTRAL REGION**
DEC	**DECEMBER**
E/R	**EASTERN REGION**
FEB	**FEBUARY**
GA/R	**GREATER ACCRA REGION**
JAN	**JANUARY**
JIT	**JUST IN TIME PRODUCTION**
KSI PLT	**KUMASI PLANT**
KSI WHS	**KIMASI WAREHOUSE**
LP	**LEAN PRODUCTION**
MAR	**MARCH**
MP	**MASS PRODUCTION**
N/R	**NORTHERN REGION**
NOV	**NOVEMBER**
OCT	**OCTOBER**
PPC	**PRODUCTION PLANNING AND CONTROL**
PTP	**PRODUCTION-TRANSPORTATION PROPLEM**
SEPT	**SEPTEMBER**
UE/R	**UPPER EAST REGION**
UW/R	**UPPER WEST REGION**
V/R	**VOLTA REGION**
W/R	**WESTERN REGION**

CHAPTER 1

INTRODUCTION

The problems of producing goods and transporting them to meet the demands of final consumers in a satisfactory way at a minimized cost to the producer play an important role in the management of many manufacturing industries, and its adequate programming may produce significant profit.

A common problem for large manufacturing firms with geographically wide distribution is the need to find a tactical plan (monthly or quarterly plan) for goods production, which maximizes the total supply chain distribution. The desired optimal plan is the one that simultaneously calculates (a) production mix at plants and (b) secondary transport allocation from warehouses customers. It is assumed that materials and resources are available at their release dates at the producers' site; the producer should process them in accordance with technological constraints; finally, finished goods should be delivered to various warehouses by their due dates. The general problem in such a situation is how to determine a producer's production schedule that meets all pre-determined demand and the transportation of products to customers satisfying the demand at various destinations at a total minimum cost. This calls for the introduction of the production-transportation technique into the production planning process.

The production-transportation problem (PTP) is one of the very important problems in management science, which needs a serious attention in the continuous production industries. It is assumed that the customers' demand for each product in a short term planning period as well as the unit transportation costs from various plants to various destinations are known.

Now the PTP consists of determining producers' production schedule as well as the transportation of products to the destinations at a minimal cost (which is production cost, storage cost and transportation cost), which meets the predetermined customers' demand at a minimum cost.

1.1.BACKGROUND OF THE STUDY

The background of this study will look at the profile of the study area, the production system, the transportation problem, the pre-industrial production-transportation era and the production-transportation network today.

1.1.1 PROFILE OF THE STUDY AREA

Latex Foam Rubber Products Limited is a manufacturer and exporter of polyurethane flexible foam, spring mattresses and pillows.

The company was incorporated on March 8th, 1969 to produce quality foam products for the bedding and furniture Industry. The company entered the market using the Dunlop Technology under license from the Dunlop Company for the production of its products. The technology gave Latex Foam the desired push in quality in the rather traditional market at the time. Since then, the company has not relented in its efforts to assert itself in the Foam Industry.

In 1972, three years after its inception, Latex Foam started the production of Spring Interior Mattresses. It is worth mentioning that both the Interior production and assembly of the unit springs for the mattresses were done at the factory premises.

The company had grown to become one of the strongest forces in the West African sub-region, with factories in Ghana, Niger and Burkina Faso. Their products are also shipped to Togo, Mali, Benin Republic, Ivory Coast and Angola, making it one of the premium suppliers of polyurethane foam products in West Africa. Latex Foam products are sought by furniture upholstery manufacturers, assembly plants, department stores, hotels, hospitals, government institutions and the general public.

There are two factories in Ghana located in Accra (head quarters) and Kumasi. The Kumasi plant was established on the 12th of September, 1996 with the aim of increasing its proximity to its numerous customers in the northern sector of Ghana. When compared in terms of capacity the Accra plant is one and half times the capacity of the Kumasi plant.

Latex Foam Ghana Limited has stood the test of time and is the oldest in the industry. It is also the leading manufacturer of quality Foam products in Ghana and West Africa. Their products are enjoyed with maximum satisfaction in several institutions, hotels, corporate bodies and the general public. The company has wholesale and retail shops throughout Ghana and also in Togo, La Cote d'Ivoire, Mali and Benin and also have show rooms in Tamale (Central and Aboabo), Sunyani, Tema, Takoradi and Kumasi and several depots nationwide. Their products cater for all levels of society irrespective of social-economic backgrounds. With Latex Foam products, you are sure to have great value for your money and lasting benefits for your investment. The main objective of the company is to continue to be the leading manufacturer of quality foam products and also satisfy its numerous customers in the most effective manner.

1.1.2THE PRODUCTION SYSTEM

The production system of an organization is that part, which produces products of an organization. It is that activity whereby resources, flowing within a defined system, are combined and transformed in a controlled manner to add value in accordance with the policies communicated by management. All production systems, when viewed at the most abstract level, might be said to be "transformation processes"—processes that transform resources into useful goods and services. The transformation process typically uses common resources such as labour, capital (machinery, materials, etc.), and space (land, buildings, etc.) to effect a change. These resources are the “factors of production” and usually refer to as land, labour, capital and entrepreneur. Production managers refer to them as the “five M's”: men, machines, methods, materials, and money (Encyclopedia Britannica, 2010a).

When viewed as a process, production is seen as any activity that increases the similarity between the patterns of demand for goods and services, and the quantity, form, and distribution of these goods and services available to the market place (Moffatt, 2011).

The basic production system is classified into three: the batch, the continuous, and the project production systems. The first two are often found in combination. It may be further characterized by flows (channels of movement) in the process: both the physical flow of materials, work in the intermediate stages of manufacturing, and finished goods; and the flow of information and the inevitable paperwork that carry and accompany the physical flow. The physical flows are subject to the constraints of the capacity of the production system, which also limits the system's ability to meet output expectations. Similarly, the capacity of the information-handling channel of the production system may also be an important measure of a system's output. The capacity of the system is designed to be a function of the amount of available capital, the demand forecast for the output of the facility, and many other minor factors. It’s the major factor in determining whether output expectations can be met. It can be adjusted by hiring or firing workers, by scheduling overtime or cutting back on work hours, by adding or shutting down machines or whole departments or areas of the facility, or by changing the rate of production within reasonable limits. If the required production levels fall below that rate, operators and machines are being inefficiently used; and if the rate goes too high, operators must work overtime, machine maintenance cannot keep up, breakdowns occur, and the costs of production rise. Thus, it is extremely important to anticipate production demands accurately (Encyclopedia Britannica, 2010b).

Production firms endeavour to produce goods as cheaply as possible by taking the quality of the product and the prices of the productive factors in to consideration. The firm's task is to determine the cheapest combination of factors of production that can produce the desired output. This task is best understood in terms of what is called the production function, *i.e.,* an equation that expresses the relationship between the quantities of productive factors used and the amount of product obtained. It states the amount of product that can be obtained from every combination of factors, assuming that the most efficient available methods of production are used. It can also be used to determine the cheapest combination of productive factors that can be used to produce a given output. This relationship can be written mathematically as

$y = f(x_1, x_2, \ldots, x_n; k_1, k_2, \ldots, k_m)$. Here, y denotes the quantity of output. The firm is presumed to use n variable factors of production. In the formula the quantity of the first variable factor is denoted by x_1 and so on. The firm is also presumed to use m fixed factors of production. The available quantity of the first fixed factor is indicated in the formula by k_1 and so on. The entire formula expresses the amount of output that results when specified quantities of factors are employed. It must be noted that though the quantities of the factors determine the quantity of output, the reverse is not true, and as a general rule there will be many combinations of productive factors that could be used to produce the same output. Finding the cheapest of these is the problem of cost minimization. The cost of production is simply the sum of the costs of all of the various factors. It can be written as:

$$C = p_1x_1 + \cdots + p_nx_n + r_1k_1 + \cdots + r_nk_n,$$

where $p1$ denotes the price of a unit of the first variable factor, r_1 denotes the seasonal cost of owning and maintaining the first fixed factor, and so on.

1.1.3 THE TRANSPORTATION PROBLEM

The transportation industry facilitates the movement of goods for the purposes of trade, production and consumption. Good transportation systems are often described as satisfying several quality factors such as cost, time and length (Angus, 2005).

Transportation problems are primarily concerned with the optimal (best possible) way in which a product produced at different factories or plants (called supply origins) can be transported to a number of warehouses (called demand destinations). Transportation problems arise whenever there is a physical movement of goods through a variety of channels of distribution (wholesalers, retailers, distributors etc.); there is therefore a need to minimize the cost of transportation so as to increase the profit on sales.

It aims at providing assistance to the top management in ascertaining how many units of a particular product should be transported from each supply origin to each demand destination so that the total prevailing demand for the company's product is satisfied, while at the same time the total transportation cost is minimized.

1.1.4THE PRE-INDUSTRIAL PRODUCTION-TRANSPORTATION ERA

During the pre-industrial era, households were the major sites of production. It was characterized by craft production, which proved itself as the most effective system of production (Sriariyawat and Zunder, 2009).

Goods were produced by highly skilled craftsmen who often prepared their basic raw materials, carried the product through each of the stages of manufacturing, and ended up with the finished product. Typically, the craftsman spent several years at apprenticeship learning each aspect of his trade; often he designed and made his own tools. He was identified with his product and his craft, enjoyed a close association with his customers, and had a clear understanding of his contribution and his position in society. At this point in time, the methods and procedures used to organize human labour, to plan and control the flow of work, and to handle the myriad details on the shop floor were largely informal and were based on historical patterns and precedents (Encyclopedia Britannica, 2010c).

It was characterized by low productivity, high cost of production and low or no cost of transportation. Production was labour intensive and as a result time wasting.

1.1.5 THE INDUSTRIAL REVOLUTION

In the age of knowledge, economic and information technology, the household method of production could not satisfy the increasing consumer needs. This led to an acceleration of technological change, occasioned by the scientific revolution characterized by an ability to devise new industrial methods faster than previously possible.

The industrial revolution was a period in the late 18^{th} and early 19^{th} centuries (Maddison, 2003). It successfully reduced costs, manpower and promoted mass production through the use of machinery (Yin, 2009).

It was championed by Taylor in 1881 when he began studies of the organization of manufacturing operations that subsequently formed the foundation of modern production planning. By the middle of the 19th century the general concepts of division of labour, machine-assisted manufacture, and assembly of standardized parts were well established. Large factories were in operation on both sides of the Atlantic, and some industries, such as textiles and steel, were using processes, machinery, and equipment that would be recognizable even in the late 20th century. The growth of manufacturing was accelerated by the rapid expansion of rail, barge, ship, and road transportation. The new transport companies not only enabled factories to obtain raw materials and to ship finished products over increasingly large distances, but they also created a substantial demand for the output of the new industries (Encyclopedia Britannica, 2010d).

1.1.6 PRODUCTION AND TRANSPORTATION TODAY

The effect of industrialization coupled with an increased in population has caused manufacturing firms to shift away from the household method of production to a mass production (MP) system in order to satisfy the unlimited needs of consumers.

MP is the name given to the method of producing goods in large quantities at a low cost per unit (Hounshell, 1984). It is as a result of the application of specialization, division of labour and standardization of parts to the manufacture of goods. Such manufacturing processes attain high rates of output at low unit cost, with lower rates expected as volume rises. It is applicable in non manufacturing industries and became the most efficient production system in the middle of the 20^{th} century (Encyclopedia Britannica, 2010e).

During the decline period of MP, the concept of Lean Production (LP) also known in western countries as Just-in-Time (JIT) manufacturing was introduced by a Japanese automotive company, Toyota after the Second World War (Womack et al., 1991).

LP is regarded as a production strategy that strives to improve a business return on investment by reducing in process inventory and associated carrying cost. It's described as a system of production, where actual orders serve as a signal as to when a product should be produced. This saves warehouse space and costs. This production practice considers the expenditures of resources for any goal other than the creation of valve for the end customer to be wasteful, and thus a target for eliminating waste (Womack and Jones, 2003).

Internationalization of production today, requires an increasing focus on transportation, inventory, logistics on production planning and global sourcing decisions. Clearly, a primary driver to internationalization is the desire for lower cost of production. Lower cost of production directly decreases the investment per unit in work in process and finished goods inventory. Meanwhile, these inventories are travelling over dramatically increasing the total transportation cost per unit of finished products. As a result, transportation cost composes a large percentage of the total product cost of internationally produced goods than their domestic counterparts. This pattern is apparent when observing the steady growth in freight transportation expenditures as a percentage of total manufacturing cost throughout the 1990's. With higher fuel prices spiking up transportation cost, this pattern promises to continue into the future (Gorman, 2006).

1.2 STATEMENT OF THE PROBLEM

Manufacturing firms produce and deliver products to their customers using a logistics distribution network. Such networks typically consist of product flows from the producers to the customers through distribution centres (warehouses or depots).

Most researchers have established that the cost of production is the largest cost component in almost every manufacturing firm followed by transportation and inventory costs. The firms generally need to make decisions on production planning, inventory levels, and transportation in each level of the logistics distribution network in such a way that customer's demand is satisfied at a minimum cost. This calls for the introduction of mathematical techniques into the production planning model.

The production problem involves a single product, which is to be manufactured over a number of successive time periods to meet pre-specified demands. Once manufactured, units of product can be either shipped or stored. Both production cost and storage cost are known. The objective is to determine a production schedule, which will meet all future demands at minimum total cost (which is total production cost plus total storage cost, as total shipping cost is presumed fixed. The production problem is basically the optimization of output subject to cost minimization.

The transportation problem is to transport the commodity from various sources to the various destinations at a minimum cost while satisfying constraints of productive capacity and demands.

This thesis seeks to determine the optimal monthly production plan of Latex Foam Ghana Ltd to meet its pre-determined demands and the optimal transportation of goods to meet customers demand at a minimum cost.

1.3 OBJECTIVES OF THE STUDY

The high cost of production and transportation is a major hackle to many manufacturing firms. This has called for a study to explore ways to effectively manage production planning related problems. This technique aims at profit maximization and cost minimization.

A school of thought is of the view that profit is not maximized since supply does not meet demand. Another is also of the view that the unit cost of transporting a product to a destination is not minimized since supply does not also meet demand. We seek to delve into the PTP of Latex Foam Ghana ltd.

The main objective of the study is to use the transportation model to determine:

(i) an optimal monthly production plan that meet all pre-determined demand at a minimal cost

(ii) the optimal monthly transportation of goods from warehouses to depots to meet customers demand at a minimum cost

1.4 RESEARCH METHODOLOGY

The production and transportation planning problems are solved in a sequential fashion.

We first solve the production planning model by the transportation model and obtain a optimal monthly production plan consisting of production mix at plants. Using the monthly production mix at plants as supply and the monthly requirement at depots as demand, we solve the transportation model. As a result we get a complete solution consisting of production and transportation plans.

Data on production and transportation was obtained from the company's production and marketing managers respectively and analyzed by using QM for windows computer software. Literature on the topic was done which gave insight into what has already been done and the knowledge gab to be filled. Several mathematical concepts and theories were examined and finally the selection of the most appropriate approach.

1.5 JUSTIFICATION

An increase in competition forces manufacturing firms to develop manufacturing capabilities that enable them to embrace changes in manufacturing systems to increase efficiency, productivity, and offer superior value to the customer. In addition to profit maximization, the application of modern techniques of production has led to major improvements in uniformity and quality. Such manufacturing processes attain high rates of output at low unit cost, with lower rates expected as volume rises. It must be emphasized, that on signal system of forecasting, preplanning, planning and control is suited to all industrial enterprises, no matter how well it may meet its objectives. Optimization models are widely efficient for providing decision support in this context.

1.6 SCOPE OF THE PROBLEM

The study primarily focuses on determining a monthly production schedule that will meet the pre-determined demand of customers and the optimal transport of products from warehouses to depots. Due to time and financial constraints only one firm was chosen on merit.

The study took place at Latex Foam Ghana Ltd. Most firms were not considered due to the following reasons:

(i) Lack of adequate records.

(ii) Some have only one plant.

1.7 THE MANUFACTURING ENVIRONMENT AND MEANS OF TRANSPORTATION IN GHANA

Compared to other Sub-Saharan African countries, Ghana is endowed with rich natural resources and skilled labour during independence. Immediately after independence, Ghana pursued a reward-oriented state-directed industrialization policy to modernize its economy. These policies were pursued because Ghana, at that time, lacked a strong domestic entrepreneurial know-how and did not want to depend on foreign investment for development (Adu, 1999). Inefficiencies in the management of the state-owned manufacturing enterprises has however, led to huge excess capacity. Today, most manufacturing firms in Ghana are privately owned.

There are four major manufacturing industries in Ghana, namely wood working, metal working food processing, and textiles and garments and together they comprise 70% of manufacturing employers in Ghana. The sector has undergone several changes since the economic recovery programme of 1983 (CSAE and University of Ghana, 1994).

The characteristics of production today, are low costs, mass production, considerable use of machinery and labour savings and the adoption of modern technological methods of production as well as the use of appropriate optimization skills with modern algorithmic features and the application of JIT system of production. Manufacturing firms are becoming more customer and competitor-focused by improving quality, relationships with customers and suppliers, and distribution and delivery of their products. These strategic initiatives are being undertaken so as to reduce operating cost, increase demand, and to deal with heightened competition both on the domestic and foreign markets.

Transportation in Ghana is accomplished by road, rail, air and water.

Transport is essential so that products can be moved to places where they are required; to factories where they are manufactured or to markets where they are sold to the people. Ghana's transportation and communication networks are centered in the southern regions especially the areas in which cocoa and timber are produced. The northern and central areas are connected through a major road system; some areas however remain relatively isolated. The deterioration of the country's transportation and communications networks has been blamed for impeding the distribution of economic inputs and food as well as the transport of crucial exports.

1.7.1 ROAD TRANSPORT IN GHANA

Road transport is by far the dominant carrier of freight and passengers in Ghana's land transport system. It carries over 95% of all passenger and freight traffic and reaches most communities, including the rural poor and is classified under three categories of trunk roads, urban roads, and feeder roads. The Ghana Highway Authority is tasked with developing and maintaining the country's trunk road network totaling thirteen thousand three hundred and sixty-seven (13,367) km, which makes up 33% of Ghana's total road network of forty thousand one hundred and eighty-six (40,186) km (Ghana Highway Authority, 2011).

1.7.2 RAIL TRANSPORT IN GHANA

Rail transport facilitates long distance travel and the transport of bulky goods that cannot easily be transported by motor vehicles. Additionally, it is believed to be one of the safest forms of transport. The chances of accidents and breakdown are minimal as compared to other modes of transport. Moreover, it helps in the management of road traffic.

The railway system in Ghana has historically been confined to the plains south of the barrier range of mountains north of the city of Kumasi. However, a thousand and sixty-seven (1,067) mm (3 ft 6 in) narrow gauge railway, totaling nine- hundred and thirty-five (935) km, is presently undergoing major rehabilitation and inroads to the interior are now being made. In Ghana, most of the lines are single tracked, and in 1997 it was estimated that thirty-two (32) km were double tracked. There are no rail links with adjoining countries (Ghana Railway Corporation, 2011).

1.7.3 AIR TRANSPORT IN GHANA

Domestic air transport in Ghana has in recent times received a little attention. This is normally patronized by the rich because it is relatively expensive. It is safe and very fast.

Ghana has twelve landing fields, six with hard surfaced runaways. The most important are Kotoka International Airport in Accra and airports at Sekondi-Takoradi, Kumasi and Tamale that serve domestic air traffic (Clark, 1994).

1.7.4 WATER TRANSPORT IN GHANA

Domestic water transport in Ghana is as a result of non availability of road network connecting the source and destination in question, and its cost effectiveness as compared to other modes of transportation. This mode of transport is essential for passenger, liquid and dry cargo. Relatively short distance travel in the farming communities is normally done by canoes often powered by man. Long distance travel often involves Passenger and cargo transport. The types of boats used under this mode are normally powered by internal combustion engines assisted by gear box and propellers. Passenger boat is normally used to transport passengers, charcoal and other food items like salt, fish and yams from the southern to the northern part of Ghana and vice versa. Also cargo boats aided by tug boats normally transport heavy industrial products like cement, fuel and other minerals in the same direction.

The Volta, Ankobra and Tano rivers provide one-hundred and sixty- eight (168) km of perennial navigation for launches and lighters; Lake Volta provides one thousand one hundred and twenty- five (1,125) km of arterial and feeder waterway. There are ferries on Lake Volta at Yeji and KwadjoKrom. There are ports on the Atlantic Ocean at Takoradi and Tema for international transactions (Ghana marine transport, 2011).

1.8 LIMITATION OF THE STUDY

Although, Latex foam Ghana has a lot of products on its product line, the scope of this study is limited to the production and transportation problem of the High Density Honeymoon Mattress produced for domestic purposes only. Different cost elements such as: production, inventory, transportation, royalties, advertisement, taxes such as excise duty and VAT and other practical constraints are normally considered in production planning models, the study takes into consideration the first three.

The proposed model under this study is limited to the available data used for the study.

1.9 THESIS ORGANISATION

The historical background of PTP, objectives, scope and limitations of the study were covered in Chapter 1. In Chapter 2 we shall put forward pertinent literature in the area of production and transportation. Research methodology is detailed in Chapter 3. Data collection and analysis are presented in Chapter 4. Findings, conclusion and recommendations are discussed in Chapter 5.

CHAPTER 2

LITERATURE REVIEW

2.0 INTRODUCTION

In this chapter, we shall review some literature in the area of production and transportation.

The chapter is organized as follows: literature review on production scheduling and that of transportation problem and on integrating production and transportation problems are presented.

2.1 PRODUCTION SCHEDULING, A FUNCTION OF PRODUCTION PLANNING AND CONTROL

Production is an organized activity of converting raw materials into useful products.

Production planning is done in order to anticipate possible difficulties and decide in advance as to how the production should be carried out in the best and economical way.

Planning is the preparation activity while control is the post-operation function. Both of them are so closely related that they are treated as Siamese twins. Planning sets the objectives, goals, targets on the basis of available resources with their given constraints. Control is the integral part of effective planning. Similarly, control involves assessment of the performance; such assessment can be made effectively only when some standards are set in advance. Planning involves setting up to such standards. The controlling is made by comparing the actual performance with these present standards and deviations are ascertained and analyzed (http://www.scribd.com/doc).

Production Planning and Control (PPC) address decisions on the acquisition, utilization and allocation of production resources to satisfy customer requirements in the most efficient and effective way. Typical decisions include work force level, production lot sizes, assignment of overtime and sequencing of production runs. The identification of the relevant costs is also an important issue in production planning. One typically needs to determine the variable production costs, including setup related costs, inventory holding costs, and any relevant resource acquisition costs. There might also be costs associated with imperfect customer service, such as when demand is backordered. Optimization models are widely applicable for providing decision support in this context (Graves, 1999a).

Major cost factors likely to come across within a supply chain include production, transportation, inventory and material holding costs. The portion of these costs within the total cost varies from industries. Production cost is however, the largest followed by transportation and inventory cost (Chen, 1997).

Cost of production per unit is the costs associated with production divided by the number of units produced. The difficulty in calculating the cost of production is usually thought to be in assembling all the costs associated with production and there are volumes written about the correct procedures (see http://www.thetimes100.co.uk;).The question of the relationship of the cost of production to the price of the product is seldom discussed. One reason for this is that the relationship seems very straightforward. In single product enterprises, the cost of production can be compared directly to the price of the product, regardless of the method used to calculate the cost of production (Gary, 1998).

In many planning contexts, an important issue is to set a planning hierarchy. That is, one structures the planning process in a hierarchical way by ordering the decisions according to their relative importance (Graves, 1999b).

Hax and Meal (1975) introduced the concept of hierarchical production planning and provide a specific framework for this, whereby there is an optimization model with each level of the hierarchy. Each optimization model imposes a constraint on the model at the next level of the hierarchy. Bitran and Tirupati (1993) provided a comprehensive survey of hierarchical planning methods and models.

According to Slack et al., (2002) the intention of the PPC is to guarantee that the processes of the production occur efficiently and that they produce products and services as required by the consumers.

One of the functions of the production planning and control system is scheduling, where each task is placed with indication, in the time, of the work rank that will execute it (Heizer and Render, 2001).

Through the late 1800s, manufacturing firms were concerned with maximizing the productivity of the expensive equipment in the factory. Keeping utilization high was an important objective. Foremen ruled their shops, coordinating all of the activities needed for the limited number of products for which they were responsible. They hired operators, purchased materials, managed production, and delivered the product. They were experts with superior technical skills, and they (not a separate staff of clerks) planned production. Even as factories grew, they were just bigger, not more complex (Herrmann, 2008). Production scheduling started simply also. Schedules, when used at all, listed only when work on an order should begin or when the order is due. They didn't provide any information about how long the total order should take or about the time required for individual operations (Roscoe and Freark, 1971). This type of schedule was widely used before useful formal methods became available (and can still be found in some small or poorly run shops). Around the beginning of the 1890, manufacturing firms started to make a wider range of products, and this variety led to complexity that was more than the foremen could handle. Scientific management was the rational response to gain control of this complexity, hence the rise of the formal systems of production scheduling (Herrmann, 2008).

Taylor's separation of planning from execution justified the use of formal scheduling methods, which became critical as manufacturing organizations grew in complexity. Taylor proposed the production planning office around the time of World War I. Many individuals were required to create plans, manage inventory, and monitor operations. (Computers would take over many of these functions decades later.) The "production clerk" created a master production schedule based on firm orders and capacity. The "order of work clerk" issued shop orders and released material to the shop (Wilson, 2000).

Computer-based production scheduling emerged later. Wight (1984) lists three key factors that led to the successful use of computers in manufacturing:

1) IBM developed the Production Information and Control System starting in 1965.
2) The implementation of this and similar systems led to practical knowledge about using computers.
3) Researchers systematically compared these experiences and developed new ideas on production management.

Modern computer-based scheduling systems offer numerous features for creating, evaluating, and manipulating production schedules with ease.

According to Yen and Pinedo, (1994), the three primary components of a scheduling system are the database, the scheduling engine, and the user interface.

The production schedule (PS) is derived from the production plan; it is a plan that authorizes the operations function to produce a certain quantity of an item within a specified time frame. In a large firm, it is drawn in the production planning department, whereas, within a small firm, a PS could originate with a lone production scheduler or even a line supervisor. It has three primary goals: avoiding lateness in job completion, minimizes throughput times, and the utilization of work centres (Kreipl and Pinedo, 2004).

PS is done by others in the firm but with the assistance of the logistics staff in an attempt to balance demand for products with plant capacity and availability of inputs. Inbound materials and components must be scheduled to fit into the production process. The production process itself is scheduled to fulfill existing and planned orders. Manufactured products must also be scheduled for shipment to the various destinations (Encyclopedia Britannica, 2010f).

Scheduling is an important tool for manufacturing and engineering, where it can have a major impact on the productivity of a process. It is purposed to minimize the production time and costs, by telling a production facility when to make, with which staff, and on which equipment and also aims to maximize the efficiency of the operation and reduce costs. Most companies use backward and forward scheduling to allocate plant and machinery resources, plan human resources, plan production processes and purchase materials. Forward scheduling is planning the tasks from the date resources become available to determine the shipping date or the due date whereas backward scheduling is planning the tasks from the due date or required-by date to determine the start date and/or any changes in capacity required (http://en.wikipedia.org/wiki/Scheduling).

Scheduling decisions may have significant impact on overall company profitability by defining how capital is utilized, the operating costs required, and the ability to meet due dates (Niem, 2000).

An effective PS provides the basis for making good use of manufacturing resources, making customer delivery promises, resolving trade–offs between manufacturing and sales, and attaining the firm’s strategic objectives as reflecting in the sales and operations plan (Vollmann,2005) whereas poor one may cause manufacturing delays (Kathryn and Xuying, 2004).

The scheduling depends on the sequencing of the production that specifies the order in which the tasks must be executed.

Gaither and Frazier (2002) presented some rules to define priorities at the moment of the sequencing. Vollmann et al. (2005) presented quite a few sequencing rules (for determining the sequence in which production orders are to be run in the production schedule) in operations scheduling.

PS is a part of operational research which relies on combinational optimization solved by discrete methods. This wide area covers different variety of problems like; vehicle routing problem, bin packing problem and job priority. In order to solve these problems, operational research applies two main principles: exact methods, which provide the absolute best solution but solve only small sized problems, and approximate methods, which provide only good solution but solve near real life sized problem. The second category provides various methods divided into: problem dedicated methods called heuristics and general method called meta-heuristics. Many of these meta-heuristic methods are leading the literature of production scheduling for past two decades, like; Genetic Algorithm, Neural Network, and Fuzzy Logic (Nehzati and Ismail, 2011). Exact methods, such as mixed-integer linear programming and non-linear programming are enumerative techniques that ensure that the schedule provides an optimal solution for simple cases of the scheduling problem and for larger and more complicated problems; it is recommended that approximation methods also known as heuristics must be mathematically proven to generate a solution within a certain percentage of optimality no matter what problem instance is solved to obtain near-optimal results (Sipper and Bulfin 1997).

In general, exact methods depend on characteristics of the objective function (e.g. strictly integer values) and specific constraint formulations (e.g. only single-mode tasks). Many of the constraints commonly found in real scheduling problems do not lend themselves well to traditional operations research or math programming techniques (Davis, 1971)

Whereas exact solution methods are guaranteed to find the optimal solution (if one exists), heuristic methods sometimes find optimal solutions, but more often find simply "good" solutions. Heuristic methods typically require far less time and/or space than exact methods. The heuristics specify how to make a decision given a particular situation; heuristics are rules for deciding which action to take (Wall, 1996)

Again, scheduling methods, such as Simulated Annealing (SA) and tabu search, provide at least local optimal solutions (Romeo and Vincentelli, 1991). SA is very attractive for solving large-scale production scheduling processes because of its generality and simplicity (Ku and Karimi, 1991). It's however, a very time consuming technique (Boissel and Kantor 1995).

Palmer (1995) described an approach to manufacturing planning that seeks to integrate both process planning and scheduling by a solution technique based on SA. The author was motivated by the fact that separating these two related tasks, as is the common practice, can impose constraints that substantially reduce the quality of the final schedule. These constraints arise from premature decisions regarding operation sequence and allocation of manufacturing resources. The author performed a detailed empirical comparison between SA and the popular technique of dispatching rules and achieved two distinct sets of example problems, show that SA can produce solutions of significantly higher quality than those achieved through a published dispatching rule approach.

Felinskas and Sakalauskas (2008) explored the application of SA method combined with variable neighborhood to schedule optimization in a manufacturing industry. The authors particularly considered job scheduling and optimization algorithms related to resources, time and other constraints. The aim was to find such schedule, which would meet the requirements of job priority relations, resource constraints, minimizing it by a criterion of project's finishing time.

On a real case study concerning a Tunisian firm, Loukil et al**.** (2010) proposed a multi-objective SA approach to tackle the problem of production scheduling in a flexible job-shop with particular constraints: batch production; existence of two steps: production of several sub-products followed by the assembly of the final product; possible overlaps for the processing periods of two successive operations of the same job. The objective was to propose to the manager an approximation of the set of efficient schedules such as the makespan, the mean completion time, the maximal tardiness and the mean tardiness.

The GA is also another technique to optimize highly complex functions based on the mechanisms of natural evolution and genetics (Haupt and Haupt, 1998).The GA refers to a model introduced and investigated by Holland and his students. It is an evolutionary algorithm inspired by Darwin's theory of 'the survival of the fittest (DEJONG, 1975).

GA uses the concept of survival of the fittest by rejecting strings that are not good enough to take part in producing the next generation. A new set of strings is created in every generation using parts of the fittest strings from the previous generation(s). Since survival of the fittest is enforced, strings become better with each generation. The best value is selected as the optimal solution after creation of a few generations (Vose, 1998).

A good deal of previous research on GAs in scheduling concentrates on the static job shop problem (Mattfeld, 1996). The transfer of GA experiences to production control was first approached in Bierwirt et al., (1995) and has been taken up recently in Lin et al., (1997) by addressing the GA effectiveness.

Vieira et al., (2002) presented the result of the master production planning elaborated through GA. The objective was to generate an optimized plan of production, taking into account costs of production, supplies, set-ups, allied to parameters on stock levels and availability of capacity and materials.

Villar and Tubino (2001) used GA to define physical arrangements in industrial facilities, objectifying prevention and combat of fire.

Ozgur and Brown (2009) listed a number of obstacles in relation to production scheduling and suggested ways to overcome them.

2.2 THE TRANSPORTATION PROBLEM

Transportation networks are complex, large-scale systems, and come in a variety of forms, such as road, rail, air, and waterway networks. Transportation networks provide the foundation for the functioning of our economies and societies through the movement of people, goods, and services (Nagurney, 2004).

A competitive transportation network must answer to the economic requirements. An important economic issue is the investment decision regarding transportation network improvement that involves the interaction of two parties with own objectives: the network planner and the network users (Dinu and odagescu, 2011).

The transportation problem is one of the subclasses of linear programming problems for which simple and practical computational procedures have been developed to take advantage of the special structure of the problem with the objective to transport various quantities of a single homogeneous product that are initially stored at various origins, to different destinations in such a way that the total transportation cost is minimum.

Hitchcock (1941) developed the basic traditional transportation problem, in which the objective is to minimize the cost of transportation of various amounts of a single homogeneous commodity from different sources to different destination.

Koopman (1947) based on the work done earlier by Hitchcock, led an independent research on the tendencies of linear programs for the study of problems in Economics. Hence, referring to the classical case of the transportation problem as Hitchcock-Koopman's transportation problem which aims at total transport cost minimization associated with moving a commodity to its final destination.

The transportation problem however, could be solved for optimally as an answer to complex business problem only in 1951, when. Dantzig applied the concept of Linear Programming in solving the transportation model (http://businessmanagementcourses.org).

Hammer (1969) introduced a concept of time-minimizing algorithm for solving the transportation problem.

In a related development, a school of that is of the view that the objective of the transportation problem is to minimize total transportation cost plus expected penalty costs arising from stochastic transportation problems. This is seen as an iterative method for the solution of time-minimizing transportation problems.

Bhatia et al., (1974) discussed such a problem with stochastic demand and penalties for over supply and under supply demand.

Wilson (1975) used a linear approximation method to solve the stochastic transportation problem as a capacitated transportation problem.

2.3 INTEGRATING PRODUCTION AND TRANSPORTATION PROBLEMS

Historically, production and transportation logistics have been dealt with separately both in industry and academia. In industry, a production plan is developed and then a transportation plan is worked out by either the transportation department of a company, or a third party transportation provider, who adheres to an established shipping plan aiming at reducing transportation costs (Kadir et al., 1998).

Even though sophisticated heuristic approaches had achieved exceptional results in handling production and transportation problems in isolation, they are not able to achieve the competitiveness obtained by a combined view of production and transportation systems. An integrated alignment of production and transportation scheduling at the operational level holds a great potential for strengthening the competitiveness of supply chains (Liu, 2003).

The integration of production and distribution functions of a manufacturing firm, as a step towards enterprise integration, has become more urgent than ever before. This is because of the advent of advanced manufacturing technologies, the emphasis on meeting or exceeding customer needs, and the strategic impact of shortening cycle times on almost all competitive priories of the firm. If these functions are optimized independently, the above mentioned synergistic results will be difficult to realize. It is important to determine simultaneously the overall operating levels for the production and distribution facilities in order to achieve an optimal logistic system (Youssef and Mahmoud, 1994).

The strategy of coordination and integration of the production (supply), inventory, and distribution (demand) operations is seen as the next source of competitive advantage as more and more companies become aware of their supply chain performance and the importance of their performance improvement (Thomas and Griffin, 1996).

The integration of inventory control and physical distribution brings much closer ties to the production and distribution functions in many firms, such that in the future, we may see production and logistics merging much closer in concept and practice. As companies require less and less inventory levels, models for the integrated production and transportation (distribution) problem will become more and more important (Ballou, 1992).

Most of the models presented so far have treated subsystems of production and distribution network (transportation) separately, or attempted to coordinate only parts of the whole network (Liu, 2003). The transportation cost per trip is simplified to be proportional to the amount of product shipped, instead of a fixed quantity shipped in most of these production-transportation models. Thus the optimal solution is to ship every item direct from the plants to the destination (warehouse) soon as it has been produced (Daganzo, 1991).

Hunjet et al (2002) formulated the PTP for the continuous production industry as a large-scale linear programming problem. The authors also considered the PTP with several modes of transportation and their capacities, the production–transshipment transportation problem and the multimodal PTP with capacity constraints as extensions of the PTP. They proposed an algorithm based on the combination of the penalty function method and the Frank-Wolfe's method (see Frank and Wolfe, 1956) among others to solve the PTP.

Boudia et al., (2007) developed a reactive Greedy Randomized Adaptive Search Procedure (GRASP) method for a combined production-distribution problem where the goal was to minimize the sum of three costs, namely: production, transportation and inventory costs.

Mak and Wong (1995) proposed the use of a GA to solve the inventory-production distribution problem. Their model was made up of three echelons consisting, one manufacturing plant, several suppliers and several retailers with the objective of determining the optimal stock levels, production quantities and transportation quantities simultaneously in order to minimize total system costs (production, inventory holding, shortage, and transportation costs). The problem was formulated as an integer programming, by assuming delivery costs known and fixed for every period, direct shipments between all locations and weight limits for shipping products and in every period.

Van et al., (1999) gave a mathematical formulation for single-plant, multiple-product, single-period production scheduling and distribution routing problem in the newspaper industry. The authors proposed several heuristic search algorithms, such as tabu search, reactive tabu search, and S.A. to solve the problem.

Pinedo (2005) proposed an integrated optimization model of production, inventory and distribution with the goal to coordinate important and interrelated decisions related to production schedules, inventory policy and truckload allocation. The integrated model was solved by modified Benders Decomposition Algorithm. The author applied this proposed algorithm on a real distribution problem faced by a large national manufacturer and distributor. This proves that such a complex distribution network with 22 plants, 7 distribution centres, 8 customer zones, 9 products, 16 inbound and 16 outbound shipment carriers in a 12-month planning period can be redesigned within 33 hours.

Özdamar and Yazgac (1999) considered a production-distribution model involving production and transportation decisions in a central factory and its warehouses based on the operating system of a multi-national company producing detergents in a central factory from which products are shipped to geographically distant warehouses. The model seeks to optimize the overall system cost by considering factory cost, warehouse inventory cost and transportation cost. Constraints included production capacity, inventory balance and fleet size integrity.

Haq et al, (1991) considered a three echelon system with one production facility, several warehouses and several retailers. The authors used a multi-stage model for the production facility. The problem was formulated as a mixed integer program with the objective to determine the production and distribution quantities and the inventory levels at all the locations, so as to minimize total operational cost (production, set-up and recycling costs at production stages, distribution cost.

Fumero and Vercellis (1999) develop a model for single plant production-distribution system, in which several products produced and delivered with limited available resources, for both production system and a homogeneous distribution fleet. The tradeoff is among production setup cost, inventory cost and transportation cost.

Chandra and Fisher (1994) developed a model for production-distribution system. The authors first solved a multiproduct capacitated lot-sizing problem, and then develop a delivery schedule based on the production schedule.

Blumenfeld et al., (1987) reported on the successful implementation of an optimization model that integrated scheduling of production and distribution. A work done at Delco electronics division of General motors resulted in about a 26% reduction in logistics costs.

Condotta (2007) designed a Branch-and-Bound algorithm to optimally solve the general case of the PTP. In particular, a heuristic method was design to generate feasible solutions and study two possible lower bounds as well as important dominance properties. A second Branch-and-Bound algorithm based on a more efficient branching scheme and on a problem specific lower bound was also designed.

Sahoo et al., (2011) developed an optimization based model and Decision Support System (DSS), for tactical supply chain planning for a large cement making firm in India. The DSS used Mixed Integer Linear Programming (MILP) model labeled as Manufacturing and Logistics Planner (MLP). The MLP gave a tactical plan (monthly or quarterly plan) for goods production and distribution which maximized the expected supply chain-wide contribution. The multi-time period model considered production costs, transportation costs, taxes such as excise duty, VAT and numerous practical constraints, and simultaneously calculated production mix at plants, primary transport allocation and mode selection from plants to warehouses and plants to markets, inventory stocking at warehouses, and secondary transport allocation between warehouses and markets.

(EKS¸IO˘GLU, 2002) proposed a class of optimization models that consider coordination of production, transportation and inventory decisions in a particular supply chain consisting a number of facilities and retailers. The particular scenario presented considered a set of facilities where K different product types can be produced. Products were stored at the facilities until demand occurs. Moreover, retailers are supplied by the facilities and keep no inventories. Production and transportation cost functions are considered to be of the fixed charge form. The problem is formulated as a multi- commodity network flow problem on a directed, single source graph consisting of T layers. The objective was to find the production, inventory, and transportation quantities that satisfy demand at minimum cost.

Boudia and Prins (2009) developed and applied a Mimetic Algorithm with Population Management (MA|PM) to the exact same test-instances. These instances concern a single product and 50, 100 and 200 customers in a horizon of 20 time-periods. The results showed a saving of 23 % or more, over classical decoupled optimization methods.

Lukac et al, (2008) formulated two new models of the PTP on the assumption that there were several plants at different locations producing certain number of products and large number of customers of their products where each plant can operate in several modes characterized by different quantities of products and variable production costs and customers' demand for each product during the considered time period is known. The authors considered the problem of finding the production program for each plant as well as the transportation of products to customers for which the sum of the production and transportation costs was minimized given the condition that each customer can satisfy its demand for a given type of product from one plant only. The authors also formulated the problem as a bilevel mixed-integer programming problem by introducing a hierarchy of decision making into the production-transportation problem. The bilevel programming is motivated by the fact that many planning problems contain a hierarchical decision structure where each level has independent and often conflicting objective. To the authors, bilevel programming is the simplest case of such a situation where there are only two independent decision makers located at different levels of decision making.

Gupta and Bhunia (2006) applied a real-coded Genetic Algorithm (RCGA) for integer linear programming to solve a PTP; firstly, the model was developed under the assumption that a company produces a single commodity in different factories, situated at different places. The raw material cost, production cost as well as marketing costs per unit are different for different factories. The transportation cost from a particular factory to a particular market is not fixed, but flexible. It depends upon the transported units and the capacity of transport vehicle.

Zergordi and Nia (2009) were concerned with the integration of production and transportation scheduling in a two-stage supply chain environment while considering the assignment of orders to the suppliers. The first stage contains *m* suppliers distributed in various geographic zones, and the second stage composed of *l* vehicles with different speeds and transportation capacities that transport *n* jobs from the supplier to a manufacturing company. In addition, it was assumed that each job occupies a different vehicle size and could be processed by some permissible suppliers. The problem was modeled as a mixed integer programming problem and solved by a genetic algorithm named Dynamic Genetic Algorithm (DGA). The performance of DGA was evaluated by comparing its outputs with optimum solutions for small-sized problems and to the random search approach for larger problems.

Wu et al., (2004) proposed an integrated production and transportation scheduling model based on a multi-item capacitated lot sizing and facility location type models with the objective of minimizing the total production and transportation cost. The integrated model was solved by Lagrangian Decomposition Method and the decomposed two sub-problems were further solved by GA and Simplex method respectively. Computational results showed that the overall cost was reduced by 4 % to 10 % compared with the other two sequential optimization algorithms.

Kadir et al., (1999) proposed a model that integrates production and transportation routing at the operational level with the objectives of reconciling the view points from transportation and production planning. The optimization process was viewed metaphorically as a negotiation process between a set of interrelated production facilities and a third party logistic provider. The model was solved by using a Lagrangean Decomposition Scheme.

King and Love, (1980) developed a model on the coordination of production and distribution systems by describing a coordinated system for manufacturing plants and distribution centres A work done in a major tire manufacturing company with four factories and nine major distribution centres within the five United States. Implementation of the model resulted in a massive improvement in overall lead times, customer service and average inventory levels by reducing annual costs by almost eight million dollars ($8).

Coordinating operational and logistic functions across facilities and companies is a key to supply chain integration. While the concept of integrating production and transportation planning is very important very few mathematical models try to combine and tackle these problems simultaneously.

Kadir et al., (1998) proposed an analytic study that investigated the effects of integrating production and transportation planning and studied integrated optimization models that reconciled the viewpoints from transportation and production planning and analyzed the costs introduced by coordination. Using a Lagrangean decomposition scheme, the authors demonstrated computationally the nature of the comprise between production and transportation decisions, and the value of integration.

2.4 SUMMARY

In this chapter we have reviewed literature on production scheduling and that of transportation problem and on integrating production and transportation sub problems.

Research methodology is detailed in the next chapter.

CHAPTER 3

METHODOLOGY

3.0 INTRODUCTION

In this Chapter, the production and transportation problems and the various methods of solving transportation problems are discussed.

3.1 THE PRODUCTION PROBLEM

The Production problem is converted into transportation problem by considering the time periods during which production can take place as source, and the time periods in which units will be shipped as destinations. The production capacities are taken to be supplies. Therefore x_{ij} denotes the number of units to be shipped during period i for shipment during time period j, and c_{ij} is the unit production cost during time period i plus the cost of storing a unit of product from time period i until time period j. since units cannot be shipped prior to being produced, c_{ij} is made prohibitively large for $i > j$ to force the corresponding x_{ij} to be zero. As a result the transportation approach is used to solve the production problem.

3.2 GRAPHICAL REPRESENTATION OF TRANSPORTATION MODEL

A commodity is being produced at the sources S_1, S_2 and S_3 and shipped to the various destinations W_1, W_2 and W_3.The transportation problem is to transport the commodity from the various sources to the various warehouses at a minimum cost while satisfying all constraints of productive capacity and demands. Graphically, the problem is represented below.

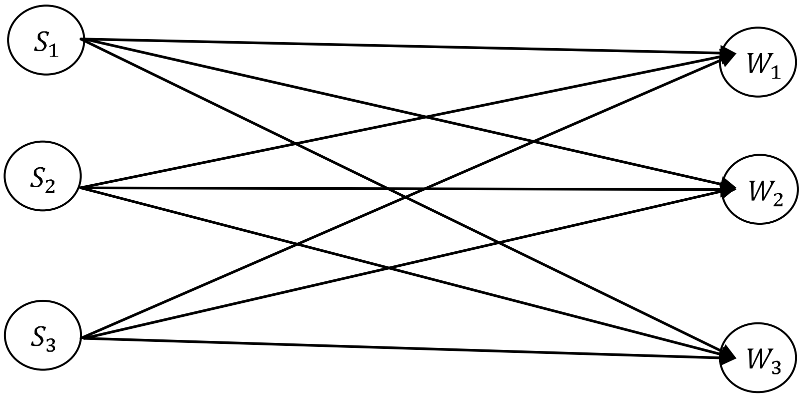


Figure 3.1 Graphical Representation of Transportation Model

3.3 MATHEMATICAL MODEL OF TRANSPORTATION PROBLEM

A commodity is being produced at the sources s_1, $s_{2,}$ $s_{3,\ldots,}s_n$ and shipped to the various destinations $w_{1,}w_{2,}.w_{3,\ldots}$, w_n The transportation problem is to transport the commodity from the various sources to the various warehouses at a minimum cost while satisfying all constraints of productive capacity and demands.

Mathematically, a transportation problem is nothing but a special linear programming problem in which the objective function is to minimize the cost of transportation subjected to the demand and supply constraints

Let

$a_i =$ quantity of the commodity available at the source s_i

b_j = demand of the commodity at destination $w_{j,}$

c_{ij}= transportation cost of a unit of commodity from source i to destination j, and

x_{ij} = quantity transported from source i to destination j.

Mathematically, the problem is

$$Minimize \qquad Z = \sum_{i=1}^{m}\sum_{j}^{n} c_{ij}x_{ij} \qquad (3.1)$$

Subject to

$$\sum_{j=1}^{m} x_{ij} \leq a_i \qquad i = 1,2,\ldots,m \qquad (3.2)$$

$$\sum_{i=1}^{n} x_{ij} \leq b_j \qquad j = 1,2,\ldots,n \qquad (3.3)$$

$$x_{ij} \geq 0, \qquad i = 1,2,\ldots m, \qquad j = 1,2,\ldots n \qquad (3.4)$$

The objective function (3.1) implies minimization of the total cost of shipping goods from source i to destination j. Constraint (3.2) stipulates that the amount of goods to be shipped from source i cannot exceed the level of supply at source i. Constraint (3.3) stipulates that the total amount of goods arriving at destination j cannot exceed the demand at destination j. Constraint (3.4) stipulates that goods shipped from source i to destination j cannot be less than zero (i.e. the non negativity constraint).

3.4 FORMULATING THE TRANSPORATATION PROBLEM AS A LINEAR PROGRAMMING MODEL

We consider an example to understand the formulation of mathematical model of transportation problem of transporting single commodity from three sources of supply (production facilities) to three demand destinations (warehouses).

Let S denote the plant (factory) where the goods are being manufactured and W denote the warehouse where the finished products are stored by the company before shipping to various destinations. Further let,

x_{ij} = quantity shipped from plant s_i to the warehouse w_j and

c_{ij}= transportation cost per unit of shipping from plant s_i to the warehouse w_j

The problem can be represented as:

$$Minimize \quad Z = \left.\begin{aligned} & c_{11}x_{11} + c_{12}x_{12} + c_{13}x_{13} \\ & + c_{21}x_{21} + c_{22}x_{22} + c_{23}x_{23} \\ & + c_{31}x_{31} + c_{32}x_{32} + c_{33}x_{33}. \end{aligned}\right\} \text{Cost of shipping from plants to warehouses}$$

Subjects to

$$\left.\begin{aligned} x_{11} + x_{12} + x_{13} &\leq s_1 \\ x_{21} + x_{22} + x_{23} &\leq s_2 \\ x_{31} + x_{32} + x_{33} &\leq s_3 \end{aligned}\right\} \text{Supply constraints}$$

$$\left.\begin{aligned} x_{11} + x_{12} + x_{13} &\leq d_1 \\ x_{21} + x_{22} + x_{23} &\leq d_2 \\ x_{31} + x_{32} + x_{33} &\leq d_3 \end{aligned}\right\} \text{Demand constraints}$$

$$x_{ij} \geq 0$$

It is further assumed that:

$$s_1 + s_2 + s_3 = d_1 + d_2 + d_3$$

(i.e.; the total supply available at the plants exactly matches the total demand at the destinations (warehouse). Hence, there is neither excess supply nor excess demand).

Since number of variables is very high, simplex method is not appropriate.

3.5 THE BALANCED TRANSPORTATION PROBLEM

In a transportation problem, the total supply is expected to be equal to the total demand at any instant. Such types of problems where supply and demand are exactly equal are known as Balanced Transportation Problem**.**

$$\sum_{i=1}^{m} \boldsymbol{a_i} = \sum_{j=1}^{n} \boldsymbol{b_j}$$

The opposite is said to be an Unbalanced Transportation Problem

$$\sum_{i=1}^{m} \boldsymbol{a_i} \neq \sum_{j=1}^{n} \boldsymbol{b_j}$$

Unbalanced transportation problem can always be converted to an equivalent balanced transportation problem to which the special method may be applied.

Remarks:

(i) We note that if a problem is balanced, then

$$\boldsymbol{a_i} = \sum_{j=1}^{n} \boldsymbol{x_{ij}}, \qquad for\ each\ i$$

and

$$b_j = \sum_{i=1}^{m} x_{ij}, \qquad for\ each\ j$$

For if there exist $i = i_0$ such that

$$a_{io} > \sum_{j=1}^{n} a_{io}\, b_j$$

Then

$$\sum_{i=1}^{n} a_i > \sum_{i=1}^{m} \sum_{j=1}^{n} x_{ij} \geq \sum_{j=1}^{n} b_j$$

And the problem is said to be unbalanced. Hence for each i, we have

$$\sum_{j=1}^{a} x_{ij} = a_i$$

Similarly,

$$b_j = \sum_{i=1}^{m} x_{ij},\ for\ each\ j$$

Hence the balanced transportation problem may be written as

Minimize

$$\sum_{i=1}^{m}\sum_{j=1}^{n} c_{ij}x_{ij}$$

Subject to

$$\sum_{j=1}^{n} x_{ij} = a_i, i = 1,2,3,\dots,m$$

$$\sum_{i=1}^{m} x_{ij} = b_j, j = 1,2,3,\dots,n$$

This balanced problem may therefore be represented by the table below

Table 3.1: Format of a balanced transportation tableau

Warehouse

Source	w_1	w_2		w_n	Supply
s_1	c_{11}	c_{12}		c_{1n}	a_1
s_2	c_{21}	c_{22}		c_{2n}	a_2
s_m	c_{m1}	c_{m2}		c_{mn}	a_m
Demand	b_1	b_2		b_n	

Supplies (from various sources) are written in the rows, while a column is an expression for the demand of different warehouses. The unit costs are shown in the upper left hand corners of the cells.

(ii) We observe that

a. The coefficient of each variable x_{ij} in each constraint is either 1 or 0

b. The constant on the R.H.S of each constraint is an integer

c. The coefficient matrix A has a certain pattern of 1's and 0's.

(iii) We note that the *m*+ *n* conditions.

$$\sum x_{ij} = b_{j,} \quad 1 \leq j \leq n$$

$$\sum x_{ij} = a_{i,} \quad 1 \leq i \leq m$$

are not independent since

$$\sum_{i=1}^{m} b_j = \sum_{j=1}^{n}\sum_{i=1}^{m} x_{ij} = \sum_{i=1}^{m} a_i$$

Thus the effective number of constraints on the balanced transportation problem is *m*+ *n* -1. Hence we expect a basic feasible solution of the balanced transportation problem to have *m*+ *n* -1 non-negative entries.

3.6 BALANCING AN UNBALANCED TRANSPORTATION PROBLEM

The unbalanced problem is converted to a balanced problem in the following ways:

3.6.1 IF THE TOTAL SUPPLY EXCEEDS TOTAL DEMAND

If the total supply exceeds the total demand, we create a fictitious warehouse W_F whose demand is precisely the excess of supply over demand and such that the unit cost of each source to the fictitious warehouse W_F is zero. This produces a balanced transportation problem of the type shown below:

Table 3.2 A balanced transportation tableau from an unbalanced problem with excess supply

	W_1	W_2	Warehouse	W_n		
S_1	c_{11}	c_{12}		c_{1n}	W_F	a_1
S_2	c_{21}	c_{22}		c_{2n}	0	a_2
Source						
S_n	c_{m1}	c_{m2}		c_{mn}	0	a_n
	b_1	b_2		b_n		

Where,

$$b_n = \sum_i a_i - \sum_j b_j$$

3.6.2 IF TOTAL DEMAND EXCEEDS TOTAL SUPPLY

If the total demand exceeds total supply, create a fictitious source S_F whose capacity is precisely the excess of demand over supply and such that the unit cost from source to every warehouse is zero.

This produces a balanced transportation problem of the type shown below:

Table 3.3 A balanced transportation tableau from an unbalanced problem with excess demand

	Warehouse				
	W_1	W_2		W_n	
s_1	c_{11}	c_{12}		c_{1n}	a_1
Source					
s_m	c_{m1}	c_{m2}		c_{mn}	a_m
S_F	0	0		0	
	b_1	b_2		b_n	

Where,

$$a_m = \sum_j b_j - \sum_i a_i$$

3.7 METHODS OF SOLVING TRANSPORTATION PROBLEMS

There are several methods for solving transportation problems. Two of such methods are the Stepping stone Method and the Modified Distribution Method (MODI) initiated by Dantzig. These methods are variants of the Simplex Method and therefore require initial basic feasible solutions to start with. These initial basic feasible solutions may be obtained by the Northwest Corner Method (NWCM), the Least Cost Method (LCM) or Vogel's Approximation Method (VAM) or others. It is important to note that the IBFS is not the optimal solution to transportation problems.

Definitions

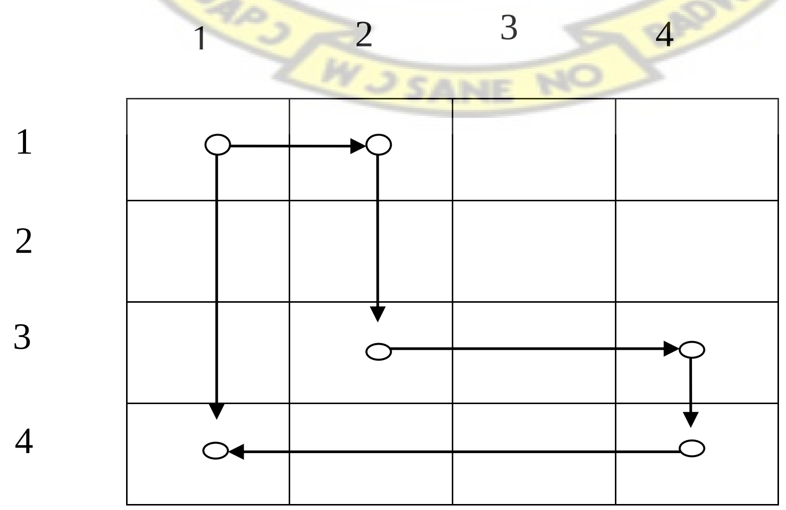
(i) **Cell:** It is a small compartment in the transportation tableau.

(ii) **Circuit:** it is made up of cells of the tableau of the balanced transportation problem in a sequence of cells such that

   a) It starts and ends with the same cell.

   b) Each cell in the sequence can be connected to the next member of the sequence by a horizontal or vertical line in the tableau.

Table 3.4. An example of a circuit



$(1,1) \rightarrow (1,2) \rightarrow (3,2) \rightarrow (3,4) \rightarrow (4,4) \rightarrow (4,1) \rightarrow (1,1)$

(i) **Allocation:** The number of units of products shipped from a source to a destination which is recorded in a cell in the transportation tableau.

(ii) **Basic variables:** In a basic solution, the variables whose values are obtained as the simultaneous solution to the system of equations that conform to the functional constraints.

(iii) **Basic Feasible Solution (BFS):** A solution is called a basic feasible solution if

a) It involves (m+n-1) cells with non-negativity allocation.

b) There are no circuits among the cells in the solution.

REMARKS:

- The optimal solution to the balanced transportation problem is achieved by some BFS.
- A transportation problem will have feasible solutions if and only if

$$\sum_{i=1}^{m} \boldsymbol{s_i} = \sum_{j=1}^{n} \boldsymbol{b_j}$$

3.7.1 FINDING INITIAL BASIC FEASIBLE SOLUTION OF BALANCED TRANSPORTION PROBLEMS (IBFS).

3.7.1.1 THE NORTHWEST CORNER RULE

The North West corner rule is a method for computing a basic feasible solution of a transportation problem where the basic variables are selected from the North–West corner (i.e., top left corner).

Steps:

(i) Select the north–west (upper left-hand) corner cell of the transportation tableau and allocate as many units as possible equal to the minimum between available supply and demand requirements ,i.e., min (s_1,d_1)

(ii) Adjust the supply and demand numbers in the respective rows and columns allocation.

(iii) If the supply for the first row is exhausted then move down to the first cell in the second row

(iv) If the demand for the first cell is satisfied then move horizontally to the next cell in the second column.

(v) If for any cell supply equals demand then the next allocation can be made in cell either in the next row or column.

(vi) Continue the procedure until the total available quantity is fully allocated to the cells as required

REMARK:

In certain cases, called Degenerate, the solution obtained by this method is not a BFS because it has fewer than $(m+n-1)$ cells in the solution. This happens because at some point during the allocation when a supply is used up there is no cell with unfulfilled demand in the column. In the non-degenerate case, until the end, whenever a supply is used up there is always an unfulfilled demand in the column. Even in the case of degeneracy the Northwest corner Rule still yield a BFS if it is modified as follows. Having obtained a solution which is not a BFS choose some empty cells and add there the solution with circled zeros in them, so to produce a BFS, that is

(i) The total number of cells with allocations should be $(m+n-1)$

(ii) There should be no circuit among the cells of the solution

3.7.1.2 THE LEAST COST METHOD

This method identifies the least unit cost in the transportation tableau and allocates as much as possible to its cell without violating any of the supply or demand constraints. The satisfied row or column is then crossed out. The next least weight cost is identified and as much as possible is allocated to its cell, without violating any of the supply or demand constraints. The satisfied row or column is deleted (crossed out). This procedure is repeated until all rows and columns have been cross out.

3.7.1.3 THE VOGEL'S APPROXIMATION METHOD (VAM)

The VAM is an iterative procedure for computing a basic feasible solution of the transportation problem. It is a variant of the LCM and is based on the idea that if for some reason the allocation cannot be made to the least unit cost cell via row or column then it is made to the next least cost cell in that row or column and the appropriate penalty paid for not being able to make the best allocation.

Steps:

(i) Compute rows and columns penalties (i.e. subtract the least cost element on each row or column from the next least cost element).

(ii) Identify the row or column with the maximum penalty.

(iii) Identify the cost element in that row or column

(iv) When left with only one row or column ,use the Least Cost Method

REMARKS:

(i) VAM provides a BFS which is close to optimality and thus performs better than the NWCR or the LCM.

(ii) Unlike the NWCR, VAM may lead to an allocation with fewer than $(m+ n -1)$ non-empty cells even in the non-degenerate case.

3.7.2 METHODS FOR SOLVING TRANSPORTATION PROBLEMS TO OPTIMALITY

The solutions obtained from the three methods discussed earlier are feasible but not the optimal.

We improve them to optimal by employing the following methods.

3.7.2.1 THE STEPPINGSTONE METHOD

The Steppingstone Method, being a variant of the simplex method, requires an initial basic feasible solution which it then improves to optimality. Such an initial basic feasible solution may be obtained by any of the methods (NWCM, LCM or VAM) discussed earlier on.

(i) **Test for optimality:** To test the current basic feasible solution for optimality, take each of the unoccupied cells in turns and place 1 unit allocation in it. This is indicated by just the sign +. Following the unique circuit containing this cell as described above place alternately the signs – and + until all the cells of the circuit are covered. Knowing the unit cost of each cell, we compute the total change in cost produced by the allocation of 1 unit in the empty cell and the corresponding placements in the other cells of the circuit. This change in cost is called improvement index of the unoccupied cell. If the improvement index of each unoccupied cell in the given basic feasible solution is nonnegative then the current basic feasible solution is optimal since every reallocation increases the cost. If there is at least one unoccupied cell with a negative improvement index then a reallocation to produce a new basic feasible solution with a lower cost is possible and so the current basic feasible solution is not optimal. Thus the current basic feasible solution is optimal if and only if each unoccupied cell has a nonnegative improvement index.

(ii) **Improvement to optimality:** if there exist at least one unoccupied cell in a given basic feasible solution which has a negative improvement index then the basic feasible solution is not optimal. To improve this solution, we find the unoccupied cell with the most negative improvement index say N. Using the circuit that was used in the calculation of its improvement index find the smallest allocation in the cells of the circuit with the sign "–". Call this smallest allocation *m*. Subtract *m* from the allocations in all the cells in the circuit with the sign "–". Add in to all the allocations in the cells in the circuit with the sign "+" this has the effect of satisfying the constraints on demand and supply in the transportation tableau. Since the cell which carried the allocation *m* now has a zero allocation, it is deleted from the solution and is replaced by the cell in the circuit which was originally unoccupied and now has an allocation *m*. the result of each reallocation is new basic feasible solution. The cost of this new basic feasible solution in N less than the cost of the previous basic feasible solution. The new basic feasible solution is tested for optimality and the whole procedure repeated until an optimal solution is attained.

3.7.2.2 THE MODIFIED DISTRIBUTION METHOD (MODI)

Considering the balanced transportation problem below:

Table 3.5 the modified distribution method tableau

Warehouse

	W_1	W_2		W_n	
S_1	c_{11}	c_{12}		c_{1n}	a_1
S_2	c_{21}	c_{22}		c_{2n}	a_2
Source					
S_m	c_{m1}	c_{m2}		c_{mn}	a_n
	b_1	b_2		b_m	

Assuming an initial basic feasible solution is available. Then (m+ n −1) cells are occupied.

(i) **Test for optimality:** For each occupied cell (i, j) of the transportation tableau, compute a row index u_i and a column index v_j such that $c_{ij} = u_i + v_j$.

Since there are (m+ n −1) occupied cells, it follows that there are m+ n −1of these equations. Since there are (m+ n) row and column indices altogether, it follows that by prescribing an arbitrary value for one of them, say $u_1 = 0$, we then solve the equations for the remaining (m+ n −1) unknowns $u_{i,} v_j$

With all the $u_{i,} v_j$ known, we compute for each unoccupied cell such that the evaluation factor $e_{st} = c_{st-} u_{s_{v_t}}$.

It can be shown that the evaluation factors are the relative cost factors corresponding to the non-basic variables when the simplex method is applied to the transportation problem. Hence the current basic feasible solution is optimal if and only if $e_{st} \geq 0$ for all unoccupied cells (s, t), since the transportation problem is a minimization problem. If there are unoccupied cells with negative evaluation factors, then current basic feasible solution is not optimal and needs to be improved.

(ii) Improvement to optimality: To improve the current non-optimal basic feasible solution we find the unoccupied cell with the most negative evaluation factor, construct its circuit and adjust the values of the allocation in the cells of the circuit in exactly the same way as was done in the steppingstone method. This yields a new basic feasible solution. With a new basic feasible solution available, the whole process is repeated until optimality is attained.

Remark

The fact that the circuit is not constructed for every unoccupied cell makes the MODI more efficient than the Steppingstone Method. In fact the MODI is currently the most efficient method of solving the transportation problem.

3.8 SUMMARY

The production and transportation problems and the various methods of solving transportation problems are discussed. In the next chapter, we shall discuss data collection and analysis using the transportation approach.

CHAPTER 4

DATA COLLECTION AND ANALYSIS

4.0 INTRODUCTION

In this Chapter, I present how data was collected and analyzed. The transportation problem is analyzed by POM-QM for windows software (version 2) by using the Vogel Approximation Method to obtain initial basic solution and optimality is tested for by the Modified Distribution Method.

4.1 PROBLEM DESCRIPTION

The outbound supply chain of Latex Foam Ltd. is shown in Figure 4.1. It consists of three echelons – Plants, Warehouses and Depots. There are two plants, two warehouses, one in each factory and over one hundred and ten (110) depots spread out nationwide. The products get to depots from plants through warehouses. For brevity all the depots are grouped into ten (10) according to regions under this study. Being a multi time period model, it allows for inventory storing in warehouses.

Figure 4.1.The outbound supply chain of Latex Foam Ltd

4.2 PRODUCTION LEVELS

The high density honeymoon mattress is a complete foam mattress of high density foam covered with Belgium Jacquard Quilts for good sleeping comfort. The product is the end result of the appropriate combination in their right proportion of the following imported chemicals with the exception of the last one: Polyol, Toluene Diisoscyanante (TDI), Silicon, Amine, Stenaus Octoite (SO), Methylene Chloride, Colour (red, yellow, blue, black) and Water. The product comes out from the production plant first as a block comprising of six mattresses. The block is dried for some time and then shipped to the cutting room for cutting and packaging making the product ready for the market.

Material, labour and power are the main components of production cost to Latex Foam Ghana Ltd.

The production department must plan for each of the twelve months over the 2012 production year. The company's production capacities, the expected demands and the associated cost of production (all in units and in thousands except for the various productions cost in GH¢) are shown in appendix A.

The company has no initial inventory to begin with; this is because units produced over the year are shipped to the various depots before the beginning of the next production year.

With Latex Foam Ghana Ltd., products manufactured during a month can be used to meet demand for the current month. At the end of each month (after production has occurred and the current month's demand has been satisfied), a carrying or holding cost of GH ¢1.5 per unit is incurred.

We seek to determine a monthly production schedule that meets all demands at minimum total cost.

4.3 FORMULATING THE PRODUCTION PLANNING PROBLEM BY THE TRANSPORTATION MODEL

Time periods during which production can take place are: shifts for the twelve seasons at both plants. Each of these twenty-four periods becomes a source. The total supply is 69,750,000 units. Time periods in which products will be required are the twelve months; these become the destinations, with total demand of 50,440,000 units. Since total supply exceeds total demand, a fictitious destination must be created, with a demand equal to the 19,310,000 units excess.

Positive allocations from a source to the fictitious destination represent units that could be produced by the source but will not be, because they are not needed. Since all units in initial inventories already have been produced a positive allocation from initial inventory to the dummy must be avoided. This is done by assigning a prohibitively large number ($10000) as the associated unit cost. All other costs associated with the dummy are, as usual, taken to be zero.

Other allocations, which must be avoided, are also assigned prohibitively large cost. Cost associated with the initial inventories are future carrying costs only, since production costs and past carrying charges have already been incurred and cannot be minimized. The remaining cost entries are simply the production cost plus the storage charges as shown in appendix C.

4.4 SOLUTION TO THE PRODUCTION PROBLEM

Applying the transportation algorithm, we obtain an optimal tableau as shown in appendix D as the solution to the problem.

4.5 TRANSPORTATION (DISTRIBUTION) LEVEL

Latex Foam Ghana Ltd., after production, stores its products in the warehouses and finally ships them to the various depots. The company uses trucks in the distribution process. Fuel and vehicle maintenance are the major components of transportation cost to the company.

The marketing department must also plan a monthly distribution plan for each monthly over the 2012 operational year.

The expected monthly requirement (demand) at the various depots (all in units and in thousands) and the associated unit cost (in GH¢) of shipping from plants to the various depots are shown in appendix B.

Table 4.2 the expected unit cost (GH¢) of transportation from warehouses to depots for Jan-June.

	A/R	B/R	W/R	N/R	UE/R	UW/R	C/R	E/R	V/R	GA/R
ACC WHS	5.5	7	5	11	12	12	4.5	3.5	5.5	2.8
KSI WHS	2.5	3.5	5.5	7	8.5	8.5	4.5	4.5	8	5.5

Source: Marketing Department, Latex Foam Ghana Ltd

Table 4.3 the expected unit cost (GH¢) of transportation from warehouses to depots for July-Dec.

	A/R	B/R	W/R	N/R	UE/R	UW/R	C/R	E/R	V/R	GA/R
ACC WHS	6.5	8	6	12	13	13	5.5	4.5	6.5	3.8
KSI WHS	3.5	4.5	6.5	8	9.5	9.5	5.5	5.5	9	6.5

Source: Marketing Department, Latex Foam Ghana Ltd

We are tasked to determine a monthly distribution schedule that meets the demands at the various depots at minimum total cost.

4.6SOLUTION TO THE TRANSPORTATION PROBLEM

The actual monthly production mix at plants used to satisfy the demands for the various months are taken as supply and the monthly requirements at depots are taken as destinations for each month.

Applying the transportation algorithm separately for each month, we obtain an optimal solution to the problem as shown in appendix D.

CHAPTER 5

FINDINGS, CONCLUSION AND RECOMMENDATIONS

5.0 FINDINGS

Combining the production and transportation sub problems, we have the following findings as the optimal production-transportation plan for Latex Foam Gh. Ltd.

In order to meet demand in JAN., ACC. PLT should produce 1,050,000 units production in JAN, ship 190,000 to E/R, 260,000 units to V/R and 600,000 units GA/R. The KSI PLT should also produce 2,200,000 units in JAN, ship 500000 units to A/R, 380000 units to B/R, 290,000 units to W/R, 400,000 to N/R, 120,000 units to UE/R, 120,000 units to UW/R and 320000 units to C/R.

To meet demand in FEB., ACC. PLT should produce 965,000 units in Feb, ship 105,000 units to E/R, 260,000 units to V/R and 600,000 units to GA/R. The KSI PLT should also produce 2,200,000 units in FEB, ship 500000 units to A/R, 380000 units to B/R, 290,000 units to W/R, 250,000 to N/R, 185,000 units to UE/R, 100,000 units to UW/R and 320000 units to C/R.

To meet demand in MAR, ACC. PLT should produce 875,000 units in MAR., ship 15,000 units to E/R, 260,000 units to V/R and 600,000 units to GA/R. The KSI PLT should also produce 2,200,000 units in MAR., ship 500,000 units to A/R, 380,000 units to B/R, 290,000 units to W/R, 250,000 to N/R, 115,000 units to UE/R, 115,000 units to UW/R, 285,000 units to C/R. and 265,000 units to E/R.

To meet demand in APR., ACC. PLT should produce 1950,000 units in APR, ship 365,000 units to W/R, 255,000 units to C/R, 290,000 units to E/R, 315,000 units to V/R and 725,000 units to GA/R. The KSI PLT should also produce 1,202,000 units in APR, ship 380,000 units to A/R, 400,000 units to B/R, 160,000 to N/R, 120,000 units to UE/R and112,000 units to UW/R.

To meet demand in MAY, ACC. PLT should produce 1,822,000 units in MAY, ship 420,000 units to W/R, 72,000 to C/R., 290000 units to E/R, 315,000 units to V/R and 725,000 units to GA/R. The KSI PLT should also produce 1,300,000 units in MAY, ship 380,000 units to A/R, 280,000 units to B/R., 160,000 to N/R, 120,000 units to UE/R, 132,000 units to UW/R and 228,000 units to C/R.

To meet demand in JUNE, ACC. PLT should produce 1,766,000 units in JUNE, ship 420,000 units to W/R, 159,000 units to C/R, 290,000 units to E/R, 315,000 units to V/R and 582,000 units to GA/R. The KSI PLT should also produce 1,300,000 units in JUNE, ship 380,000 units to A/R, 352,000 units to B/R, 160,000 to N/R, 135,000 units to UE/R, 132,000 units to UW/R. and 141,000 units to C/R.

To meet demand in JULY, ACC. PLT should produce 1,459,000 units in JULY, ship 224,000 units to E/R, 335,000 units to V/R and 900,000 units to GA/R. The KSI PLT should also produce 2,600,000 units in JULY, ship 800,000 units to A/R, 352,000 units to B/R, 160,000 units to N/R, 142,000 units to UE/R, 220,000 units to UW/R, 255,000 units to C/R. and 101,000 to E/R.

To meet AUG demand, ACC. PLT should produce 1,577,000 units in AUG, ship 17,000 units to W/R, 325,000 units to E/R, 335000 units to V/R and 900000 units to GA/R. The KSI PLT should also produce 2,600,000 units in AUG, ship 800,000 units to A/R, 412,000 units to B/R, 310,000 units to N/R, 150,000 units to UE/R, 225,000 units to UW/R and 420,000 units to C/R.

To meet SEP demand, ACC. PLT should produce 2,447,000 units in SEP, ship 110,000 units to W/R, 420,000 units to C/R, 412,000 units to E/R, 385,000 units to V/R and 1,120,000 units to GA/R. The KSI PLT should also produce 2,600,000 units in SEP, ship 920,000 units to A/R, 485,000 units to B/R, 310,000 units to N/R, 150,000 units to UE/R, and 256,000 units to UW/R

To meet OCT demand, ACC. PLT should produce 48,000,000 units in OCT, ship 1,000,000 units to A/R, 158,000 to B/A, 580,000 units to W/R, 300,000 to UE/R, 265,00 UE/R, 500,000 to C/R, 412000 units to E/R, 385,000 units to V/R and 12,000,000 units to GA/R. The KSI PLT should also produce 804,000 units in OCT plus 98,000 units produced in APR and stored ship 592,000 units to B/R and 310,000 units to N/R.

To meet demand in NOV., ACC. PLT should produce 2,925,000 units in NOV, ship 580,000 to W/R, 155,000 units to C/R, 425,000 units to E/R, 415,000 units to V/R and 1,350,000 units to GA/R. The KSI PLT should also produce 3,200,000 units in NOV, ship 1,100,000 units to A/R, 630,000 units to B/R, 375,000 units to N/R, 390,000 units to UE/R and 350,000 units to UW/R and 355,000 units to C/R.

To meet demand in DEC, ACC. PLT should produce 3,300,000 units in DEC., ship 620,000 to W/R, 240,000 units to C/R, 520,000 units to E/R, 520,000 units to V/R and 1,400,000 units to GA/R. The KSI PLT should also produce 3,200,000 units in DEC, ship 1,250,000 units to A/R, 600,000 units to B/R, 375,000 units to N/R, 420,000 units to UE/R, 385,000 units to UW/R and 170,000 units to C/R.

5.1 CONCLUSION

This study has found an optimal production and transportation schedule as presented in appendices C and D. This reveals that with the introduction this proposed model solution, Latex Foam Ghana ltd could reduce production and transportation cost by 43% and 38% respectively.

5.2 RECOMMENDATIONS

Based on the findings of the study, we recommend to management of Latex Foam Ghana Ltd. to adopt this proposed model solution for the 2012 operational year since it has demonstrated improvement in cost optimization as compared to the rule-of-thumb based planning.

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APPENDIX A

The production capacity and unit cost of production of Latex Foam Ghana Ltd. for the study

	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
ACC PLT	3300	3300	3300	1950	1950	1950	3900	3900	3900	4800	4800	4800
KSI PLT	2200	2200	2200	1300	1300	1300	2600	2600	2600	3200	3200	3200
COST	190	190	190	200	200	200	210	210	210	220	220	220

Source: Production Department, Latex Foam Ghana Ltd

APPENDIX B

The expected monthly demand at various depots.

DEPOT / MONTH	JAN	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	TOTAL
A/R	500	500	500	380	380	380	800	800	920	1000	1100	1250	8510
B/R	380	380	380	400	280	352	352	412	485	750	630	600	5401
W/R	290	290	290	365	420	420	300	300	580	580	580	620	5035
N/R	400	250	250	160	160	160	160	310	310	310	375	375	3220
UE/R	120	185	115	120	120	135	142	150	150	300	390	420	2347
UW/R	100	100	115	112	132	132	220	225	265	265	350	385	2401
C/R	320	320	285	285	300	300	525	420	420	500	510	410	4595
E/R	280	280	280	290	290	290	325	325	412	412	425	520	4129
V/R	260	260	260	315	315	315	335	335	385	385	415	520	4100
GA/R	600	600	600	725	725	582	900	900	1120	1200	1350	1400	10702
TOTAL	3550	3165	3075	3152	3122	3066	4059	4177	5047	5702	6125	6500	50440

source: Marketing Department, Latex Foam Ghana Ltd

APPENDIX C

The transportation tableau for the production planning problem of Latex Foam Gh. Ltd.

	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DUMMY	SUPPLY
JAN (ACC PLT)	190	191.5	193	206	207.5	209	219	220.5	222	233.5	235	236.5	0	3300
FEB (ACC PLT)	10000	190	191.5	203	204.5	206	217.5	219	220.5	232	233.5	235	0	3300
MAR (ACC PLT)	10000	10000	190	201.5	203	204.5	216	217.5	219	220.5	222	223.5	0	3300
APRIL (ACC PLT)	10000	10000	10000	200	201.5	203	214.5	216	217.5	229	230.5	232	0	1950
MAY (ACC PLT)	10000	10000	10000	10000	200	201.5	213	214.5	216	227.5	229	230.5	0	1950
JUNE (ACC PLT)	10000	10000	10000	10000	10000	200	211.5	213	214.5	226	227.5	229	0	1950
JULY (ACC PLT)	10000	10000	10000	10000	10000	10000	210	211.5	213	224.5	226	227.5	0	3900
AUG (ACC PLT)	10000	10000	10000	10000	10000	10000	10000	210	211.5	233	224.5	226	0	3900
SEP (ACC PLT)	10000	10000	10000	10000	10000	10000	10000	10000	210	221.5	233	224.5	0	3900
OCT (ACC PLT)	10000	10000	10000	10000	10000	10000	10000	10000	10000	220	221.5	233	0	4800
NOV (ACC PLT)	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	220	221.5	0	4080

DEC (ACC PLT)	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	220	0	4800
JAN KSI PLT)	190	191.5	193	206	207.5	209	219	220.5	222	233.5	235	236.5	0	2200
FEB KSI PLT)	10000	190	191.5	203	204.5	206	217.5	219	220.5	232	233.5	235	0	2200
MAR (KSI PLT)	10000	10000	190	210.5	203	204.5	216	217.5	219	220.5	232	233.5	0	2200
APRIL (KSI PLT)	10000	10000	10000	200	210.5	203	214.5	216	217.5	229	230.5	232	0	1300
MAY (KSI PLT)	10000	10000	10000	10000	200	210.5	213	214.5	216	227.5	229	230.5	0	1300
JUNE (KSI PLT)	10000	10000	10000	10000	10000	200	211.5	213	214.5	226	227.5	229	0	1300
JULY (KSI PLT)	10000	10000	10000	10000	10000	10000	210	211.5	213	224.5	226	227.5	0	2600
AUG (KSI PLT)	10000	10000	10000	10000	10000	10000	10000	210	211.5	223	224.5	226	0	2600
SEPT (KSI PLT)	10000	10000	10000	10000	10000	10000	10000	10000	210	221.5	223	224.5	0	2600
OCT (KSI PLT)	10000	10000	10000	10000	10000	10000	10000	10000	10000	220	221.5	223	0	3200
NOV (KSI PLT)	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	220	221.5	0	3200
DEC (KSI PLT)	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	10000	220	0 -	3200
DEMAND	3250	3165	3074	3152	3122	3066	4059	4177	5047	5702	6125	6500	19310	

APPENDIX D

The optimal production schedule of Latex Foam Ghana Ltd.

	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	DUMMY	SUPPLY
JAN (ACC PLT)	190 1,050												0 2250	3300
FEB (ACC PLT)		190 965											0 2335	3300
MAR (ACC PLT)			190 875										0 2425	3300
APRIL (ACC PLT)				200 1950										1950
MAY (ACC PLT)					200 1, 822								0 128	1950
JUNE (ACC PLT)						200 1766							0 184	1950
JULY (ACC PLT)							210 1459						0 2441	3900
AUG (ACC PLT)								210 1577					0 2323	3900
SEP (ACC PLT)									210 2477				0 1453	3900
OCT (ACC PLT)										220 4800				4800
NOV (ACC PLT)											220 2925		0 1875	4080

DEC (ACC PLT)												220 3300	0 1,500	4800
JAN KSI PLT)	190 2200													2200
FEB KSI PLT)		190 2200												2200
MAR (KSI PLT)			190 2200											2200
APRIL (KSI PLT)				200 1202						220 98				1300
MAY (KSI PLT)					200 1300									1300
JUNE (KSI PLT)						200 1300								1300
JULY (KSI PLT)							210 2,600							2600
AGU (KSI PLT)								210 2600						2600
SEPT (KSI PLT)									210 2600					2600
OCT (KSI PLT)										220 804			0 2396	3200
NOV (KSI PLT)											220 3200			3200
DEC (KSI PLT)												220 3200	-	3200
DEMAND	3250	3165	3074	3152	3122	3066	4059	4177	5047	5702	6125	6500	19310	

APPENDIX E

The optimal monthly distribution plan

		A/R	BA/R	W/R	N/R	UE/R	UW/R	C/R	E/R	V/R	GA/R	SUPPLY
JAN.	**ACC WHS**								3.5 190	5.5 260	2.8 600	1050
	KSI WHS	3 500	5.5 300	5.5 290	7 400	8.5 120	8.5 100	4.5 320	4.5 90			2200
	DEMAND	500	380	290	400	120	100	320	280	260	600	
FEB.	**ACC WHS**								3.5 105	5.5 260	2.8 600	965
	KSI WHS	3 500	3.5 380	5.5 290	7 250	8.5 185	8.5 100	4.5 320	4.5 175			2200
	DEMAND	500	380	290	250	185	100	320	280	260	600	
MAR.	**ACC WHS**								3.5 15	5.5 260	2.8 600	875
	KSI WHS	3 500	3.5 380	5.5 290	7 250	8.5 115	8.5 115	4.5 285	4.5 265			2200
	DEMAND	500	380	290	250	115	115	285	280	260	600	

APRIL	**ACC WHS**			5 365				4.5 255	3.5 290	5.5 315	2.8 725	1950
	KSI WHS	3 380	3.5 400		7 160	8.5 120	8.5 112	4.5 30				1202
	DEMAND	380	400	365	160	120	112	285	290	315	725	

MAY	**ACC WHS**			5 420				4.5 72	3.5 290	5.5 315	2.8 725	1822
	KSI WHS	3 380	3.5 280		5 160	8.5 120	8.5 132	4.5 228				1300
	DEMAND	380	280	420	160	120	132	300	290	315	725	

JUNE	**ACC WHS**			5 420				4.5 159	3.5 290	5.5 315	2.8 582	1766
	KSI WHS	3 261	3.5 352		7 160	8.51 135	8.5 132	4.5 141				1300
	DEMAND	380	352	420	160	135	132	300	290	315	582	

JULY	**ACC WHS**								4.5 224	6.5 335	3.8 900	1459
	KSI WHS	4 800	4.5 352	6.5 300	8 160	9.5 142	9.5 220	5.5 525	5.5 101			2600
	DEMAND	800	352	300	160	142	220	525	325	335	900	

AUG.	**ACC WHS**			6 17					4.5 325	6.5 335	3.8 900	1577
	KSI WHS	4 800	4.5 412	6.5 283	8 310	9.5 150	9.5 225	5.5 420				2600
	DEMAND	800	412	300	310	150	225	420	325	335	900	

SEP.	**ACC WHS**			6 110				5.5 420	4.5 412	6.5 385	3.8 1120	2447
	KSI WHS	4 920	4.5 485	6.5 470	8 310	9.5 150	9.5 265					2600
	DEMAND	920	485	580	310	150	265	420	412	385	1120	
OCT.	**ACC WHS**	6.5 1000	8 158	6 580		13 300	13 265	5.5 500	4.5 412	6.5 385	3.8 12000	4800
	KSI WHS		4.5 592		6 310							902
	DEMAND	1000	570	580	310	300	265	500	412	385	12000	
NOV.	**ACC WHS**			6 580				5.5 155	4.5 425	6.5 415	3.8 1350	2925
	KSI WHS	4 1100	4.5 630		8 375	9.5 390	9.5 350					3200
	DEMAND	1100	630	580	375	390	350	510	425	415	1350	
DEC.	**ACC WHS**			6 620				5.5 240	4.5 520	6.5 520	3.8 1400	3300
	KSI WHS	4 1250	4.5 600		8 375	9.5 420	9.5 385	5.5 170				3200
	DEMAND	1250	600	620	375	420	385	410	520	520	1400	