INBOUND SUPPLY CHAIN NETWORK DESIGN FOR COFFEE PROCESSING: ALEMAYHU YIRDAW COFFEE PROCESSING PLC.

MSc THESIS

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HAWASSA UNIVERSITY, HAWASSA, ETHIOPIA

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ADVISOR APPROVAL SHEET

This is to certify that the thesis entitled "INBOUND SUPPLY CHAIN NETWORK DESIGN FOR COFFEE PROCESSING: ALEMAYHU YIRDAW COFFEE PROCESSING PLC." submitted in partial fulfillment of the requirements for the degree of masters with specialization in Industrial engineering and logistics management, the graduate program of the department of mechanical and industrial engineering, and has been carried out by MILION BEKELE, under our supervision.

Therefore, we recommend that the student has fulfilled the requirements and hence hereby can summit the thesis to the school.

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We, the undersigned members of the board of examiners of the final open defense by MILION BEKELE have read and evaluated his thesis entitle "INBOUND SUPPLY CHAIN NETWORK DESIGN FOR COFFEE PROCESSING: ALEMAYHU YIRDAW COFFEE PROCESSING PLC." and examined the candidate. This is therefore to certify that the thesis has been accepted in partial fulfillment of the requirement for the degree master of science.

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SGS	Signature	Date

DECLARATION

I declare that this dissertation is my own original work and that it has not been presented and will not be presented to any other University for similar or any other degree award.

MILION BEKELE

Signature: _______________

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To all, I say thank you.

Abbreviation

BFA-LFO	Budget, Finance, and Award management -Large Facilities Office
CD	Compact Disc
CPP	Coffee Processing Plant
D.C	Distribution Center
DEA	Data Envelopment Analysis
DS	Dry Solid
DSC	Dry Solid Content
EOQ	Economic Order Quantity
ECX	Ethiopia Commodity Exchange
FTL	Full Truck Loads
GHE	Greenhouse Effect
GMP	Good Manufacturing Practice
GSD	Greenhouse Solar Dyer
GTSD	Greenhouse Type Solar Dryer
ITC	International Trade Centre
ITF	International Transport Fund
JIT	Just In Time
NPGP	Non Pre-emptive Goal Programming
NSF	National Science Foundation
SNNPR	South Nation Nationality People Region
SCN	Supply Chain Network
KPIs	Key Performance Indicators
LTTL	Less Than Truck Load

OTA	Ochra Toxin A
PV	Photo Voltaic
ROI	Return of Investment
SP	Solar Panel
STD	Solar Tunnel Dryer
TBC	Time Based Competition
TES	Thermal Energy Storage
UNIDO	United Nations Industrial Development Organization
URRAP	Universal Rural Road Access Programme

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Abstract

Coffee is the most important export for the country, accounting for about 34 percent of the value of all exports in 2017/18. However, coffee farmers in producing area are operating at a loss due to selling at low prices to intermediaries who control the downstream channels. The correct transporting and processing of beans are a precondition for good quality coffee which might achieve a higher price. Drying in backyards without any equipment often compromises the quality. Therefore, to provide higher income to coffee farmers, effective integration of downstream operations is vital. This inbound supply chain network design should include the intermediate processes and transportation of coffee from primary market in each kebele to processing plant. The objectives of the thesis was to develop a mathematical model that selects the best supply and drying facility option for coffee product in the coffee processing industry; develop network design optimal cost of coffee drying facility and to identify and describe the key steps in the supply activity and coffee processing facility. In order to address the objectives of the research used questionnaire, interview, experiment and observation to collect data from different primary source of data. On the other hand, assessment of documents or reports of the transport cost, warehouse cost, and inventory cost, drying material cost and labor cost. The model is illustrated using a combination of real and simulated data from the coffee sector. To address the issues of limited plant capacity and increased delivery lead times, including a warehouse located closer to the plant is proposed. The selected options have an influence on the delivery lead time, because delivery lead times should not exceed that assured to processor, which impose restrictions in the model on delivery lead times for maintain the quality of coffee product. An alternative to improve the drying process has been the use of solar energy with solar dryers. Area limitation was used as a constraint in this optimization problem. The results of the optimization model indicated that the total production and transportation costs of the network can be reduced by 5.48% to 13.45%. And also the model selected greenhouse solar dryer facility for dry coffee parchment due to area limitation of the constraint which avoid congestion and mould formation for maintain the quality of coffee product.

Keywords: Cost optimization, Delivery time, best supply option, Coffee drying, Greenhouse solar dryer, Solar panel

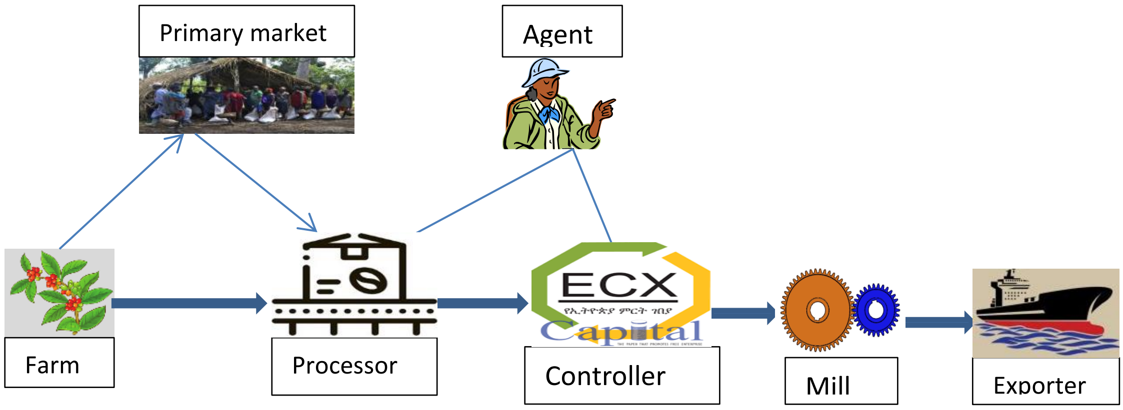
CHAPTER ONE

INTRODUCTION

1.1 Background of the study

Coffee is the backbone of Ethiopia economy, contributing the highest of all exports revenues. Additionally, Ethiopia has a longstanding tradition of consuming coffee and therefore knows a significant domestic demand. UNIDO (2009) on the other hand coffee in the group of commodities that are highly important to the economy due to the large population involved in their production and to their contribution to national food security, important as a source of foreign exchange and have good potential for short-term impact with relatively low investments. The coffee sector in Ethiopia suffers from insufficient road infrastructure; washing and drying stations are often very small and compared to other countries inefficient. Therefore, transport, handling and processing costs of coffee are very high, which reduces the percentage of the world market price, which goes as a farm gate price to the farmers. Most of farmers sell their coffee to local traders, which sell the coffee to collectors (Adams, 2020).

Ferguson (2017) recognized that advanced logistics for reducing transportation time and costs have greatly improved supply chain conditions for delivering consistency and uniformity of physical coffee quality attributes. Logistics and supply chain are concerned with physical and information flows and storage from raw material through to the final distribution of the finished product. Thus, supply and materials management represents the storage and flows into and through the production process, while distribution represents the storage and flows from the final production point through to the customer or end user (Rushton et al., 2010). Supply chain network design decisions include the assignment of facility role, location of processing plant, storage, or transportation related facilities and the allocation of capacity and markets to each facility. Network design decisions have a significant impact on performance because they determine the supply chain configuration and set constraints within which the other supply chain drivers can used either to decrease supply chain cost or to increase responsiveness (Chopra and Meindl, 2007). Adams (2020) specified that necessary environmental conditions and providing adequate space for drying coffee influence decisions on which drying method best suited for operation. The overall performance of an industrial firm is significantly affected by the design of its supply chain network. Figure 1.1 illustrates the stages in the coffee value chain and the intermediaries involved.



Coffee cherry coffee parchment green coffee

Figure1.1 Coffee value chain (López and Chaudhry, 2020)

Coffee involved undergoes four main transformation stages. These stages are:

1) Pulping: at processing plant where the skin and pulp of the red cherry coffee bean are separated to get parchment coffee beans,
2) Drying: where the wet parchment coffees are loss of water and the physical transformation when exposed to the high temperatures
3) Milling: where the dried husk is removed from parchment coffee beans to get green coffee beans and
4) Roasting: where the green coffee beans are heated and beans, transformed into the aromatic brown dried coffee beans.

Processors are responsible for pulping operations at the start of the value chain while pulping and drying done by companies in the supply chain. The additional intermediaries only trade the product without transforming it. Although the intermediaries provide important distribution functions such as transportation, drying, and sales, producers can take more steps downstream to capture a higher share of value (López and Chaudhry, 2020).

In every coffee property in Ethiopia is necessary to have separate areas for coffee processing, pulping, drying and storage, distant from facilities for the storage of other materials such as tools, and equipment. The optimization purpose is to minimize the total cost calculated from integrated activities should be applied to optimize entire system in order to reach useful decisions.

1.2. Statement of the problem

The average net profit income of coffee farmers and collectors involved in coffee production, processing and marketing per kilogram are 17.40 % and 2.83 % of the final price of their products, which is very low (Abebe et al., 2020). However, coffee farmers in producing area are operating at a loss due to selling at low prices to intermediaries who control the downstream channels. Adams (2020) presents handling and processing costs of coffee are very high, which reduces the percentage of the world market price, which goes as a farm gate price to the farmers. Another problem is the infrastructure, which is so inadequate in some coffee producing regions that the transport of the fresh cherries to washing stations might not be possible in time or if so would be too costly. Therefore, to provide higher income to coffee farmers, effective integration of downstream operations is vital. The major problem currently facing Ethiopia coffee production is lack of proper storing, transporting and processing facilities; there is poor supply network and handling of coffee and lack of proper storage with adequate facilities.

Interventions were focused on drying, depulping to facilitate drying, and moisture content determination to monitor moisture content levels especially during storage. Sun drying is still the most practical and still recommended for drying (Idago and Cruz, 2015). The sun-drying method has the lowest fixed costs but produces coffee of inferior quality compared with the other the processing methods. In Ethiopia farmers and processor dry their coffee using different approaches. About 48.0% spread their coffee on and dried on the ground, 49.5% dry on raised drying beds and 2.5% dry on cemented floors (Mitku, 2007). Dried product quality improvement and reduction of losses can be achieved by the introduction of suitable drying technologies such as solar drying. Due to the high price of solar dryers and the different costs of each area size, an optimization model utilized to calculate costs and area requirements. Improvement of the value chain will come from improvement in quality and reduction in cost through design of appropriate primary postharvest facilities. The collectors play an essential role to bring coffee from very remote areas to the market. The coffee cherry passing from farm by farmers themselves or assemblers normally use horses and donkeys. Longer distance transport is largely being contracted by merchants, rather than merchants having their own vehicle. Since most of the harvest is transported by freelance truck owner located sparsely throughout the country, it is difficult to have a clear picture in terms of cost. The wholesalers of coffees are the main users of freight transport. They use trucks to move their coffee from primary market to their terminal markets and other shortage areas. Coffee cherry transported by freelance truck owner is quite costly; the average cost in quintal per kilo meter in asphalt road is 11.5 Birr and the average cost in quintal per Kilo meter in gravel road is 15 Birr now a day more than these (Debela, 2013).

The company for the case study is coffee processing plant in Yirgacheffe coffee district, from which daily collection routes operate to gather inbound coffee cherry from suppliers located in around 124 kebele of Gedio zone. The cherries pass through the wet and dry processing. This system fully integrated so that the quality of the product monitored along the chain. The focus put in producing a high quality coffee that is able to compete in the coffee international market. The large distances involved in making collections from these suppliers and transporting coffee cherry to the plant imply that an efficient flow structure is important monetarily. In this research, to develop minimization model that determines the cost and time efficient inbound supply chain network, starting from the supplier around Yirgacheffe district to the processing plant in Arecha site. In order to address the issues mentioned in above, the organizations are considering the following plans of action:

- ✓ The processing industries buy the red coffee cherries at the primary market and take care of the transport on own account.
- ✓ The overflowing of coffee at the plants storage area avoided by utilizing a central warehouse located close to the plants. The coffee cherries can be stored until it is required at each plant.
- ✓ Uses greenhouse solar dryer for coffee drying in order to preserve the product quality.

The company has the option to place orders at the collectors or other suppliers and the delivery of the coffee cherries can take place via the warehouse/consolidation center/ or directly to the plants.

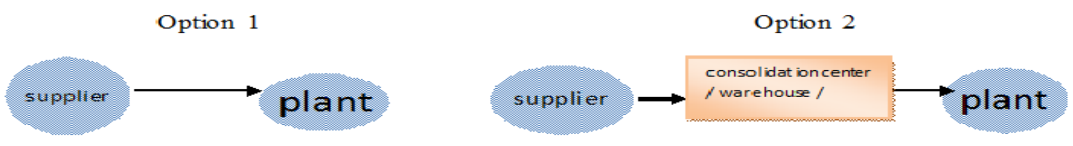


Figure 1.2 Illustrate the various available options to ship coffee cherries

Depending upon the stated problem, a mathematical model is required to make a cost effective inbound supply chain network that guarantee a competitive selling price and an improved profit to enable a higher payment to farmers.

1.3 Research questions

1. How to develop a mathematical model that select the best option for shipping coffee cherries and coffee product drying facility in case company?
2. How to compare total cost of baseline scenario and the model?

1.4 Objective of the research

1.4.1 General objective

The purpose of this study is to design inbound supply chain network for cost reduction in Alemayhu Yirdaw and family coffee processing company.

1.4.2 Specific objectives

1.To develop a mathematical model that selects the best option for supply coffee cherries and coffee product drying facility in case company;

2.To compare total cost of baseline scenario and the model

1.5 Scope of the Study

The scope of this work mainly focuses on design of the inward flow logistic, and drying facility of Alemayhu Yirdaw and family coffee processing industry Plc. The flow is starting from the supplier location until the coffee processing industry. Therefore, in this study among Yirgacheffe coffee producer Yirgacheffe district with plenty of supply is considered and the farmers (producers), collectors, the coffee processing industries and others if any included under investigation.

1.6 Limitation of the study

In this study, the researcher measures Yirgacheffe district coffee inbound supply network design performance by taking the performance characteristics of logistic and facility efficiency. Moreover because of scarcity of time and budget, Yiregacheffe coffee inbound logistic, and drying facility are studied only by taking a narrow part of supply chain design as a study area. Therefore making a research on Yiregacheffe, coffee or Ethiopia's coffee with more sample area can bring results that are more positive.

1.7 Significance/contribution of the research

The importance of this study is used to show alternative ways of cost and time minimization of inbound supply chain for the case company. The other significance of the study is to provide knowledge to the new investor, cooperative and coffee processing industries about the way of cost minimization of inbound activity and coffee processing facility specially coffee drying process. The significances of this study viewed from two dimensions: theoretical contributions and practical implications. Theoretically, the study would fill an important gap in the literature that is factors affecting the cost of coffee. Therefore, the findings of this study would add to the existing body of the literature and can serve as a starting point on which future studies can build. On the practical side, this study can help collector (sebsabi), cooperatives sector and coffee processing industries to identify the major factors that might be affected the coffee inbound logistics and drying facility cost and time required for coffee processing. Such information should help the management of organization to select appropriate option inbound logistics network and to increase profitability of coffee market to with local as well as international market by increasing their quality of coffee and it also helps to identify the best draying facility of coffee product in the study area. This study could be a good stepping ground for other studies on inbound logistics and processing facility of coffee in Ethiopia.

1.8. Organization of the thesis

This thesis organized in to five chapters. In Chapter one, background of the study, statement of problem, research question and objective are included. Chapter Two, present a review of literature relevant to this research work, which has investigated by different researchers, is given. In Chapter Three, methodology of the study presented. In Chapter, Four model validation, analysis and discussion are included. Chapter, Five gives conclusion and recommendation achieved from this thesis work.

CHAPTER TWO

LITERATURE REVIEW

To start literature review with an overview of the coffee collection and production process, this helps understand the structure and properties of the supply chain. Next, the researcher dive into relevant literature on logistics network design and the methods utilized to solve them. This information is guidance for designing and optimizing a customized network for Alemayhu Yirdaw and their family coffee processing Plc. from each kebele primary market to processing plant.

2.1. Coffee production process

Correct coffee processing is important in sustaining bean quality as it ensures better prices to growers. Coffee beans undergo several transformation operations at different locations along the supply chain, and each of them influences the total weight and volume of the beans (Hicks, 2002). The industrial process for the transformation of coffee cherry to parchment, it called profit and comprises the steps: sorting, pulped, washing, mucilage removal and drying. Coffee is not a highly perishable product, but its quality is affected through time (Bladyka, 2013). However, it is important to consider that the rate at which coffee loses its quality depends on its state. There are 3 main states: The initial state is called cherry coffee, which is picked by farmers. The second state is called parchment coffee, which is a result of the pulping process. Green coffee, when packed under the right conditions, can be stored without significantly losing quality for at least 12 months (Borém et al., 2013). The third state is dried coffee, which is a result of the drying process. The case of dried coffee is more complex in terms of freshness and shelf life. One of the most determinant factors in slowing the loss of freshness is the packaging technology (Bladyka, 2013). Research focused on Ethiopia specialty coffee suggests that experts can perceive a loss of quality in only 10 days, but regular customers will not significantly notice it even 60 days after drying when packed in traditional bags (Bladyka, 2013). Challenges that are disturbing the chain while doing its business include lack of knowledge on modern coffee production, poor quality coffee followed by low price offer for the suppliers and lack of well-developed logistic providers, high logistics cost and low government concern to the sector at the export side; although being the country's pride make coffee respected commodity (Tsige, 2018).

Coffee processing is the industrial activity that converts the raw fruit into the finished (or roasted) coffee. From primary processing, what is obtained is green coffee while secondary processing enables the roasting of coffee and its subsequent grinding and packaging. Almost all the coffee produced in Ethiopia sold on domestic and international markets in the form of green coffee after undergoing only primary processing. Debela (2013) stated that there are two coffee processing; primary processing transform from coffee cherry to coffee parchment and secondary processing is conducted by suppliers who generally operate hulling mills, where the parchment is hulled and prepared(make to green coffee bean) before transport to coffee auction centers. After the coffee leaves the farm, it is transported into two types of facilities: direct sun drying facilities and pulping machine and dryer (Debela, 2013).

Figure 2.1 illustrates these transformation processes.

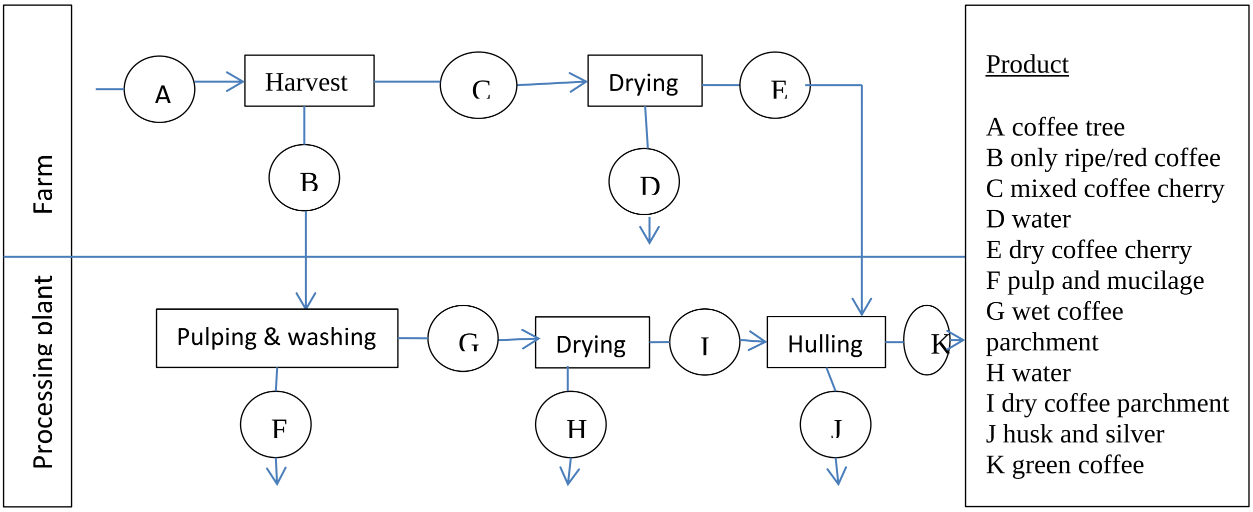


Figure 2.1 Coffee transformation processes adapted from (López and Chaudhry, 2020).

Improper post-harvest processing techniques such as lack of sorting during grading and processing, improper drying without considering drying time, drying place, thickness layer and drying material, transportation, storage, over fermentation etc. largely contribute to the decline in coffee quality of Ethiopia (Tesfa, 2019).

1. Primary processing

There are two method of primary coffee processing used in Ethiopia. Debela (2013) identified that dry processing and wet processing (washing). Under dry processing unpulped cherries are dried completely in the sun under natural conditions after harvesting. In the washing method, the cherries pulped immediately after picking, followed by fermentation and washing to remove mucilage cover. The resulting parchment dried in the sun.

According to(UNIDO project team, 2016), coffee harvested in Ethiopia from November to February in the form of cherries that have to be processed in order to remove the outer skin, the pulp, the pectin layer and the parchment and to obtain the “green coffee” ready for the market. Several hundred thousand workers employed in processing of either red cherry (key eshet) or dried pulp coffee (jenfel) in hundreds of washing stations and hulling mills around the country and, therefore coffee processing is a major source of employment and income in the country. The washing must be done in the same day of the harvest and the washed coffee must not be piled up, being immediately transported to the drying spot, in the case of dry processing.

Dry processing

In the natural (sun dried in the fruit) dry process, (Poltronieri and Rossi, 2016) described that no layer removed from the coffee cherries and the final product develops characteristic fruity and cherry flavours. During drying, fermentation occurs. Coffee processed by natural sun drying represents more than 80% of Yemen Arabica and 60% of Brazilian and Ethiopian Arabica, and almost all Robusta varieties. Recently, a higher level of care has been put into the process, from ripening to drying, to achieve high quality productions and Robusta coffee has also made its way into the specialty coffee market.

Wet processing

In wet processing, once the cherries harvested, they brought to washing plants where they depulped, fermented in tanks and then washed in clean water to remove the mucilage. The wet parchment coffee the coffee bean with a thin layer of skin obtained then dried in the sun on raised beds to moisture content of 11.5 per cent. This process requires specialized equipment for removing the pulp and substantial quantities of water for fermentation and washing. According to various sources, the premium that washed coffee can obtain over the sun dried coffee varies depending on the coffee type and varies from year to year. In recent times, washed coffee has been sold at a price higher than sun dried coffee (TechnoServe team, 2013).

2. Secondary processing

In both dry and wet primary processing, after drying parchment coffee, the last step is coffee milling, which means mechanical hulling or de husking (removal of the parchment skin) and includes polishing, grading and bagging of clean coffee (Debela, 2013).

2.2 Coffee product supply chain

The supply chain is composed of three levels: inbound supply chain, manufacturing and outbound supply chain. Coffee based business in Garut regency is composed of various elements involved in it: suppliers (farmers and gatherers), coffee bean processors (gatherers and business people), distributors (exporters) and consumers. The business activities from upstream to downstream produce a variety of processed coffee products. Based on the supply chain, it can say that the supply chain of coffee in Garut Regency consists of suppliers and distributors who play important roles in marketing processed coffee products (Ikhwana and Tinggi, 2018). Efforts support the secured supply of coffee cherries involve various parties (seller and buyer) including farmers as the main suppliers of coffee cherries, village traders or sub-district traders as intermediary of coffee cherries, processors as consumers of coffee beans at the local level, and exporters who play a role as consumers of coffee beans at the level of foreign countries (Rosiana et al., 2017).

Most coffee processing company currently own more than one plant there is interaction with numerous suppliers to fulfill requirements of several thousand Kilogram of coffee cherries. The coffee cherry from each supplier ship directly to each plant and makes further process before provide to export market. Due to making many visits to suppliers some of which are for picking up very small quantities of coffee cherry and operating a number of truck, the companies are in high cost charge of transportation and rents vehicles trucks. A coffee processing company faced with the decision of selecting the right logistics plan for their network. In most cases, either suppliers or processing companies reminded in control of the primary supply. The exporter on the other hand, controls the secondary supply. As a result, logistics has become part of business environment of the coffee processing industries. Specifically, this means that the cost of transport is no longer included in the price that suppliers charge to the processing industries. Suppliers incur the costs of primary transport and therefore they negatively affected by many small refill orders. The processing industries on the other hand, only incur inventory costs and therefore have an incentive to decrease their order sizes. Because of this lack of overall view on logistics costs, the optimal balance of transport and inventory costs in the replenishment policy of processing industries seldom achieved. The processing industry not directly charged for the higher transport costs that are a consequence of the increased frequency of delivery. The increasing amount of coffee cherries inventory are forcing processing industries to focus on inventory reductions. In recent years, this has resulted in more frequent and smaller fill orders delivered by the suppliers to the processing industries warehouse (Cruijssen, 2006).

2.2.1 Inbound supply chain

Inbound supply chain consists of flows and operations for parts from supplier plants to assembly plants. The collection of components from suppliers can be done through direct flows or using milk run deliveries, i.e. consolidation of parts from several suppliers in one round trip. Once collected, parts are delivered to inbound distribution centres then sent to assembly plants where cars are manufactured. Each plant is designed to operate at a particular production rate measured using the number of vehicles produced per hour. Cross–docking is a well–known practice in logistics, consisting in unloading materials from ingoing trucks and loading them in outgoing trucks with little or no storage in between (Kchaou-Boujelben, 2013). Gross and Butz (2014) indicated that the metrics for assessing and measuring the transports in the network designed as nonlinear functions in inbound transportation lies in economies of scale. In further Das et al. (2017) determined that a comparison based pathway using optimization tools and techniques that a company can reduce overall logistics costs by identifying the cost factors and utilizing them properly. Inbound logistics is also an important element of logistics operations, including a wide range of activities from supplier selection to the delivery of coffee to processing plants. Effectively managing the inbound moves of red cherries coffee from a large number of different suppliers (farmer, collector) is vital for controlling overall costs (Dong, 2014). An effective inbound logistics can help to get higher quality of coffee products, more cost savings and increased export quantities and also reducing total overhead and wastage. A general view is necessary to design a logistics network that accommodates various facilities and related operational processes. In addition, the design also needs to consider the constraints that arise due to the change in physical characteristics of coffee beans such as weight and freshness as well as transportation constraints (López and Chaudhry, 2020).

2.2.2 Supply chain network designing

The thesis of Oti (2013), discusses a number of freight consolidation strategies implementable in inbound supply chains. One principal area of focus and finding was on the savings potential from aligning order frequency across multiple for shipments that would be destined for the same cross-dock hub would add incremental savings. The savings potential quantified for less than truck load shipments in this analysis ranged from 10 - 30% and hence the mid-point, a 20% saving rate, on less than truck load first leg rates was used to account for this opportunity in the more aggressive model run. Supply chain network design determines the structure of a logistics and impacts its cost and performance. Its goal is to design an efficient network structure or to reengineer an existing network to increase its total value (Ghiani et al., 2004). Gomes (2016) stated about supply chain network (SCN) design and planning became important to examine the social and environmental impacts. The design and planning is even more challenging in the food industry, concerning product perishability and short shelf lives. Supply chain network is the backbone of how materials are turned into products, and how the products are delivered to the customers. In addition Rosiana et al. (2017) discussed the quantity of Indonesian Robusta coffee supplied to the international market depends on secured supply of domestic raw materials and the efficiency of supply chain network. Efforts to ensure the domestic coffee supply do through efficiency analysis on each member of the supply chain that forms the supply chain network. There are two major functions of transshipment facilities: consolidation and break-bulk. Consolidate shipments are used to combine shipments from many scattered origins into larger loads. Break-bulk shipments provide an opposite function to split a large load into smaller shipments (Yang, 2013). In business logistics, the network planning process consists of designing the system through which commodities flow from suppliers to demand points, while in the public sector it consists of determining the set of facilities from which users serviced. In both cases, the main issues of are (Ghiani et al., 2004) to determine the number, location, equipment and size of new facilities in each stage and the flow of material/product throughout the network are made during the design process. The first step in building a logistics network design model is data collection. Related data includes transportation data, facilities data, current flows, and flow units. Transportation data consists of mainly inbound data. Facilities data consists of cost and capacity data. Costs can be further broken up into fixed costs of facilities and variable costs of units. The flow data consists of volumes flowing between nodes, which is essential in understanding the impact on network design (Watson et.al, 2014).

2.2.3 Methods for solving supply chain network design models

Supply chain network design models are solved through different methods, from exact mathematical solvers to near optimal algorithms. Considering the high- dimension (many variables) and complexity of logistics network design problems, selecting an adequate solving method can be challenging. These methods can be classified into four categories: mathematical techniques, simulation, heuristics and metaheuristics (Murry, 2020). Oti (2013) study the utilization of the "hub and spoke" distribution framework as an opportunity for the inbound supply chain to lower cost and improve transit time performance. Distributing products from multiple sources to multiple destinations (Berman and Wang, 2006) focused mostly on the issues of distribution network design with or without transshipment centers (hubs). They formulated as a nonlinear integer programming model. The objective function is highly nonlinear and neither convex nor concave. A greedy heuristic proposed to find an initial solution and an upper bound. A heuristic and a branch-and-bound algorithm developed based on the Lagrangian relaxation of the nonlinear program. Dong (2014) analyzed two major categories of suppliers. The first supplier category includes suppliers with small quantities of raw material so daily pickups may not be required. A new approach proposed that considers pick-up frequency and spatial design as joint decisions to minimize total logistics (transportation plus inventory) cost. The clustering-based optimization uses an approximation to the actual cost of a routing solution without actual route construction. A second category of suppliers ships moderately large volumes to a single plant but not enough to fill a truck themselves. One commonly used process is to have plant based collection routes on a daily basis that stop at multiple suppliers and return to the plant.

Mixed integer programming adds one additional condition that at least one of the variables can only take on integer values. The technique finds broad use in operations research. Goal programming is a variation of linear programming in that it considers more than one objective (called goals) in the objective function. The model solutions are very much like the solutions to linear programming models (Taylor III, 2013). Chen (2016) classified GP as Preemptive and Non-preemptive based on the different ways priorities are determined for each goal. In the Preemptive GP, ordinal ranking used to assign goals to different priority levels from highest to lowest. The goal assigned to a lower priority will not consider until satisfying the goal with a higher priority. In the non-preemptive GP, pre-specified weights are assigned to each goal and the objective is to minimize the weighted sum of goal deviations. In this case, the goal program can reduce to a single-objective optimization problem. It often becomes difficult in arriving at the overall best decision when a problem facing of multiple conflicting criteria. To introduce the topic of multi criteria decision making, the researcher consider a technique referred to as goal programming. This technique has developed to handle multiple criteria situations within the general framework of linear programming. As mentioned (Taylor III, 2013) a goal-programming model is very similar to a linear programming model, with an objective function, decision variables, and constraints. Like linear programming, goal-programming models with two-decision variables can solve graphically and by using QM for Windows and Excel. In addition, Chen (2016) presents under goal programming, each objective given a goal/target to achieve, and the relative importance of achieving those targets. Optimization models have successfully applied to the decision problems, and relevant research continues to seek methods that are more powerful. The logistics network models include a number of formulations ranging from linear models to non-linear ones, and from deterministic models to stochastic ones. Georgise et al. (2020) development a model for coffee processing plant location selection by using AHP method to optimize transportation cost and delivery time.

2.2.4 Cost and delivery time

Two of the most widely considered performance measures in logistics are cost and delivery time. In general, the costs of transport activities and nonphysical handling activities, such as an inventory and related time costs constitute the majority of logistics costs. An optimal shipping strategy for logistics often involves a tradeoff between inventory and transportation costs (Amaral & Guerreiro, 2014). To select distribution strategy for delivering a family of products from a set of suppliers to a set of plants (Berman and Wang, 2006) identified that the total transportation, pipeline inventory, and plant inventory costs are minimized by using non-linear integer programming model. Similarly (Vaisi and Moghaddam, 2015) presents a non-linear integer programming model for a cross-dock problem that considers the total transportation cost of inbound and outbound trucks from an origin to a destination and the total cost of assigning strip and stack doors to trucks based on their number of trips and the distance between doors in cross-dock. Also Das et al.(2017) discussed that full capacity utilizations of vehicles ensure low carrying distribution cost and also a key factor to ensure optimization of logistics cost. If company uses higher carrying capacity vehicle it will reduce the fuel cost as well as overall logistics cost. Trip utilization is one of the major factors for higher efficiency and higher responsiveness of logistics. Bonassina et al. (2018) stated that the logistics costs include the costs of acquisition, handling, storage and transport, inside the concept of integrated logistics. The control and monitoring benefit of the organization, such as the possibility of cost reduction, waste reduction and optimization of resources.

2.3 Coffee processing and quality in Ethiopia

There are many differing views as to what constitutes quality. Teshale (2017) defined product quality is a means to integrate features that can meet consumers need and gives customers satisfaction by altering products to make them free from defects. Coffee quality is critical importance to the coffee industry and could be affected by several factors from farm to cup including the post-harvest processing methods. There is different coffee processing methods under this; Ethiopians has used 29% of coffee is processed by wet (washed) method to produce green parchment coffee and 71% by dry (natural sundried) method to obtain cherry coffee. The wet processing plants very far from the farm places that lead to the majority of household farmers and suppliers to transport their coffee beans/cherry long distance which creates unfavorable conditions to them. On the one hand they are forced to travel long distances, on the other hand, they are not obtaining enough returns since damage happened to cherry due to improper transportation facilitation along with the distances that degrade the coffee beans quality. This also directly affected the competitiveness of investors in the areas and forced to supply less volume of quality coffee to the international market which is not attractive as compared to the production volume of the area (Georgise et al. 2020). And also (Marsh et al., 2006) one of main reasons for poor coffee quality is mould and the possible OTA generation occurring during the drying stage of the coffee processing. Slow and uneven drying and rewetting will result in mould generation and quality problems (Musebe and M. Mitiku, 2007). International trade centre (2011) defined quality control helps to reduce waste and loss during the processing and drying of coffee, and plays a role in the general move towards more sustainability in the coffee industry.

2.3.1. Key steps of wet coffee production process

Floating:

The purpose of the floating is to separate good cherries and bad cherries, a kind of sorting technique. Bad cherries will float and good cherries will sunk down. Good cherries pulped with machine. It was found that the processor who practiced wet method followed sorting and grading of fresh cherries after harvesting. He sorted out fresh through floatation technique. The cherries were put into bucket of water and floating cherries were separated and processed separately. The practice of grading fresh cherry after sorting was passed through the wire mesh of $16mm^2$ 30 sizes to maintain uniform size of the cherries. The cherries that pass through the wire mesh holes were considered as down-graded cherries and processed separately. Only those cherries that did not pass through the holes were processed for the export market (Subedi, 2010).

Pulping:

As stated by (TechnoServe team, 2013) coffee washing stations wet mills serve several different functions during the post-harvest processing phase. The wet mill is the place where cherry is pulped (the outer skin is removed) using a machine. Cherries pulped with pulping machines that operated mechanically. Mostly cherries pulped directly after harvesting in the coffee processing plant; only few farmers pulps cherries at their home. In a study by Daniels (2009), de pulping is the act of removing the fruit surrounding the coffee seeds. This accomplished using a de pulping machine with a rotating cylinder of copper sheeting perforated to create lines of small, raised teeth. The fruit grabbed by the teeth and squeezed against a stop, expelling the coffee beans, while the skin continues around washed away. Fruit size can vary significantly, which leads to beans which are not depulped and other beans which damaged by the machine. Scraps of the fruit skin, unpulped fruits, and damaged beans removed by hand from the samples, as these can give the coffee undesirable flavors.

Fermentation:

After the red coffee cherries pulped TechnoServe team (2013), presented that the beans fermented to break down a sticky mucilage layer. Coffee processers bring their fresh and wet coffee parchments are to fermentation site after pulping. At fermentation area, coffee beans fermented for 24-48 hours. Most of Yirgacheffe coffee processors apply wet fermentation. For this purpose, coffee beans put in water for one night (12-24 hours). Karimi et al. (2021) stated that commercial enzymes are used to fasten the fermentation process. This is commonly practiced in Brazil to avoid long periods of fermentation. These can be used especially in cold areas to enhance fermentation. According to processors, fermentation is a critical step that has an important impact on the taste of coffee. Wet fermentation known to produced better taste compare to dry processing. For this reason, Yirgacheffe coffees perceived by exporter and processors to produce a better coffee quality, compared to other regions.

Washing:

In the morning, coffee processers wash their parchment coffee to remove the mucilage and to separate remaining pulp from coffee parchment. Fermented coffees brought to rivers or swamps and skin residue separated from parchment with hand (Susila, 2005). During washing process, coffee processers separate good and bad coffee by floating. They place in different baskets and process separately. For coffee processers in Yirgacheffe, the bad beans marketed with lower price in home market. For one kg of fresh cherries, from 2 to 10 litters of water are required. The ratio in weight between a fresh cherry and a green bean is about six. Therefore, from 12 to 60 litters of water are required to produce 1 kg of washed green coffee (UNIDO project team, 2016).

Drying processing:

Despite the fact that storage is less complicated, drying coffee is comparatively more difficult to carry out than other products, due to its high initial moisture content, generally around 60%. Therefore, the speed of deterioration at the first stage of the drying process is higher, potentially causing a reduction in the quality of the product. Therefore, coffee must be dried immediately after harvest and stored in conditions that allow the maintenance of the quality of the product after drying (National Food Safety Programme team, 2004). The harvested coffee must be placed immediately in the vehicle, or in sacks, and transported for drying on terraces. The harvested coffee should never be stored for periods of time either in vehicles or the sacs, so as to minimize possible fermentation, which can take place due to the high moisture content of the fruits. Dry processing can do through the natural method. Coffee fruits, after washing and the separation of fractions containing ripe cherries and immature fruits, on one side, and floats on the other, are forwarded for drying on terraces or in artificial dryers. In Yirgacheffe after washing coffee beans directly dried under the sun by laying the bean in their plant yard, mostly on the raising bed. Drying started at 08.00 am and finished at 6.00 pm. If during drying process is rainy, processor will bring the coffee to the house or laying coffee on the raised bed and cover with plastic. Coffee after washed in water and then sorted and dried on raised bed under full sunlight for up to two weeks until they reach an ideal moisture level (TechnoServe team, 2013).

The parchment is spread on layers not exceeding 0.5 inches on wire mesh tables and turned frequently to encourage rapid evaporation and at the same time it is fully exposed to the sun. This stage is normally completed on the same day of final washing. While stirring the parchment to ensure uniform drying, discoloured and broken beans are sorted. White drying stage (44-35% mc) at this stage, the parchment is white and it is easy to sort out the defective beans. Drying at this stage is made slow and controlled, and during very hot days, the coffee is covered during the hottest part of the day, (from 10.30 a.m. to 3.00 p.m.) in order to avoid cracking of the parchment cover. This stage can be mechanized with well controlled temperatures to avoid cracking of the parchment. Soft black stage (35 -25 % mc) at this stage the parchment attains is final black colour. In Kenya, it is recommended to only sun dry in this stage, for the coffee is said to be photosensitive and the sun light makes the coffee to acquire some preferred quality characteristics. The coffee is fully exposed to the sunlight for a period of 48 -50 hours. Mechanical drying is discouraged at this stage. Hard black stage (25 -12 % mc) at this stage the parchment is hard dark in colour and can be done rapidly without any loss of quality. Fully dry and conditioning (12 -11 % mc) this is done in ventilated stores or bins in order to even out the moisture of the coffee. At this moisture content, the coffee can be stored in well controlled environment without any effect on quality (Karimi et al., 2021). Similarly Batdorf and Bronson (2018) stated that the coffee is spread on the patio to a depth of 2-3 cm for washed coffees and 5-6cm for natural process. To facilitate even drying it is necessary to constantly turn (rake) the coffee throughout the day (approx. 15-17 times). Initial drying or skin drying reduces the moisture from 55%- 60% down to 20%-25%. At this point the coffee can be layered slightly deeper. The second stage of drying reduce the moisture from 20-25% down to 10-12%

Hulling:

Padmapriya et al. (2013), described the dried cherry is then hulled to remove the pericarp. This can do by hand using a pestle and mortar or in a mechanical huller. The mechanical hullers usually consist of a steel screw, the pitch of which increases as it approaches the outlet so removing the pericarp. Hulling achieved by creating friction among the beans lying along the screw of machine. It is crucial not to heat the beans during hulling otherwise it will affect the final colour and taste of coffee. Depending on the conditions that the coffee has been dried in, or even due to changes that might occur during storage, it can be convenient to take the product carefully through ventilated storage driers, in order to homogenize the moisture content and make the material suitable for hulling. In case a high temperature drier used to solve a high humidity problem, care must take not to hull the product while it still warm. Natural cooling of the beans avoids them breaking. The actors participate in the coffee value chain farmers (grow the coffee crop for living to use money obtained from sale of coffee for basic needs), middlemen/intermediaries (for collection of coffee from farmers and supply to domestic/local market, exporter or Ethiopian commodity exchange), unions or cooperatives associations, processors (hullers and wet mills), exporting firms and local roasting firms (Debelo, 2017).

Storage of parchment:

Proper storage aims at preserving coffee quality by maintaining the right moisture content, protecting coffee from damage by insects or molds and preventing contamination. It also facilitates identification and handling of coffee lots. When storage conditions are too humid, coffee beans acquire a darker color and a moldy, fermented flavor hence loss of quality (Karimi et al., 2021).

2.4. Evaluating different coffee drying techniques

Preservation mainly involves the extension of the storage period of a product with the desired quality. Ghosh and Venkatachalapathy (2014) stated that several systems and methods such as sun drying, mechanical drying and hybrid drying have adopted for such purposes. Evaluations are made based on capital and operating costs as well as area requirement. Solar systems compared to different thermal dryer application options such as conventional thermal dryer and co-generation thermal dryer.

Drying of coffee is a critical aspect of coffee processing since the quality and price of coffee beans depends on how dry they are and also on the way in which they have been dried. Even though coffee has been cultivated for decades, the technologies used for solar drying are very limited. More than a dozen of drying methods are used in different areas ranging from a wooden dryer where the coffee is placed on boards and exposed to smoke, to the spreading of beans wherever there is space on: a straw mat, a sack or piece of canvas on the ground, an awning, under a bed or even in a rented courtyard in a nearby town. Coffee beans are sometimes dried in wood-burning ovens or in gas dryers (Karimi et al., 2021). Sami et al. (2014) investigate the effect of process parameters air mass flux ,initial moisture contents, distance between glass cover and absorber plate and length of collector cost ratio of indirect cabinet solar dryer. Mathematical model is developed and used to evaluate minimum drying cost under optimum drying conditions.

2.4.1. Direct sun drying

In the predominant smallholder sector, sun drying is the only feasible approach for economic reasons. Ghosh and Venkatachalapathy (2014) described that drying is one of the most important steps in the coffee processing. The use of natural sun drying process of coffee in terraces is still very common among the coffee producers, however, it requires high labour, and it is a time requiring operation and on dependency on the climatic conditions. As the coffee production increases the sun drying operation in terraces happen to be problematic in terms of coffee production operation. Ghosh and Venkatachalapathy (2014) reported that there are different types of sun drying method; drying ground yard is usually made of concrete, tiles or asphalt with a small slope (0.5-1%) to drain water. Depending on climatic conditions, sun drying of coffee in patios takes from 7 to15 days for parchment and from 12 to 21 days for cherries. Parchment requires more careful handling than cherry to avoid cracking and physical damage to the beans. In tropical areas, parchment often covered during the hottest hours of the day to avoid cracking caused by overheating. Tsegaye et al. (2015) studied that quality of coffee, physic chemical properties depends on the effects of altitude, sun drying methods, variety and cherry drying layer thickness on quality of coffee at Gomma-II. Different types of grounds on mesh wire, bricks floor and bamboo mats used and the thickness of layers. Coffee dried on mesh wire with thin layer thickness scored the highest raw quality mean values. Open sun drying is a simple and inexpensive way of drying coffee beans due to the availability of Sunshine. Efficient drying influences market quality, the development of flavor, final bean acidity and moldiness. Any adverse change in climatic condition can affect the drying process thus the final coffee bean quality. Due to the uncertainties in the weather, open sun drying may lead to a slow rate resulting in moldiness and the development of off flavors (International Coffee Organization Team, 2009). Long periods of drying can contribute to post harvest losses if the dried beans turn out to be of poor quality. These factors affect the final bean quality and their respective corresponding products. In similar Sahdev (2014) observed that open sun drying of products takes long time for complete drying. It can even take two to three days or even more. Moreover, the qualities of dried products do not meet the international standards. Experimental results showed that the traditional direct solar dryer taken 6 day to dry the cocoa beans while plastic roof solar dryer took only 4 day and produced better quality of produce because was completely protected from rain, animals and insects (Puello-Mendeza et al., 2017). The plastic roof solar dryer practically shortens the drying time of cocoa beans by two days. Similar behaviors using plastic roof solar dryer (greenhouse solar drying system) for agricultural products, coffee, fruits, vegetables, food grains, fish, herbs etc… are reported by (Sahdev, 2014).

Drying space limitations

The lack of adequate space for sun drying coffee can cause congestion in a coffee processing factory. Congestion can also occur where the cherry delivery to a factory exceeds its design cherry intake capacity and in the presence of irregular rains. Such adverse conditions can affect the coffee quality perhaps by inducing mould formation. The quality of the coffee from all the treatments was poor possibly due to the prolonged drying (12-20 days), thick coffee layers (4-8 cm) among other factors. Since fully dry parchment is normally at equilibrium with a relative humidity of 60% at20 °C, coffee can dry to about 12% beyond which it can take as many as 8 days without attaining the fully dry status as long as the wrong RH% prevails. However, a suitable 9th day can see the coffee through to full dry within 2 hours only. At the same time, the drying rate might be too slow from the soft black stage during overcast condition due clouds. For these and other reasons, the very wet coffee can miss drying space on the tables because of congestion (Mburu, 2021).

2.4. 2 Mechanical driers

Ghosh and Venkatachalapathy (2014) concluded that in mechanical drying the beans are heated by the passage of hot air which also carries the moisture away. Temperatures must monitor during natural and artificial drying. Coffee temperature should not exceed 40°C for parchment and 45°C for cherries. It often thought that overheating could only occur in mechanical dryers. There are mainly 2 types of dryers, static and revolving. In revolving dryers, there are tray dryers with stirrer, vertical dryers and rotary dryers, cascade driers, column driers, and flex driers. In all the cases woods, coffee husk, other solid fuel, fuel oils, diesel, gases used as the main fuel or energy sources. In case of mechanical dryers, drying time varies from 20-60 hours according to the type of driers used. National Food Safety Programme Team (2004) stated that it is necessary to take special care in the control of temperature of the mass of beans, from the moment in which coffee presents moisture content lower than 35% upper basis. For moisture contents lower than this value, depending on the drying system used, there is a tendency of the temperature of the mass of beans to equilibrate with the temperature of the drying air. This tendency caused by the difficulty of migration of moisture from the inner layers to the outer layers of the beans. Ghosh and Venkatachalapathy(2014) reported that artificially dried coffee beans are of inferior quality on the world market. Employing artificial dryers in the drying of the beans make the beans more brittle and yields a more cracked or broken bean. Artificial drying of coffee beans can also see as economically costly due to the use of electricity. In addition, (SCHIAVONE, 2011) summarized that when compared to complex solar drying systems require significant financial investment and considerably intensive construction processes. Additionally, many of these designs incorporate the use of mechanized systems, highly dependent on electricity, which often limited or absent in rural areas of developing nations, commercial applications of developing countries. Gachen et al. (2020) the cost-benefit ratio of the solar dryer is 3.52 compared with a biomass fired dryer of the same capacity and 1.12 compared to natural sun drying.

2.4. 3 Hybrid drying systems

This new method adds anon-solar thermal source to drying on a traditional terrace by pushing heated air through perforated ducting around which the coffee heaped. The heaps can spread during the day to take advantage of solar input and heaped under aplastic cover overnight where it continues to dry as the warm air conducted through it. In order to increase the efficiency of coffee drying using solar radiation, proper innovation or application needed. Owing to costly, limited, and non-environmentally friendly fossil fuels, solar drying is becoming a popular option to replace the mechanical thermal dryers.

The advantages of a solar dryer compared to mechanical drying listed by Haque (2013):-

- ✓ It is cheaper as a solar dryer can built from local building material for example, wood, plastics and chicken wire, because it is smaller.
- ✓ It is environmental friendly, as a solar dryer does not need fuel, gas or electricity to provide energy for drying.
- ✓ It is suitable for remote areas as the farmers will not have to worry about location and special set up for this type of dryer.
- ✓ It is user friendly and does not need a complicated operating manual to run it.

2.4.4. Greenhouse drying facility

The main purpose of greenhouse technology is to provide a good drying environment for successfully drying of coffee high quality product through the processing period. The overall design of the solar dryer mimics the design of a greenhouse that used for cultivating seedlings for agricultural purposes. The design of the greenhouse solar dryer are frames of inflated structure covered with a transparent material in which coffee are drying under controlled environment conditions Obimpeh (2018). The use of greenhouse dryer is applied to the drying of agricultural products, highlighting the drying of coffee, due to its great potential from the experimental and energy saving viewpoints. There are different types of solar dryers that have been designed and developed in some agroindustry sectors, producing different degrees of technical performance Bryan Briceño-Martínez, et al.(2020). Greenhouse type solar dryer was designed with a total surface area limited drying space and capacity. Use of green houses for coffee drying is enables drying to be done throughout the day and shortens the coffee drying period. Drying can be done even in rainy weather. It is a practice that can be borrowed since it prevents rewetting and saves on labor costs. However, care should be taken to avoid overdrying due to high temperatures experienced in the green house. Raised shade cover during the white stage of fully washed coffees- This ensures cool, slow drying leading to good quality beans that are not cracked. This can be borrowed and developed further to reduce the cost of establishing such shades (Karimi et al., 2021).

2.4.4.1. Greenhouse layouts

When developing plans for the inside of greenhouse, we needed to decide how the product could be dry. Beds should arrange to allow as much freedom of movement as possible but still maximize space utilization. Well-designed layout, no more than 25% of the space uses for walkways. To develop the plans, calculate how much bed and aisle space we have. We can do this by measuring the bed and calculating their area. Subtract this area from the inside area of the greenhouse to get the amount of walk area.

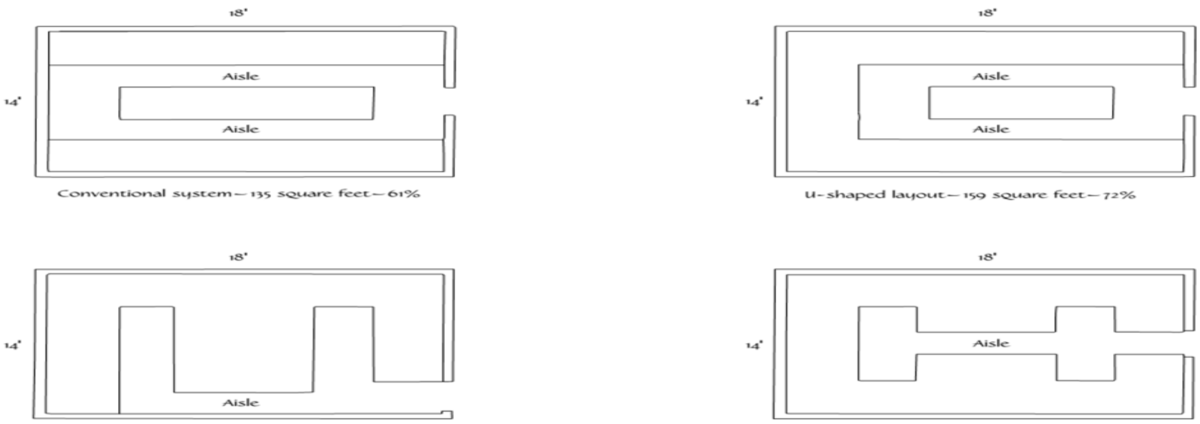


Figure 2.3 Bench system layouts sourced by (Bartok, 2000).

Bartok (2000) Benches should be arranged to allow as much freedom of movement as possible but still maximize space utilization. Bench system layouts for a 4.267m by 5.486m greenhouse showing alternate arrangements and amount of bench space. Figure 2.4 shows a comparison of bed layouts for a 4.267m by 5.486m greenhouse. Usable space increases from 61% to 72% when the center bed shortened and the side beds are connected. 60.96 cm wide walkways are adequate in most greenhouses. It also results in more sunlight reaching the drying bed. Drying beds can build as movable boxes, or they can fix permanently to the greenhouse floor. They often used along the south side glazing to allow more sunlight to reach the drying coffee on the rear beds. To dry a certain food products, one has to make sure that the air drying temperature does not exceed the maximum permissible temperature of the product as different products to be dried have different maximum permissible drying air temperature. The drying air temperature is usually adjusted in the solar dryers by changing the number of fans installed and also changing the heat collector length to achieved optimum air drying temperature as in the solar tunnel dryer (Weiss and Buchinger, 2003). Solar dryer installed with photovoltaic system is preferable as the drying air in the dryer controlled by solar radiation. The photovoltaic system can use in the area where no electric grid connection is available. The plastic covering the dryer needs constant replacement to avoid mold and opaque problem. However, this problem may be solved if the cover is replaced with polycarbonate cover for solar tunnel dryer. Solar dryer when operated fully in a year, drying different food products would reduce the payback period and therefore would justify the alternative choice of choosing solar dryer as an alternative dryer (Olguin and Durán, 2017).

Haque (2013) listed the advantages of using a greenhouse solar dryer as compared to open sun drying:-

- ✓ It is faster as in the food dried inside the solar dryer will be heated with solar radiation concentrated by a collector to generate a higher air temperature.
- ✓ It is more efficient since the food can dried faster and therefore will spoil less. Thus, less food product will be lost.
- ✓ It is hygienic. The solar dryer is an enclosed system that prohibits animals, insects, dust and any other contaminants from damaging the dried food products.

2.4.4.2. Facilities of greenhouse solar dryer application examples

There are many full-scale examples and studies about greenhouse solar driers in the world. Esquivel et al. (2018) studied that analyzes the efficiency of parchment coffee drying process in a forced greenhouse type solar dryer. The environmental conditions in the solar dryer measured during a day of operation, in which the air introduced to the dryer by means of two driving fans and leaves the other side, with two extractor fans.

Figure 2.4 Trays distribution for drying coffee inside the GSD (Esquivel et al., 2018)

By the end of 2019 proposes for implantation of coffee drying greenhouse with parabolic cover and adapted modular structure (Briceño-Martínez et al., 2020) demonstrated that the design of the assembly couplings facilitates their mobilization, reduces costs and allows the application of accessible materials for the solar parabolic dryer.

Figure 2.5 Greenhouse type solar dryer with drying beds by (Briceño-Martínez et al., 2020).

2.5. Literature research gap

The review of the available literature reveals that there is a gap in the literature focusing on modeling the coffee inbound supply chain network. Arguably, supply chain management has been explored regarding the application of in Ethiopia. Although supply chain network design has been touched in the area of agriculture, a gap is clearly seen on coffee inbound supply chain network design and, more precisely, in Ethiopia. The literature reviewed show that little has been exploited regarding the application of coffee SCM principles in order to link coffee production, processing and marketing in this sector. Some researchers such as Dilebo (2019), Tsige (2018), Duloma (2017) and Debelo (2017) have attempted to explain what is happening in some segments of the coffee supply chain but not deeply. A somewhat relevant model to the current research is the one presented by (Georgise et al., 2020). They found a positive relationship when the firms practiced coffee processing plant location selection model which minimize delivery time and cost of transporting their coffee to the processing plant. However, the current research problem is different because it incorporates both new and the previously establish processing plant decisions. Although mixed-integer nonlinear programming applied to the transportation-planning problem as shown in the reviewed studies, none of these models deals with the coffee processing industry and thus none focus on service times. Although minimizing total cost is an important criterion but for some services, criteria such as minimizing delivery time may be equally important that has to be accounted. Very few coffee drying optimization studies have been applied to coffee production (Sami et al., 2014). However, the current research problem is different because it incorporates inbound supply network decisions. Since it is difficult to analyses the entire supply chain, this study design transportation, and coffee drying processing support activities along the entire coffee inbound supply chain in order to fill the existing gap. Table 2.1 summarizes the previous presentation. The first column gives the authors of the articles, the second column presents the topics of the article, and the third column shows the main content in the articles.

Table 2.1 Summary of articles related to this thesis

Authors	Title	Main content
Berman and wang (2006)	Inbound logistic planning: minimizing transportation and inventory cost	Selecting the appropriate distribution strategy for delivering of products from suppliers to plants so that the total transportation, pipeline inventory, and plant inventory costs are minimized.
Rosiana et al.(2017)	Efficiency analysis of Indonesian coffee supply chain network using a new DEA model approach: Literature review	Efficiency analysis is performed by using New DEA Model where analysis is done thoroughly on supply chain network which is connected by input and output variables
Duloma (2017)	An assessment of coffee Supply chain management practices the case of Guji and west Guji Zones,	To assess of coffee supply chain management practices from the farmers to export stage.
López & Chaudhry (2020)	Designing an efficient supply chain for specialty coffee from Caldas-Colombia	Design a cost-effective supply chain network model from Caldas to the Northeastern region of the United States for Café Botero’s specialty coffee.
Georgise et al. (2020)	Model development for coffee processing plant location selection by using AHP method: Case of Guji Zone, Ethiopia	Proposed an appropriate model to suit for optimal site selection that solves challenges during collecting and transporting their coffee to the processing center.
Olguin and Durán	Thermal and financial evaluation of the drying process of coffee bean in an active solar dryer type greenhouse	Evaluate the thermal and financial efficiency of the drying process of grain coffee washing in an active solar dryer type greenhouse.

CHAPTER THREE

METHODOLOGY

3.1 Description of the study area

Yirgacheffe is one of the woredas in the Southern Nations, Nationalities, and Peoples' Region of Ethiopia, named after its major town Yirgacheffe. Yirgacheffe district is one of the six districts of the Gedeo zone, which is located in the east central part of the Gedio zone at a distance of 37 km from the capital city of the Zone/Dilla and 127 km from Hawassa and is the highest producer of coffee in the Zone. Kochere, borders Yirgacheffe on the south on the west by the Oromia Zone, on the north by Wenago, on the east by Bule, and on the southeast by Gedeb. The Zone is located in the coordinates of 6^0 06′ to6^0 29′ North latitude and 38^0 09′to$38^0$31′ East longitudes. Agro-ecologically, the district exhibits 93% Weina Dega (Midland) and 7% Dega (Highland). It has the mean annual temperature ranging from 15.1^{o}c to 20^{o}c, elevation ranging from 1501 to 3000 masl, and average annual rainfall ranging from 1201mm to 1800mm (District BoFED, 2015). Yirgacheffe is the highest producer of coffee in the Zone. It contributed around 32.1% of the total washed coffee and 26.4 % of the total unwashed coffee produced in the Zone in 2017. The total annual production of coffee in 2016/2017 was 70546 qt, which was 30.1% of the total coffee produced in the zone in 2016/2017, which is 234061qt (Dilebo, 2019).

3.2 Research Design

The research has quantitative and qualitative approaches based on data collection from case studies and survey. In a qualitative approach regarding case studies, the research aims to gather an in-depth understanding about the postharvest processing and supply activity of coffee with regard to supply aspect in the coffee supply chain. The researcher uses this information to formulate the variables, parameters and constraints of the optimization model. First, gathered and analyzed information about the coffee supply logistics from different sources. This analysis led to understand the journey of coffee from the farms in Gedeo zone to the processing plant. It also allowed understanding the constraints in terms of time, shipping options and product transformation.

3.2.1. Primary source of data

Yirgacheffe coffee processing historical data: Alemayhu Yrdaw and their family Plc. does not have a documented structured channel for operations yet. Therefore, the information that the company can provide regarding operations is very limited. The researcher needed other sources to understand the current structure of the logistics of Yirgacheffe' coffee. Given the short time available and the logistical constraints to move around the zone, much of the data was collected through targeted interviews and through the cumulative technique from a variety of key actors in the coffee chain, including different kinds of private intermediaries, service providers and private sector organizations. Direct observations of the post harvesting activities were done by the researcher to gather the time spent for each major activity, cost of transportation and processing coffee, problems encountered, quantity and quality of product recoveries and losses in each segment of the processing system. The researcher conducted a primary analysis with this data to understand the origins for the coffee product, its capacity of supply, transportation channels and requirements for drying process.

3.2.2. Secondary source of data

Coffee industry literature: The literature review of the coffee production and its logistics is presented on Section 2.3. The researcher used that information to understand three points. First, stages of the production process and the location at which they take place. Second, the type of coffee move downstream in the supply chain. Finally, the characteristics of coffee quality through drying process time.

Preliminary analysis and insights: The analysis of the data and information gathered provided insights on different aspects of the coffee supply chain. The logistics network and facility design model involves two phases of data collection and analysis:

Transportation data: The goal here is to understand the costs and capacities associated with inbound transportation. Transportation costs are assumed to be linear in logistics network design with transportation volumes. This may not always be the case in reality; however, to build a model, need to find a linear approximation. There are several ways for that:

a. Using benchmark rates from other sources.

b. Analyzing historical data to determine average transport cost.

c. Using list prices.

Facilities data: Facility costs include both fixed and variable costs in the facility design model. Capacity is a key element in the facilities data. The capacity is the maximum throughput over a specified unit of time. Coffee drying is a post-harvest process that generally preserves coffee quality rather than improving it. Washed, natural, and honey processed coffees must all be dried at some stage of processing. There are two main factors that contribute to how a coffee dries: temperature and airflow. Coffee drying is also one of the longest processes in the post-harvest stage of production, and as a result, it is a major bottleneck point. Drying timelines vary depending on a number of factors, including weather conditions and processing method. While heat and airflow are the two major factors that influence how coffee dries, it is also important to focus on how well moisture can escape from the bean. Traditional drying method can be difficult if producers are not in areas where flat spaces are available for coffees to be laid out. Along with taking up more space, generally takes longer, and is more likely to cause a bottleneck. As a result, advanced dryers method are useful for processors who have limited space, and can also improve overall productivity by saving more time.

3.3. Inbound supply chain mapping

To illustrate Alemayhu Yirdaw and their family plc.'s supply chain network, it is important to understand the different types of facilities involved in the process, their locations, and the transportation options between them.

Facilities: There are five types of facilities within the coffee supply chain which include consolidation center, pulping machines, and dryers with or without controlled atmosphere, and plant warehouses. Product transformation occurs only at pulping/milling machines and dryers. This transformation generates physical changes in the coffee beans, affecting their weight, density, and shelf life. The model also considers multiple capacities for the drying facilities. This capacity depends mainly on the area and equipment used. It is important to consider the capacity, especially for those nodes that imply setting up new facilities. To determine the optimal shipping option can be used between each node, two key factors must be considered: 1) total inbound supply chain cost and 2) quality improvement by optimize transit time and reducing congestion.

3.4. General description of inbound supply chain network design problem

As indicated in the literature review cost is a fundamental factor that considered while designing and measuring the performance of a supply chain process. Cost functions decomposed between elements dependent on time, distance, loading, unloading and reloading. Procurement, inventory, transportation, warehousing and processing are important costs that are included in most models. The parameters chosen for the mapping are the delivery lead-time that currently used and transportation cost for each supplier to processing plant relation. In order to preserve the freshness and quality of red coffee cherries, those types of logistic network require a limited transportation deadline, an additional controlled storage conditions and an increased quality of end coffee products. The time, described in this study also incorporated in the decision making process so that systems are not only efficient but highly closer as well. The drying operation is one of the most important steps in the coffee post-harvest processing that influences the final quality of the coffee. Different facility of coffee drying methods and facility are evaluate in section 2.5 In this section, to present the formulation of the inbound supply chain network design model and the variables and parameters consider in the solution. The proposed model finds the shipping option of least cost and time from the supply nodes to the demand nodes within the network of feasible solutions. The best strategy for the firm will be the option that minimizes both criteria while taking into account the constraints.

Objectives: To minimize overall costs and lead-time

Overall costs: To observe the cost components of logistics from primary marketing center or supplier position to the existing plant warehouses, it observed general road condition and distance affect the total cost. Costs also added on supplier delivery price starting from the shipping position of supplier to plant warehouses. This cost included loading and unloading, central warehouses, warehouse rent and bank service charge, and administrative costs.

1) Inventory holding costs:

These include the cost of capital tied up in inventory as well as the cost vary according to the type of storage and handling systems used, together with the volume and throughput at the site. The size and type of site will thus be important, as will the location. Inventory holding costs at the warehouse and plant is based on the interest rate (that accounts for cost of capital, physical storage and cost of labor) and the cost of the product.

2) Transport costs:

Costs vary considerably with the number of shipments, weight of shipment, distance, and points of origin and destination. In addition, the choice of transportation mode may vary the costs considerably. Depending on the unit of analysis, the costs that support transportation can view in many different ways. One measurement of the transport cost is the cost per performed transport work or Kg kilometer, which stands for one Kg of goods that is transported one kilometer. This measurement is satisfactory when handling the physical flow.

[Transport cost (Birr/Kg) x Quantity (Kg)] / [Distance (km) x Quantity (Kg)] = Birr/Kg km

The number and location of sites within the distribution structure, and the associated throughputs significantly affect transport costs. Consolidation center (warehouse) numbers and location affect both primary transport and final delivery costs.

3) Drying facility cost:

After collecting coffee cherry from supplier to processing plant the raw fruit of the coffee cherry convert into the coffee parchment or coffee beans. Coffee is either processed by wet or dry methods. Under dry processing unpulped cherries are dried after harvesting. In the washing method, the cherries pulped immediately after collecting, followed by fermentation and washing to remove mucilage cover then parchment dried.

Table3.1. Operations along the coffee production process

Process	Location	Output Coffee Product	Final weight yield (kg)
Harvesting	Farm	Cherry coffee	1
Pulping and washing	Processing plant	Wet Parchment coffee	0.57
Drying	Processing plant	Dry Parchment coffee	0.218

Total fixed (construction) and variable (operational) cost of drying facility unit.

Cost functions for open sun drying facility

Fixed cost: - raised bed construction cost and lease cost for drying area

$df^{O} = A*C_l + Cb*Ab$

Where df^o is construction cost of OSD (Birr), A is the required base area of the open sun dryer at p (m^2),C_l is the unit lease cost of the open sun dryer (Birr/m^2) and C_b is the unit construction cost of the raised bed of dryer (Birr/m^2) Nd is number of dryer per batches

Variable cost: - labor cost, premium cost and inventory holding cost during drying

$dC^{O} = C_{lab}*Ndd/ Mwp_{ip} + C_p + Hcd$

Where C_{lab} is labor cost in birr per drying day and Ndd is number of drying day. C_p premium cost in birr per kg and Mwp_{ip} is amount of coffee product in kg, Hcd inventory holding cost of drying at OSD in birr per kg per day

Cost functions for greenhouse solar dryer facility

Design parameters of a greenhouse solar dryer are evaporation rate, coffee production rate, and final dryness. Drying in this system depends on mean ambient temperature, solar radiation, ventilation, and initial dryness of coffee parchment, which are the parameters independent of the size of treatment plant. Ventilation is also significant to increase the evaporation rate.

Fixed cost: - Greenhouse construction cost, raised bed construction cost, lease cost for drying area and opportunity cost. Then the capital (construction) cost calculated based on drying area. With these assumptions, the capital cost of the greenhouse solar dryer calculated as:

$df^g = A*(C_g + C_l) + Cb*Ab + C_{opp}$

$A_{d,P} = M_{e,p}/ e_{v,p}$

$M_{ew,p}=M_{wp}(1-DS_i/DS_f)$

Where df^g is construction cost of GSD at plant p (Birr), A is the required base area of the greenhouse solar dryer at plant p (m^2),C_g is the unit construction cost of the greenhouse solar dyer (Birr/m^2). C_{opp} is (deposit interest rate 5.5% of construction cost), $M_{e,p}$ is the amount of water that should evaporated to reach the desire coffee dry matter content at plant p (kg/hr), $e_{V,p}$ is the evaporation rate at location p (kg water/m2.hr), Mwp is the wet coffee loading rate (kg/hr), DS_i is initial dry solid and DS_f is final dry solid. According to Odhiambo (2015) and P. Pankaew (2019), C_g ranges between 2404 Birr/m2 and 7495.6Birr /m^2. In this study, it was taken as 2404 Birr /m2.

Variable cost: -

In calculation of the operational cost of the greenhouse solar dryer, energy consumption for ventilation, labor cost, inventory holding cost and axillary energy consuming cost was focused.

$dC^g_{ip}= e_G M_{ew} C_{ea} + C_{la} *N_{dd}/ Mp_{ip} + Hcd*Ndd + C_{SP} (M_{rw}*C_{p-w}(T_f-T_i) + m'_{ew}(hv - hf))$

dC^g_{ip} is the cost of operation of greenhouse solar dryer at p (Birr/kg), e_G is unit energy consumption for ventilation, M_{ew} is the mass of evaporated water from coffee at plant P, C_{ea} is unit average energy cost (0.5778Birr/kWh). Maintenance cost assumed to 2% of the capital cost and C_{la} the labour cost for drying operation birr/day and N_{dd} is drying date for greenhouse dryer. Closas et al. (2017) mean evaporation rates of greenhouse solar dryers can be calculated as:

$SMER= \frac{\text{amount of moisture evaporated}}{energy\ input\ in\ dryer\ system}$, e_{vp} = SMER* I

$e_{V,p} = m_p [(1-D_{si}/D_{sm})*I]/m_a (h_f-h_i)$

Where $e_{V,p}$ is the evaporation rate at location p (kg water/m^2.hr), m_a mass of air h_i enthalpy of liquid water, h_f enthalpy of evaporate water $DS_{i,}$ is the initial dry solid content (DSC) of the material at location p (kg solids/kg material).

Solar insolation on a modules surface obtained by using online calculation (Ather, 2020) in Yirgachefe (lat. 6^0) was select coffee harvested seasonal months in November, December, and January. Idowu et al. (2013) recommended that the optimum tilt angles for solar heating for periodic tracking of the sun in the region within latitudes 1° and 14° were predicted as∅+

25° for November, December and January; ∅+ 15° for February, September and October;∅−15° for August;∅−25° for May, June and July; and ∅ for March and April.

Tilt angle = 6^0 + 25^0 =31^0 , I= 8.5wh/m2*day

I= 8.5Kwh/m2*day =8.5wh/m2*8h =1062.5 w/m2

Based on the allowable maximum of coffee dryer temperature is 50^oc and average ambient temperature is 17.5 ^{o}c.

Amount of moisture to be removed:

The amount of moisture to be removed from the product, $m_{w,ei}$, in kg was calculated equation using for given by Akoyon et al. (2015) as follows:

$m_{w,e,p}$= m_p(Mi– Mf) / (100- Mf)

Where: m_p is the initial mass of product to be dried, kg; M_i is the initial moisture content, % wet basis and M_f is the final moisture content, % wet basis.

The quantity of air needed for drying:

Using Psychometric property of air and taking input air temperature of 20°C (dry bulb) and a relative humidity of 60%, the psychometric chart gives a humidity ratio of 0.012 kg water/kg dry air. When the solar collector heats air to drying temperature of 50°C (dry bulb), the humidity ratio remains constant. If on passing through the coffee, the air absorbs moisture until its saturation line. The psychometric chart shows the humidity ratio to be 0.0245 kg water/kg dry air. The change in humidity ratio is therefore: 0.025 - 0.012 = 0.013 and the corresponding dry bulb temperature is 25°C.For a humidity ratio increase of 0.013 kg water/ kg dry air, each kg of water will require 1/0.013 = 76.923 kg dry air.

From the gas laws equation

$PV = M_A RT$

V= $M_A RT$/p

Where;

P = is the atmospheric pressure = 101.3 KPa,

V =the volume of air in m^3.

M_A= the mass of the air in kg

T =the absolute temperature in Kelvin, and 25+273=298k

R = the gas constant = 0.291 kPa m^3/kg K.

Table 3.2 Constants and the values used in thermodynamic equation

Description	Symbol	Value	Unit
Average drying day	N_{dd}	5	day/batches
Ventilation consuming energy	e_g	0.093	kWh/Kg
specific heat of water	$c_{p,w}$	4.2	kJ/ kg-C
Maximum permissible drying temperature	T_f	50	^oC
Initial temperature	T_i	17.5	^oC
enthalpy of evaporate	h_v	2592.1	kJ/ kg
enthalpy of liquid water	h_f	209.33	kJ/ kg
Mass of wet coffee product	M_{wp}	0.87%d_{ip}	Kg/hour
Mass of evaporated water	M_{ew}	0.47 M_{wp}	Kg/hour
Mass of remaining water	M_{rw}	0.53 M_{wp}	Kg/hour
Mass of final evaporated water	M'_{ew}	0.082 M_{wp}	Kg/hour

Delivery lead time:

Deterministic lead times were used in the decision making process. In wet process red coffee cherry must deliver to the processing plant with in 8 hour after harvest due to quality problem and coffee is pulped until 6 am so the delivery time is must be fixed with given time interval.

Constraints:

The model can be constrained by the capacities of the warehouse and plant. There is a limit on the capacity of the vehicles rented for transporting the coffee cherry and the number of vehicles available. The resulting delays in transporting can have adverse effects in the processed coffee. The lack of adequate space for solar drying coffee can cause congestion in a coffee processing factory thereby impairing the capacity of the factory to receive coffee in a timely manner. The best strategy for the firm was the option that minimizes both criteria while taking into account the constraints.

Assumptions

With reasonable assumptions, a simple model is presented to provide a good solution that can serve as a guideline for the design and implementation of the distribution network.

- Demand for coffee cherry is deterministic

- Supplier processing lead times are not included
- Inventory holding costs at the supplier are not considered.
- The transportation cost includes rental charges (fixed) of the trucks and cost of fuel/gas (variable).
- For ease of modeling, the suppliers (farmers and collectors) grouped together.
- Locations of all entity known

The definition of variables and data used in this study are describe below where the researcher use period for measuring quantities period can be a day because red cherry must deliver to the processing plant with 8 hour after harvest due to quality problem.

3.4.1. Definition of variables, data and optimization model formulation

Index sets:

I Coffee cherries (either red or dry coffee cherry)

J A set of supplier/farmer or collector/ j

P A set of plant/processing industry/

F Number of frequencies of shipment

W Warehouse/consolidation center

D Total demand per period

Data/fixed parameter

W_c Storage capacity of warehouse (consolidation center) in quintal (100kg)

s_{cp} Storage capacity at plant ‘p’ in quintal (100kg)

Vcap Vehicle capacity in Kg of coffee cherry

$d^o cap$ Open sun dryer capacity in Kg of parchment coffee product

$d^g cap$ Green house solar dryer capacity in Kg of parchment coffee product

C_{ij} Cost per Kg of coffee cherry ‘i’

h_i Inventory holding cost / period of coffee cherry ‘i’ (includes cost of capital, cost of physically storing inventory and cost of labor)

Hc_{ijp} Inventory carrying (holding) cost of one Kg of coffee cherry ‘i’ supplied by ‘j’ held at plant ‘p’ Where, $Hc_{ijp}= h_i C_{ijp}$

Hcw_{ij} Inventory holding cost of one Kg of coffee cherry ‘i’ supplied by ‘j’ held at the warehouse (consolidation center). Where, $Hcw_{ij} = h_i cw_{ij} tw_i/12$

Hcd_{ip} Inventory holding cost of one Kg of coffee product dry at facility available at plant p $Hcd_{ip} = h_i * C_{ip} * Ndd_{ip}$

Tcp_{ij} Transportation cost of shipping one truckload of coffee cherry ‘i’ from supplier 'j' to plant 'p'

Tcw_{ij} Transportation cost shipping one truckload of coffee cherry 'i' form supplier 'j' to the warehouse (consolidation center).

$Tcwp_i$ Transportation cost shipping one truckload of ship coffee cherry 'i' form warehouse (consolidation center) to plant 'p'.

df^o Fixed cost of open sun dryer

df^g Fixed cost of greenhouse solar dryer

dC^o Variable (operational)cost of open sun dryer

dC^g Variable (operational)cost of greenhouse solar dryer

tw_i Time spent coffee cherry 'i' at consolidation center (warehouse) in hours

d_i Demand of coffee cherry 'i' required from supplier j in Kg per period

M_{wp} Weight of wet parchment coffee product at a plant p in kg per batches

f There is the frequency of delivery (f) which coffee cherry is delivered to processing industry consolidation center or plant warehouse. ($f = \sum_{I \in I_{jp}} d_{ij} x_{ij} / V_{ca}$)

N Maximum number of shipment require for transported coffee cherries to processing plant

Tt_{ijp} Transit time for delivering coffee cherry 'i' from supplier 'j' to plant 'p' (in hours)

Ttw_{ij} Transit time for delivering coffee cherry 'i' from supplier 'j' to warehouse (in hours)

Ttw_{iP} Transit time for delivering coffee cherry from the warehouse to plant 'p' (in hours)

LTw_p Lead time for delivering coffee cherry from the warehouse to plant 'p'(hours) (tw_i+Ttw_{ij})

For model the decision variables are defined as follows

The load consolidation strategy seek to implement works off the basic idea that cost can be saved by consolidating coffee cherry early to allow for more economical high utilization trucks to carry coffee cherry over the longer distance of the transit. To that end, the optimization model is evaluating two alternatives for coffee cherry creating consolidates or ship direct. The objective function is to minimize the total inbound supply chain cost which is defined as the combination of costs from direct arcs and load consolidation arcs from changes in transit time as a result of the new coffee cherry routing plus drying cost with open sun dryer or with greenhouse solar.

x_{ijp} 1 if coffee cherry 'i' is shipped directly from supplier /collector 'j' to plant 'p' 0 otherwise

y_{ijp} 1 if coffee cherry is shipped from supplier / collector 'j' to the warehouse for plant 'p' 0 otherwise

dx_{ip} 1 if coffee product is dry with open sun dryer 0 otherwise

dy_{ip} 1 if coffee product is dry with greenhouse solar dryer 0 otherwise

f_{ijp} Number of shipment per period from the supplier 'j' to plant 'p'

fw_{ij} Number of shipment per period from the supplier 'j' to warehouse (consolidation center)

fwp_i Number of shipment per period from the warehouse (consolidation center) to plant 'p'

A^o Required area for drying coffee product in open sun dry

A^g Required area for drying coffee product in greenhouse dry

Objective function

The model objective1: Minimize total costs (inventory transportation and drying facility).

Total cost = Inventory costs + Transportation Costs + drying facility cost

Inventory costs incurred at the plant, and consolidation center:

At plant inventory cost= $\sum_i \sum_j \sum_p Hc_{ijp} d_{ip} x_{ijp}$

At consolidation center (warehouse) inventory cost= $\sum_i \sum_j \sum_p Hcw_{ij} d_{ip} y_{ijp}$

Transport Costs:

Shipped from supplier to plant = $\sum_i \sum_j \sum_p Tc_{ijp}\ f_{ijp}$

Shipped from supplier to consolidation center= $\sum_i \sum_j Tcw_{ij}\, fw_{ij}$

Shipped from consolidation center to plant= $\sum_i \sum_p Tcwp_i\, fwp_i$

Direct drying with open sun dryer= $\sum_i \sum_p (df_{ip} + dc_{ip} Mwp_{ip})\, dx_{ip}$

Drying through greenhouse solar dryer (GSD)= $\sum_i \sum_p (df_{ip} + dC_{ip} Mwp_{ip})\, dy_{ip}$

Objective1:

$$\text{Min [total Cost]} = \left(\sum_i \sum_j \sum_p Hc_{ij} d_{ip} x_{ijp} + \sum_i \sum_j \sum_p Hcw_{ij}\, d_{ip} y_{ijp}\right) + \left(\sum_i \sum_j \sum_p Tc_{ijp} f_{ijp} + \sum_i \sum_j Tcw_{ij}\, fw_{ij} + \sum_i \sum_p Tcwp_i fwp_i\right) + \sum_i \sum_p (df_{ip} + dc_{ip} Mwp_{ip})\, dx_{ip} + \sum_i \sum_p (df_{ip} + dc_{ip} Mwp_{ip})\, dy_{ip} \quad 3.1$$

Constraints

$\sum_j x_{ijp} + \sum_j y_{ijp} = 1\ \forall$ coffee cherry i, plant p 3.2

$\sum_p dx_{ip} + \sum_p dy_{ip} = 1\ \forall$ coffee cherry i, plant p 3.3

$\sum_i \sum_j d_{ip} x_{ijp} \leq s_{cp}, \forall$ plant p 3.4

$\sum_i \sum_j d_{ip} y_{ijp} \leq w_c$ 3.5

$d_{ip} x_{ijp} \leq \sum_f f_{ijp}\, v_c\ \forall$ Coffee cherry i, supplier j, plant p

$d_{ip} y_{ijp} \leq \sum_f fw_{ij}\, v_c\ \forall$ Coffee cherry i, supplier j, plant p } capacity of the vehicle 3.6

$d_{ip} y_{iwp} \leq \sum_f fwp_i\, v_c\ \forall$ Coffee cherry i, supplier, plant p

$\sum_i (\sum_j \sum_p f_{ijp} + \sum_j fw_{ij} + \sum_p fwp_i) \leq N\ \ \forall$ number of shipment 3.7

$\sum_i \sum_p Mwp_{ip}N_{dd}dx_{ip} \leq dr^{o}_{cap}$, ∀ plant p 3.8

$\sum_i \sum_p Mwp_{ip}N_{dd}dy_{ip} \leq dr^{g}_{cp}$, ∀ plant p 3.9

f_{ijp} fw_{ij} , fwp_i ,> 0 , ∀ i, j, p positivity constraints 3.10

f_{ijp}, fw_{ij} , fwp_i is integer ∀ i, j, p Integer constraints: 3.11

A > 0, ∀ i, p (Non-negativity constraint) 3.12

x_{ijp}, y_{ijp} dx_{ip}, dy_{ip} ∈ {0,1} ∀ i, j, p Binary variables 3.13

The objective function1 (3.1) minimizes the total costs of inventory, transportation and drying facility of coffee. Constraint (3.2 and 3.3) ensures that only one option selected. The amount of coffee cherry 'i' flowing into the plant/ warehouse/ is limited by the capacity of the plant / warehouse/ (constraint 3.4 and 3.5). (Constraint 3.6) to ensure that no coffee cherry shipment per period is exceeds vehicle capacity used and Constraint (3.7) ensures that the number of shipment per period from the supplier 'j' to plant p is limit by total possible number of shipment. Constraint (3.8 and 3.9) ensures that the total amount of coffee product in kilograms that goes out in pulping and washing station per day limited the capacity of drying bed. Constraint (3.10, 3.11, and 3.12) non negative integer and 3.13 binary. Area limitation is a constraint in some regions of Ethiopia, especially in Gedeo Zone, which highly densely populated. Different area constraints used to limit the area that can allocate to the coffee dryer facility.

Objective2:

Min.[delivery time] = $\sum_i \sum_j \sum_p Tt_{ijp}x_{ijp} + \sum_i \sum_j \sum_p Ttw_{ij}y_{ijp} + \sum_i \sum_j \sum_p LTwp_{ip}\, y_{ijp}$ 3.14

Constraints

$\sum_j x_{ijp} + \sum_j y_{ijp} = 1$ ∀ coffee cherry i, plant p 3.15

$Tt_{ijp} <$ 8hour, red coffee cherry i=1 3.16

$Ttw_{ij} + LTw_p <$ 8hour, for red coffee cherry i=1 3.17

$\sum_i(\sum_j \sum_p Tt_{ijp} + \sum_j Ttw_{ij} + \sum_p LTwp_{ip}) <$ 24hour, ∀ coffee cherry i, plant p 3.18

$d_{ip}x_{ijp} \leq \sum_f f_{ijp}\, v_c$ ∀ Coffee cherry i, supplier j, plant p

$d_{ip}y_{ijp} \leq \sum_f fw_{ij}\, v_c$ ∀ Coffee cherry i, supplier j, plant p } capacity of the vehicle 3.19

$d_{ip}y_{iwp} \leq \sum_f fwp_i\, v_c$ ∀ Coffee cherry i, supplier, plant p

Tt_{ijp} Ttw_{ij}, $LTwp_i$,> 0 , ∀ i, j, p positivity constraints 3.20

x_{ijp}, y_{ijp} $\in \{0,1\}$ $\forall$ i, j, p Binary variables 3.21

The objective function$_2$ (3.14) minimizes delivery lead-time of collection of all coffee cherry from the suppliers to the consolidation center (warehouse), to the coffee processing plant. Constraint (3.15) ensures that only one option selected per order placed by plant ‘p’ for the flow of coffee cherry ‘i’. (Constraint 3.16 and 3.17) to ensure the quality of red coffee cherry that transit time from supplier to plant per trip is not exceeds 8 hour and constraint (3.18) ensures that the sum of transit time from the supplier ‘j’ to plant p is limit by period of time (a day) (constraint 3.19) to ensure that no coffee cherry shipment per period is exceeds vehicle capacity used and (3.20 and 21) non negative integer and binary variables.

3.4.2 Solution methods

This section is devoted to the solution methods that applied to coffee cherries logistics of supplying network design models. The first objective function was used to minimize transportation, inventory and drying coffee costs over a series of links with coffee product. A mixed integer linear program was used to select one of the shipping options. A goal programming approach was used to solve the two-minimization model which explained in Section 2.3.2. Then, goal programming finds an optimal solution that tries to satisfy all the goals specified in order of importance. Non-preemptive goal programming methods relative weights assigned to the goals. Hence, the goals will scale by the ideal value method so that the weights can applied to comparable metrics. The ideal value for total cost refers to the minimum cost obtained by simply minimizing the first objective ignoring other objectives. Similarly, the ideal values for lead-time obtained by minimizing the respective objectives. The deviational variables in this model represent the amount by which the scaled values of the objectives are away from their targets values. The general model of the goal programming problem shown below:

Minimize $Z = \sum_{i=1}^{m} (w_i^+ d_i^+ + w_i^- d_i^-)$ 3.22

Here, w_i are the non-preemptive weights assigned to each objective.

Subject to: $\sum_{j=1}^{n} a_{ij} x_j + d_i^- - d_i^+ = b_i \ \forall_I$ 3.23

$g_i(x) \leq 0 \ \forall_j$ 3.24

$x_j, d_i^-, d_i^+ \geq 0$ for all i,j 3.25

The objective function (3.22) consists of the sum of the weighted deviations from the set goals. The next group of equations represents the goal constraints (3.23), real constraints (3.24) and the non-negativity constraints (3.25), where: X_j is decision variable, bi is the target, d_i^+ and d_i^- the over and under achievement of each goal

The current optimization problem was solved using the non-preemptive goal programming method. As mentioned above, weights are used to reduce the problem to a single objective optimization problem. Due to the difference in the units of measurement of each objective, ideal solutions can be used for scaling. An ideal solution is defined as the best achievable solution for an individual objective when all other objectives are ignored. Solving the individual objectives, helps find the upper and lower bounds for each. Target values can be set within these bounds. Setting the goal constraints for each objective and scaling using ideal values to normalize the deviational variables

Calculating ideal solutions:

Minimizing total cost while ignoring delivery lead time:

Minimize Objective1 = $(\sum_i \sum_j \sum_p Hc_{ij}d_{ip}x_{ijp} + \sum_i \sum_j \sum_p Hcw_{ij}\ d_{ip}y_{ijp}) + (\sum_i \sum_j \sum_p Tc_{ijp}f_{ijp} + \sum_i \sum_j Tcw_{ij}\,fw_{ij} + \sum_i \sum_p Tcwp_i fwp_i) + \sum_i \sum_p (df_{ip} + dc_{ip}Mwp_{ip}dx_{ip}) + \sum_i \sum_p (df_{ip} + dc_{ip}Mwp_{ip}dy_{ip})$ subject to the set of constraints 3.2-3.9.

Let ideal 1 be the minimum cost obtained.

Minimizing delivery lead-time while ignoring total cost: Minimize Objective2 = $\sum_i \sum_j \sum_p Tt_{ijp}x_{ijp} + \sum_i \sum_j \sum_p Ttw_{ij}y_{ijp} + \sum_i \sum_j \sum_p LTwp_{ip}\,y_{ijp}$ subject to the set of constraints 3.11-3.17. Let ideal 2 be the minimum delivery time obtained.

Obtaining target values:

On solving the single objective problems, upper and lower bounds obtained. As both the objectives are minimization problems, the target values can be set as a percentage of the lower bound (ideal solution).

Target value for objective $_1$: Target $_1$= $p_1 \times {}_{ideal1}$ where p1 is the percentage increase from the ideal solution for objective $_1$.

Target value for objective $_2$: Target $_2$= $p_2 \times {}_{ideal2}$ where p2 is the percentage increase from the ideal solution for objective $_2$.

Solution by goal programming:

Goal constraint for total cost: $(\sum_i \sum_j \sum_p \mathrm{Hcijdipxijp} + \sum_i \sum_j \sum_p \mathrm{Hcwij\ dipyijp}) + (\sum_i \sum_j \sum_p \mathrm{Tcijpfijp} + \sum_i \sum_j \mathrm{Tcwij\,fwij} + \sum_i \sum_p \mathrm{Tcwpifwpi} + \sum_i \sum_j \mathrm{Tcwij\,fwij} + \sum_i \sum_p \mathrm{Tcwpifwpi}) + \sum_i \sum_p (\mathrm{dfip} + \mathrm{dcipMwpipdxip}) + \sum_i \sum_p (\mathrm{dfip} + \mathrm{dcipMwpipdyip}) + d^-_1 - d^+_1 = \mathrm{Target}_1$

Goal constraint for delivery leads time:

$\sum_i \sum_j \sum_p Tt_{ijp}x_{ijp} + \sum_i \sum_j \sum_p Ttw_{ij}y_{ijp} + \sum_i \sum_j \sum_p LTwp_{ip}\,y_{ijp} + d^-_2 - d^+_2 = \mathrm{Target}_2$

The ideal values used to scale the objective and target values. The goals can rewrite as shown below:

$$\frac{Objective\ 1}{\text{ideal1}} + d^-_1 - d^+_1 = \frac{\text{Target1}}{\text{ideal1}}$$

$$\frac{Objective\ 2}{\text{ideal2}} + d^-_2 - d^+_2 = \frac{\text{Target2}}{\text{ideal2}}$$

The new objective function under consideration is: Minimize W_1 (d^+_1) + W_2(d^+_2) subject to the set of constraints mentioned above.

CHAPTER FOUR

RESULTS AND DISSCUSION

4.1 Case Study

By grouping together the supplier within a cluster, the number of supplier origin can be reduced from 124 to 4. The data used for demonstrating its a combination of real inputs from practical situation of coffee in Alemayhu Yredaw and their family coffee processing plc. and some assumed values. The company have 4 processing plants in Yirgacheffe coffee district, all dedicated to quality coffee production for international and domestic market. After the site survey and after visiting some of the plant and their facilities (including drying method and washing stations), the researcher decided to focus the integrated and inbound transport network design of coffee in one of them: (i) Edido (Arecha).

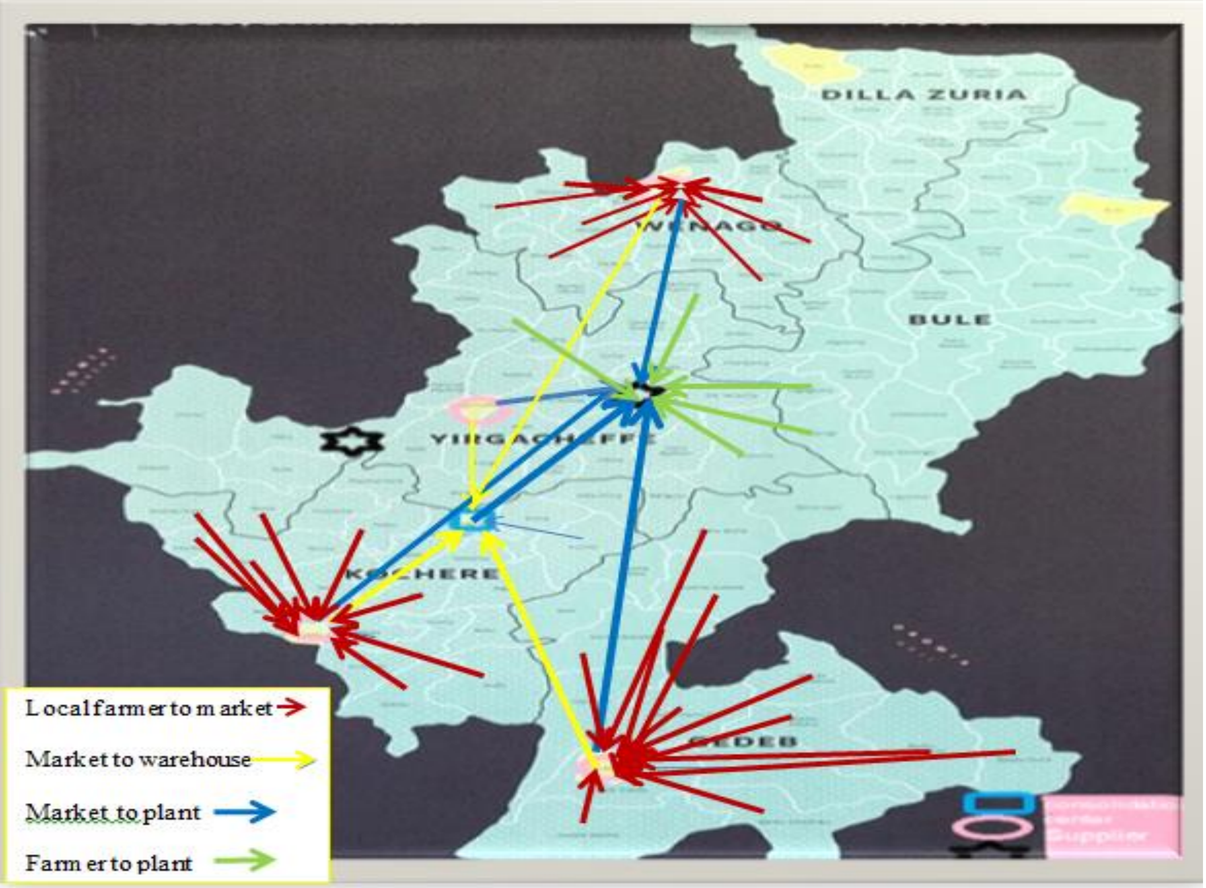


Figure 4.1 Locations of plant, central warehouse and suppliers.

The decision to concentrate on one processing plants, instead of covering all the processing plants of the districts, has been taken in order to comply, as much as possible with the aim of the research i.e. To create, in the selected intervention areas, success cases that can be replicated/up scaled in other areas. The selected processing plants have some similar problems (like the necessity to improve their inbound network and their facility of drying method). Here below there is the description of the processing plants.

Aricha - Edido processing plants

The station established over 20 years ago but has only natural (dry) coffee processing machine since 2004 after they bought it from its founder-installed washing machine. The station is well equipped with a local pulping machine, two warehouses(one small raw coffee cherry storage and one larger storage for coffee product), 350 African drying beds and mesh nets (essential to ensure that beans are air-dried evenly with no mold taking hold). The coffee comes from the supplier at Aricha, which is in the kebele, or village, of Edido, in the woreda, or district of Yirgacheffe coffee, in the Yirgacheffe region. Aricha is among the micro regions whose coffee is energetic, almost hot tasting, with a juicy fruit base and a sugary, floral sweetness. When its harvest time (October to mid-January), farmers selectively handpick red cherries from their trees and bring their produce to the station some in large batches, some in small. Every sack of coffee that the station accepts is first visually checked to ensure only red cherries is processed. Their production capacity is maximum 2000000 Kg of coffee cherries per year but only 71% of the suppliers are delivering the cherries to the plant. A big constraint to the processors of coffee in the Yirgacheffe wereda is the limited supply of locally-produced coffee. In addition, the coffee cherry offered for sale by the farmers are of poor quality with mixed unripe coffee cherry. Other coffee processors in the Yirgacheffe wereda are Bagerish, METAD agroindustry, MOPLACO, Hirut Brhanu coffee, and other processors of instant coffee. These processors obtain a portion of their coffee cherry requirements from local traders/assemblers and acquire additional coffee cherry through ingress from other wereda of Gedio zone such as Wenago, Gedebe, Kochere and Bule. Their share of coffee cherry is estimated to be 10 to 15 percent of the total local production.

Table 4.1 Washing stations status

Name of Coffee washing station	Year of establishment	Processing Capacity of cherries	Description and Status of machine in the washing station	No of People working in washing station	
				Fix term	Temporary
Edido	2004E.c	2,000 kg/h	Working with low efficiency	15	110

Farmers supply their products to local market. The farmers must have their coffee cherry delivered to the primary market/local market location at given times. When a trader has acquired a batch of coffee cherry have to be delivered to the collector location within a given time. Collectors, also part of the supplier cluster, are then bidding on the coffee cherry at the primary market. Collectors provide times at which they want to be delivered, which results in cut-off times for processes. At given times scrap products (e.g. coffee cherry offered but not shipped to the processing plant, or coffee cherry waiting to be processed for too long) are disposed as these products will no longer be able to meet the product quality requirements. Critical when redesigning a coffee inbound supply chain network is the selection of coffee product making processes. Hence, selection of the drying process is key in the trade-off between costs and product quality in the inbound supply chain network design problem. Next, the processor processes coffee cherry to produce coffee parchment, after which the coffee parchments are spread to the drying beds. For the first model that is inbound supply chain network design the network considered for the case study consists of:

Table 4.2 network considered parameter

Types	Quantity	Symbol	The index sets used
Raw coffee cherry	1	I	coffee cherries {red cherries}
Suppliers	4	J	supplier {farmer, collector}
Plants	1	P	plant {Edido}
Warehouse	1	W	Central warehouse
Vehicle type	1	v	Isuzu 35quintal for shipment

The data used in the model listed below: d_{ip} - demand of coffee cherries ‘i’ at plant ‘p’ in kg:

Table 4.3 Alemayhu Yirdaw Plc. coffee demand for each supplier and average price in 2020

Supplier	Red coffee cherry amount in kg	Price in Birr/kg
1	5539	24.15
2	5539	24.5
3	5539	25
4	5539	24.2

W_c - capacity of warehouse (in quintal) = 150(15000Kg)

S_{ca} - storage capacity at plant ‘p’ (in quintal) = 200(20000Kg)

V_{ca} - capacity of vehicle: = 3500Kg

C_{ij} - average cost per Kg of coffee cherries ‘i’ (in Birr 2012Ec):

HC_{ijp} - inventory holding cost of one Kg of coffee cherries ‘i’ supplied by ‘j’ held at plant ‘p’(in Birr): (Note: $Hc_{ijp} = h_i c_{ijp}$) h_{ip} is the plant inventory holding cost / period of coffee cherry 'i' includes cost of capital (6%), cost of physically storing inventory(1%)) and cost of labor(0.15%) (Assume h_i = 7.15 %). Capital cost is a cost of debt or/and equity in this case assume capital cost is only debt cost.

Debt cost = borrowed interest + service charge

Borrowed interest=14.5%, Service charge= 9.8% source CBE in 2020

For three month debt cost is (14.5 + 9.8)(3/12) =6.07=6%

Cost of physically storing inventory is cost rent of warehouse (depreciation) and insurance in the case company= 140000 birr

Monthly required amount of coffee cherry=22156kg, average price=24, working day =26

Cost of physically storing inventory =140000/ (22156*24*26) = 0.0101=1%

Table 4.4 Inventory holding cost in Birr per kg per day

Supplier	Plant (HC_{ijp})	Warehouse(HCw_{ip})
1	1.726725	0.1449
2	1.7875	0.15
3	1.75175	0.147
4	1.7303	0.1452

HCw_{ip} - the inventory holding cost of one Kg of coffee cherries 'i' supplied by 'j' that waited in consolidation center (warehouse) :(Note: $Hcw_{ip} = hw_i c_{ip}$ the truck pick the cherry every two hour difference from the consolidation center (warehouse), hwi is the consolidation center (warehouse) inventory holding cost / period of coffee cherry 'i' includes cost of capital, cost of physically storing inventory and cost of labor (assume hw_i = 1.2 %)

Table 4.5 Transportation cost from supplier to plant/ warehouse and warehouse to plant

From	1	2	3	4	warehouse
Plant	1429.062	991.481	221.56	775.46	465.276
Warehouse	897.318	498.51	293.567	991.481	0

The open sun dry processing requires a lower initial investment in term of equipment, but higher labor, large area requirement and wider drying facilities. It is because the drying process requires approximately 7-12 days. Meanwhile, the greenhouse solar drying requires high initial investment in equipment because it requires complex equipment. The greenhouse solar drying has smaller area, drying time and labor requirement for drying. From experimental result in appendix 3 indicate that coffee drying time requirement for open sun and greenhouse solar drying processing was 9 days and 5 days, respectively.

Table 4.6 Drying facility cost for parchment coffee

Open sun drying cost			Greenhouse solar drying cost		
Parameter	symbol	Cost	Parameter	symbol	Cost
Land lease cost	C_l	3.47birr/m^2 year	Construction cost dep.	C_g	480.8Birr/ m^2/year
Raising bed construction cost	C_b	101.19birr/m^2	Land lease cost	C_l	3.47birr/m^2 year
Area of bed	A_b	0.75A_d	Raising bed construction cost	C_b	101.19birr/ m^2
Labor cost	C_{la}	70birr/day	Labor cost	C_{la}	70birr/day
Average drying day	N_{dd}	9 day/batches	Opportunity cost	C_{op}	30.81*A_g
Premium cost	C_p	1.75birr/kg	Cost of solar panel dep.	Csp	5.63birr/watt/year
Inventory holding cost	Hcd	1.75birr/kg /day	Cost of electricity	C_{ea}	0.5778birr/ kwh

The construction cost of greenhouse solar dryer was taken from (Karimi et al., 2021) project budget or a bill of quantities of all materials needed to construct the drier.

Tt_{ijp} - Transit time for delivering coffee cherry 'i' from supplier 'j' to plant 'p' (in hours). It assumed that the lead time for shipping from a supplier 'j' using truck is the same for all coffee cherries.

Table 4.8 Transit time from supplier to plant and warehouse in hours

supplier	Transit time from supplier to plant	Transit time from supplier to warehouse
1	2.68	2.15
2	2.6	2.07
3	1.98	1.9
4	2.3	2.27

$Ttwp_i$ - transit time for delivering coffee cherry from the warehouse to plant 'p' (in hours) Assume transit time for delivering coffee cherry from the Consolidation center(warehouse) to plant 'p' (in hours) is t_w - average waiting time of red coffee cherry in consolidation center(warehouse) is 1 hours

$LTw = Ttwp + t_w$

Table 4.9 Transit time from warehouse to plant

Symbol of transit time	warehouse to plant
$TtWp_i$ (in hours)	1.32h
LTw	2.32

N - Maximum allowable number of shipment per period is 15

4.2 Solution approach and initial results

The mathematical model was run in LINGO 18 trial version, with the input data given in Section 4.1 and as mentioned in Section 3.4.1, the solution of a mathematical model would select either direct shipment or shipment via a warehouse by considering costs and delivery time as conflicting criteria. Bi-criteria mixed integer linear program was developed and solved using non preemptive goal programming. In addition to the cost, the red coffee cherry demand was chosen as a delivery lead time objective to minimize.

4.2.1 Mathematical optimization model

[TC]min = $9564.33*X_{111} + 39702.943*X_{121} + 9900.96*X_{131} + 9584.132*X_{141} + 802.60*y_{111} + 814.233*y_{121} + 830.85*y_{131} + 804.263*y_{141} + 1429.062*f_{111} + 991.481*f_{121} + 221.56*f_{131} + 775.46*f1_{41} + 897.318*fw11 + 498.51*fw_{12} + 293.567*fw_{13} + 991.481*fw_{14} + 465.276*fwp1 + 1.33*A^o + 73054.98*dX_{11} + 7.83*A^g + 62646.09*dy_{11}$;

!Constraints;

!only one option is selected per order placed by plant ‘p’ for the flow of coffee cherry ‘i’;

$X_{111} + y_{111} = 1$;

$X_{121} + y_{121} = 1$;

$X_{131} + y_{131} = 1$;

$X_{141} + y_{141} = 1$;

$dx_{11} + dy_{11} = 1$;

$5539* (X_{111}+X_{121} + X_{131} + X_{141}) <= 20000$;

$5539*(y_{111}+ y_{121} + y_{131}+ y_{141}) <= 15000$;

$5539* (X_{111}+X_{121} + X_{131} + X_{141}) <= 3500*(f_{111} + f_{121} + f_{131} + f_{141})$;

$5539*(y_{111}+ y_{121} + y_{131}+ y_{141}) <= 3500*(fw_{11} + fw_{12}+ fw_{13} + fw_{14})$;

$5539*(y_{111}+ y_{121} + y_{131}+ y_{141}) <= 3500*(fwp_1)$;

$f_{111} + f_{121} + f_{131} + f_{141} + fw_{11} + fw_{12} + fw_{13} + fw_{14} + fwp_1 <= 15$;

Totaltracost = $9564.33*X_{111} + 39702.943*X_{121} + 9900.96*X_{131} + 9584.132*X_{141} + 802.60*y_{111} + 814.233*y_{121} + 830.85*y_{131} + 804.263*y_{141} + 1429.062*f_{111} + 991.481*f_{121} + 221.56*f_{131} + 775.46*f1_{41} + 897.318*fw11 + 498.51*fw_{12} + 293.567*fw_{13} + 991.481*fw_{14} + 465.276*fwp1$;

tracost $=1429.062*f_{111} + 991.481*f_{121} + 221.56*f_{131} + 775.46*f1_{41} + 897.318*fw11 + 498.51*fw_{12} + 293.567*fw_{13} + 991.481*fw_{14} + 465.276*fwp1$;

invcost$=9564.33*x_{111} + 9900.96*x_{121} + 9702.94*x_{131} + 9584.13*x_{141} + 802.60*y_{111} + 830.85*y_{121} + 814.23*y_{131} + 804.26*y_{141}$;

invwcost $= 802.60*y_{111} + 830.85*y_{121} + 814.23*y_{131} + 804.26*y_{141}$;

Drycost $=1.33*A^o + 78651.2*dX_{11} + 7.83*A^g + 62646.09*dy_{11}$;

Costgrehoudry $=7.83*A^g + 62646.09*dy_{11}$;

Costopsudry $=1.33*A^o + 78651.2*dX_{11}$;

$134930.04*dx_{11} <= 20*A^o$;

$96378.6*dy_{11} <= 45*A^g$;

$A^o <= 3360$;

$A^g <= 3360$;

Objective 2

[DLT] min $=2.65*X_{111} + 2.0*X_{121} + 1.0*X_{131} + 1.45*X_{141} + 3.1*y_{111} + 2.89*y_{121} + 2.45*y_{131} + 3.21*y_{141}$;

!Constraints

!only one option selected per order placed by plant ‘p’ for the flow of coffee cherry ‘i’

$X_{111} + y_{111} = 1$

$X_{121} + y_{121} = 1$

$X_{131} + y_{131} = 1$

$X_{141} + y_{141} = 1$

$2.65*X_{111} + 2.0*X_{121} + 1.0*X_{131} + 1.45*X_{141} < 8$;

$3.1*y_{111} + 2.89*y_{121} + 2.45*y_{131} + 3.21*y_{141} < 8$;

$5539* (X_{111}+X_{121} + X_{131} + X_{141}) <= 3500*(f_{111} + f_{121} + f_{131} + f_{141})$;

$5539*(y_{111}+ y_{121} + y_{131}+ y_{141}) <= 3500*(fw_{11} + fw_{12}+ fw_{13} + fw_{14})$;

$5539*(y_{111}+ y_{121} + y_{131}+ y_{141}) <= 3500*(fwp_1)$;

$2.65*X_{111} + 2.0*X_{121} + 1.0*X_{131} + 1.45*X_{141} + 3.1*y_{111} + 2.89*y_{121} + 2.45*y_{131} + 3.21*y_{141} <=24$;

Obtaining ideal values

Minimizing objective 1 (total transport cost) while ignoring objective 2 (delivery time):

The total transport cost obtained by optimization model = 106982 birr in this case the upper bound delivery lead time obtained by the sum of time taken in the optimal option selected in objective1 of each supply process = 9.44 hour

The ideal solution for objective 1 - Ideal solution1= 106982birr

Minimizing objective 2 (delivery lead time) while ignoring objective 1 (cost):

The total lead time obtained by optimization model (the ideal solution for objective 2) = 7.55hour in this case the upper bound cost ost in optimal option selected in objective2 of each supply process = 139408.59 birr

Obtaining target values

The upper and lower bounds on each of the objectives listed in the table below:

Table 4.10 Upper and lower bounds on the objectives

Parameter	Lower bound	Upper bound
Total transport cost (in birr)	106982birr	139408.59 birr
Total transit time (in hour)	7. 55hour	9.55hour

The percentage difference between the upper and lower bounds for cost is 33.9%. The percentage difference between the bounds for delivery time is 25%. As noted in section 3.4.2, the two objectives have different magnitudes, and scaling is necessary. In this case, simple scaling is utilized to scale the objectives, ideal solutions can be used for scaling. To increase for both cost and delivery time add 10% of the ideal value i.e. p1= 1.1 and p2= 1.1.

Target for objective 1 (cost): Target1 = p1* Ideal1 = 1.1* 106982birr = 117680.2 birr

Target for objective 2 (delivery lead time): $Target_2$ = p2* $Ideal_2$= 1.1 * 7.55 = 8.31hour

4.2.2 Solution by non-pre-emptive goal programming (NPGP)

The solution methods as shown in methodology section 3.4.2 and present on the literature 2.2.3 setting the goal constraints for each objective and scaling using ideal value to normalize the deviational variables:

Goal constraint for total cost: $\frac{\text{Objective 1}}{\text{ideal1}} + d^-_1 - d^+_1 = \frac{\text{Target1}}{\text{ideal1}}$

$$\frac{\text{Objective 1}}{\text{106982Birr}} + d^-_1 - d^+_1 = \frac{\text{117680.2 Birr}}{\text{106982 Birr}} = 1.1$$

Goal constraint for total delivery time: $\frac{\text{Objective 2}}{7.55} + d^-_2 - d^+_2 = \frac{\text{8.3hour}}{7.55} = 1.1$

The objective function can rewrite as: Minimize w_1 (d^+_1) + w_2 (d^+_2) subject to the set of constraints mentioned equation 3.1-3.17. The weights assigned to the deviational variables have been used such that they add up to 1, i.e., w1 + w2= 1. The following set of weights used for an initial analysis. The total cost and lead-time achieved in each case listed in Table 4.11.

Table 4.11 Objective values achieved for the selected set of weights

Weight of the deviational variable associated with cost (w1)	Weight of the deviational variable associated with lead time(w2)	Total cost	Target values for cost	Total lead time (hours)	Target values for lead time (hours)
1.0	0.0	107995.9	117680.2	9.75	8.3
0.8	0.2	107995.9	117680.2	7.99	8.3
0.5	0.5	108778.0	117680.2	7.99	8.3
0.2	0.8	115631.1	117680.2	7.99	8.3
0.0	1.0	168868.1	117680.2	7.55	8.3

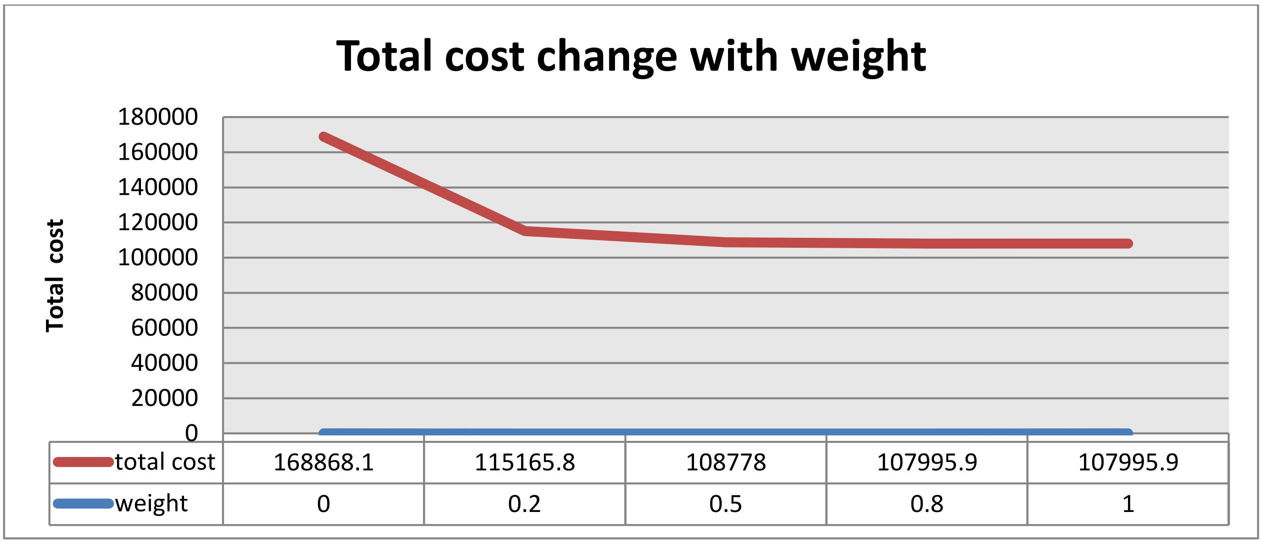


Figure 4.2 Variation in total cost with change in weights (w1)

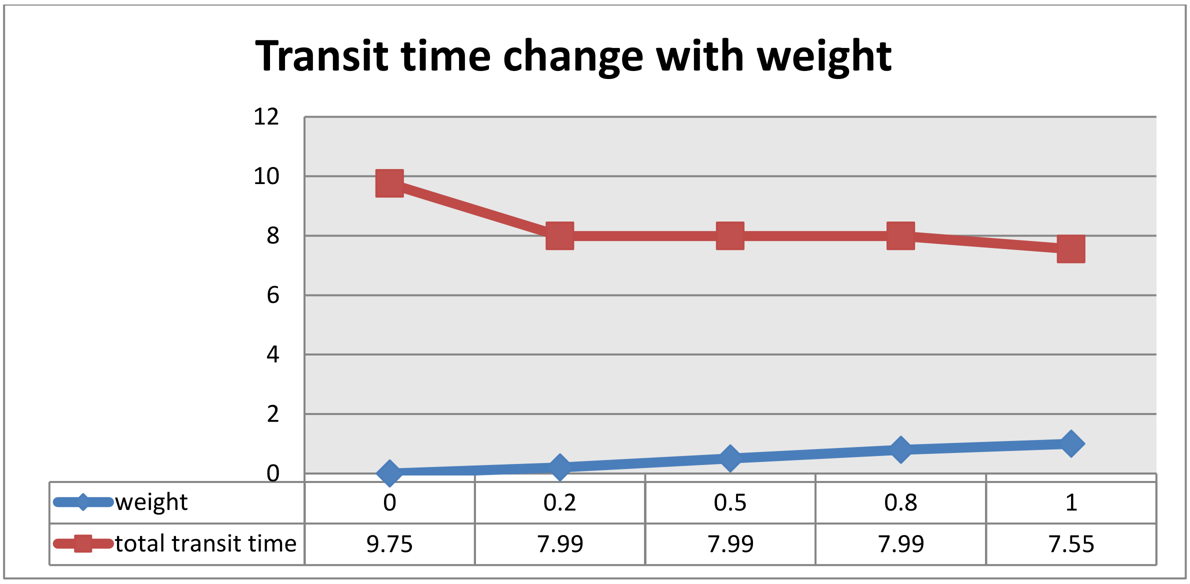


Figure 4.3 Variation in total transit time with change in weights (w2)

It can be observed from the Figure 4.2 that as to increase the weight on achieving the cost target, the objective for total cost decreases. With a weight of w1= 1, the objective achieved is 107995.9 birr while the set target is 117680.2 birr. When w1= 0, the cost increases to 168868.1birr. Similarly, with the weight of w2= 1, the delivery time reaches a value of 7.55 hours while the set target is 8.3 h and with a weight of w2= 0, the objective for delivery time attains a value of 9.75 hours (Figure 4.3). Table 4.12 represents the assignments made for coffee cherry to be shipped to the plant under each test scenario.

Table 4.12 Assignments made for coffee cherry to shipped to the plant

Test Cases							
Type of coffee cherry	Ideal Cost	w1 = 1 w2 = 0	w1 = 0.8 w2 = 0.2	w1 = 0.5 w2 = 0.5	w1 = 0.2 w2 = 0.8	w1 = 0 w2 = 1	Ideal lead time
1(Red)	Supplier 1 and 4 Direct shipping to plant Supplier 2 and 3 Via Warehouse to plant	Supplier 1, 3 and 4 Direct shipping to plant Supplier 2 Via Warehouse to plant	Supplier 1 ,3 and 4 Direct shipping to plant Supplier 2 Via Warehouse to plant	Supplier 1, 3 and 4 Direct shipping to plant Supplier 2 Via Warehouse to plant	Supplier 1, 3 and 4 Direct shipping to plant Supplier 2 Via Warehouse to plant	Supplier 2 ,3 and 4 Direct shipping to plant Supplier 1 Via Warehouse to plant	Supplier 2 ,3 and 4 Direct shipping to plant Supplier 1 Via Warehouse to plant

In the instances where only cost is minimized and lead time is ignored (i.e. calculation of ideal cost), suppliers 1 was selected as the optimal supply options. Although Supplier 2 quotes higher prices than supplier 4, it is located closer to the warehouse. This shows that the model selects the option that minimizes both criteria of cost and lead time. Therefore, the researcher can conclude that the model is accurate, and its solutions are representative of the real inbound supply of coffee cherry. For the cases with higher weights associated with costs, it can observed that although located farthest from the plant and warehouse, Suppliers 1 is frequently selected as it quote the lowest price for the coffee cherry. When the weight on the lead time is increased, the model selects shipping coffee cherry from suppliers 2 and 3 as they are located closest to the facility. It also found that supplier 2 is the most frequently selected option via warehouse to plant among all test cases. A supply option is an assignment made to ship a particular coffee cherry from a supplier to a plant.

4.2.3 Scenario analysis

To account for the variability in demand the program is run for different demand scenarios to select the best solution for coffee production process. For the validation, researcher developed a calculation testing for a baseline scenario. In this scenario the model's parameters were fixed at historic real levels and the results were compared with the real observed values in the area. Then, three scenarios with different month of demand level and compared the results of the scenarios with the baseline and assessed the impact of the optimization model. The objectives of the models are to minimize the total inbound supply chain network costs and time, including those incurred at facilities and transportation. Evaluate each scenario with the change in transportation and production cost across the network. In addition, the researcher observes the variation of the solution compared to the historic baseline.

Table 4.13 Amount of coffee demand per day for scenario analysis

Demand scenario	Amount of coffee cherry(in kg)	Amount of coffee parchment (in kg)
Initial demand	22156	12628.92
Increase 10% initial	24372	14013.9
Decrease 10% initial	19940	11465.5

The available capacity level of the company for the open sun dryer is 67200 kg per batches, and the greenhouse solar dryer is recommended for drying to extend the drying capacity of the company. For the case study, it has been assumed that coffee cherry is available at all suppliers (4 in total).The coffee cherry can either shipped directly or via the warehouse (i.e. 2 options). Hence a total of: 4 * 2 = 8 options are available for each coffee cherry from which the model selects the optimal solution. For example, the optimal options selected for coffee cherry one (red) from the 30 instances have listed below:

Supplier 1 – Direct Shipments
Supplier 2 – Direct Shipments
Supplier 3 – Direct Shipments
Supplier 4 – Direct Shipments
Supplier 1 –Via Warehouse
Supplier 2 –Via Warehouse
Supplier 3 –Via Warehouse

This sums up to a total of 7 different optimal options selected for coffee cherry 1. Figure 4.4 lists the number of optimal options selected for each coffee cherry. Due to the difference in monthly demand and weights assigned to each criterion, the assignments made in each instance are also different. The shipping option selected is optimal for a given scenario. This leads to a variety of supply options selected for each coffee cherry to ship. The most frequently occurring option (Supplier 4 – Direct Shipping to plant) was selected 15 times out of the 15 instances (100%). Hence, this solution selected as the best supply option for coffee cherry one under all conditions. Table 4.14 lists the best shipping option selected for coffee cherry along with the percentage occurrence of the solution.

Table 4.14 Best shipping option and percent occurrence of optimal solution for coffee cherry

Coffee cherry	Best shipping option	Percent occurrence of most frequently selected option
Red	Supplier 4 – Direct Shipping Supplier 1 – Direct Shipping Supplier 3 – Direct Shipping Supplier 2 – Direct Shipping Supplier 2 – Shipping via warehouse Supplier 1 – Shipping via warehouse Supplier 3 – Shipping via warehouse	100% 66.67% 93.33% 20% 80% 33.33% 6.67%

The most frequently occurring optimal solution from the scenario analysis selected as the best shipping option for red coffee cherry. This option minimizes total costs and delivery time in the system. Table 4.14 listed the best shipping option for coffee cherry and the percentage of its occurrence. The model selected 100% greenhouse drying facility option for dry coffee parchment due to high capacity to dry coffee product and lower operational cost.

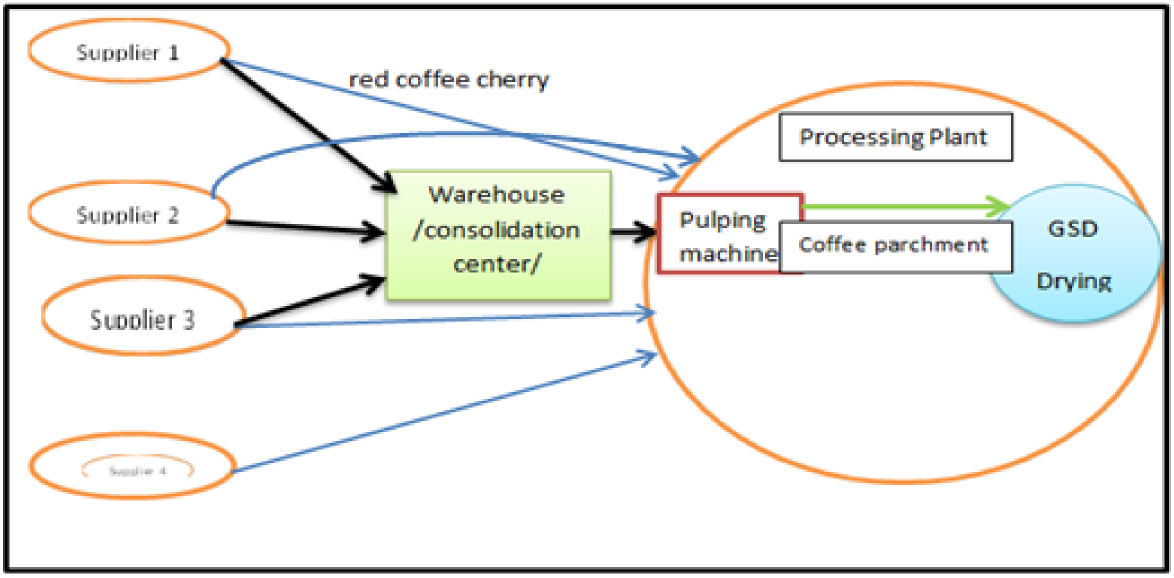


Figure 4.4 Illustration of best shipping and drying option for coffee product

The non-preemptive goal programing model select optimal shipping option minimizes both total cost and delivery time. It found that a majority of the total shipment cost was associated with the inventory holding cost (Fig 4.5) which depends on the cost of the coffee cherry.

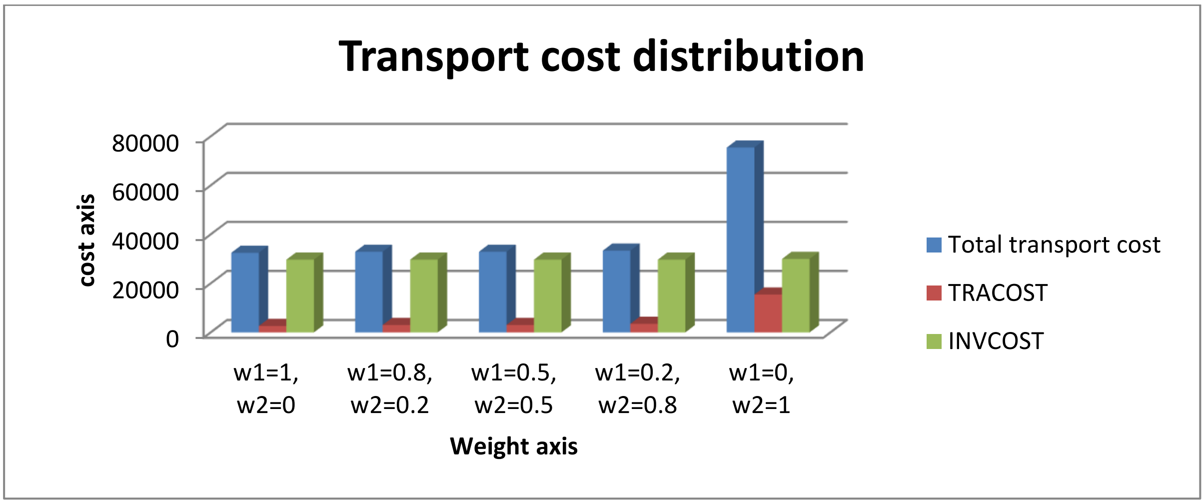


Figure 4.5 Distributions of inventory and transportation costs with weight

On average, the transportation cost accounts only for 28% of the total shipment cost. Hence preference is given to the suppliers that offer the lowest coffee cherry price. Among all the test cases the model was selected the greenhouse solar dryer than open sun dryer because of the bottle neck in coffee processing during drying time, which requires longer duration in open sun drying process method. Time influences the labor cost. Meanwhile, greenhouse solar coffee drying processing method requires shorter duration for drying process.

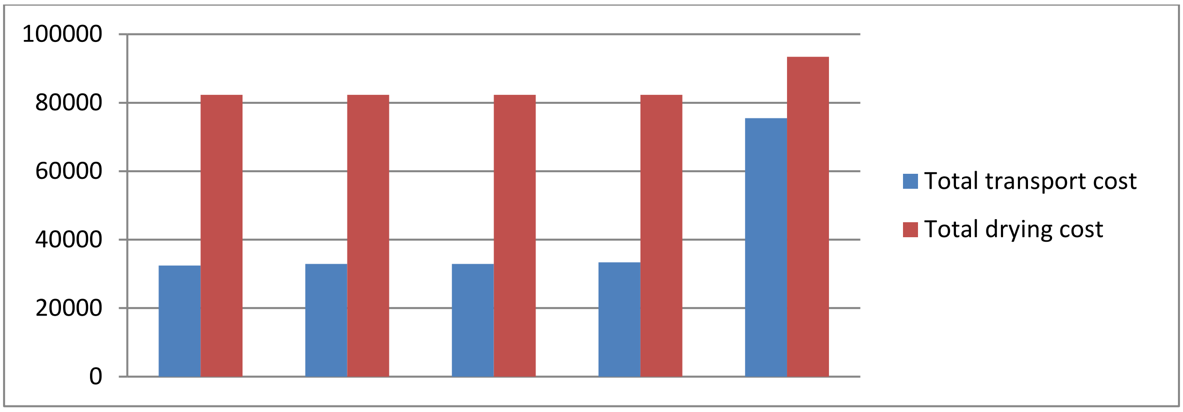


Figure 4.6 Distributions of total drying cost and total shipping costs with weight

Based on the output of optimization model it can be seen that there is the higher production cost due to drying processing cost than transportation cost. Fig. 4.6 shows the comparison of total transportation cost and total drying cost of coffee production process. With increasing the weight both total transportation cost and total drying cost of coffee production process is decrease. On average, the total shipment cost contributes approximately 32.85% of the total coffee processing cost.

Baseline scenario

To design a baseline scenario for validation purposes based on previous shipments and dried coffee done by Alemayhu Yirdaw and their family Plc. in 2020. For these shipments, the company pulped and dried the coffee in Yirgacheffe at their plant. To replicate the historic scenario, fixed all the demand and cost parameters, and required the model to utilize the route that used for the real shipments in 2020. Then, to compare the total cost per kilogram calculated by the model selected option and the real shipment cost per kilogram with the supplier transported their coffee cherries by freelance truck owner observed and the processing company uses for drying coffee parchment in 2020. The researcher presents the results in Table 4.15.

Table 4.15 Result of baseline scenario analysis

Cost driver	Baseline	Model’s output	Variation
shipment cost (birr/kg)	1.5	1.27	-15.3%
Drying cost (birr/kg)	3.63	3.58	-1.38%
Total cost	5.13	4.85	-5.48

There was 15.33% variation for transport cost and 1.38% for drying cost. The total cost per kilogram calculated by the model was 5.48% lower than the real observed cost per kilogram of the historic shipments and drying.

High demand scenario

To calculate the demand of scenario, considered 10% growth. Then, adjusted the values using the demand indexes calculated in section 4.1 the total demand was 24372 kg. As Table 4.16 shows, there is a total reduction in costs of 13.45%. The main driver for this cost shows, reduction is transportation, with an improvement of 25.33%. This improvement is achieved by implementing consolidation shipping by the company responsibility instead of direct shipping by suppliers uses freelance trucks. A cost reduction of 8.45% is achieved in the drying facilities, due to the savings attained by operating with greenhouse drying facilities instead of open sun dryer for the coffee parchment drying processes.

Table 4.16 Result of 10% increase demand of scenario analysis

Cost driver	Baseline	Model's output	Variation
Transportation cost (birr/kg)	1.5	1.12	-25.33%
Drying cost (birr/kg)	3.63	3.32	-8.54%
Total cost	5.13	4.44	-13.45

Low demand scenario

For this scenario, 11.33% variation for shipment and 1.38 % for drying and the total cost reduction was 9.16 %. The driver for this cost reduction was the cost of shipment is lower than the cost reduction of drying.

Table 4.17 Result of demand scenario 10% decrease analysis

Cost driver	Baseline	Model's output	Variation
Transportation cost (birr/kg)	1.5	1.33	-11.33%
Drying cost (birr/kg)	3.63	3.58	-1.38%
Total cost	5.13	4.66	-9.16%

By comparing the solutions for three scenarios low demand, baseline and high demand the researcher can also conclude that economies of scale play an important role in reducing costs of shipment and drying cost throughout the process.

4.2.4. Use of a central warehouse

The option of shipping via the central warehouse is selected 18 times out of the 60 instances i.e. 30% of the runs. The percentage of direct ships and shipping via warehouse illustrated in Fig 4.7 Although, the inventory holding costs at the plant are higher, direct shipping to the plant selected in 70% of the instances. This is due to the limited capacity of the warehouse.

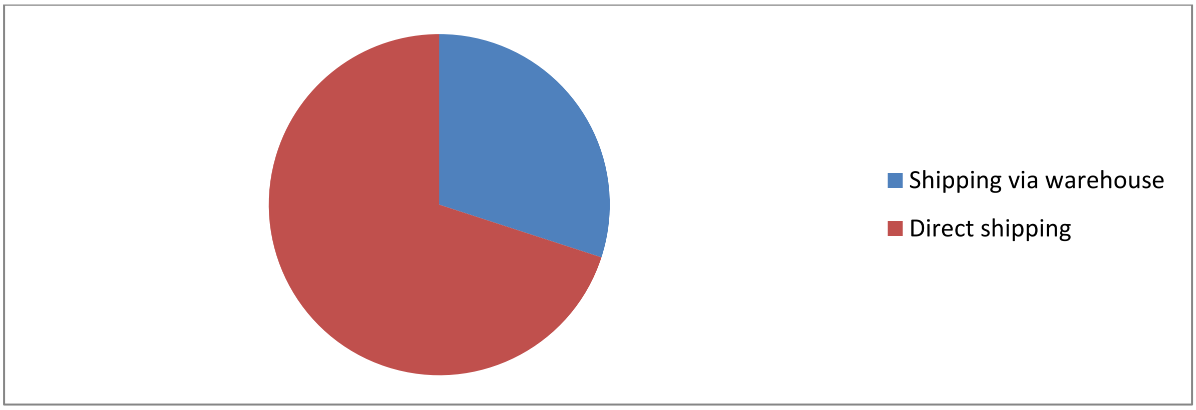


Figure 4.7 Ratio of assignments made to shipping via warehouse and direct shipping

Centralization of warehouse is beneficial to gain economies of scale in processing. Furthermore, away from farmers increases the risk of poor timing of the different coffee cherry flows and with that the risk of poor coffee product quality. Coffee is not a highly perishable product, but its quality is affected through time (Bladyka, 2013). However, it is important to consider that the rate at which coffee loses its quality depends on its state. There are 3 main states: The initial state is called cherry coffee, which is picked by farmers. The second state is called parchment coffee, which is a result of the pulping process. The third state is dried coffee, which is a result of the drying process. After collecting coffee cherry from supplier to processing plant the raw fruit of the coffee cherry convert into the coffee parchment or coffee beans. Coffee is either processed by wet or dry methods. Under dry processing unpulped cherries are dried after harvesting. In the washing method, the cherries pulped immediately after collecting, followed by fermentation and washing to remove mucilage cover then parchment dried. In Ethiopia, sun drying of coffee has been most preferred in comparison to mechanical drying and this has produced the best quality coffee. However, though congestion due to shortage of drying tables sometimes causes a reduction in the quality of the dried coffee, the remedy is not the building of more tables since many factories do not have or are unable to purchase the necessary land and/or do not have sufficient labour to operate extra tables. Otherwise, doubling the coffee depth on the tables from the soft black to fully dry phase can also serve to overcome congestion. The available factory land for the drying might also be the limiting factor for expansion. In such a case, it would be prudent to consider the services of a coffee dryer. If the coffee is on the table for so many days without attaining fully dry status during adverse weather conditions, the factory would be experiencing serious congestion.

4.2.5. Optimization with coffee product quality constraints

Dynamics in product quality complicate the design of supply networks for perishable products, like coffee and other agricultural products. Figure 4.8 illustrate the relationship between cost, time and qualities which are the indicator of efficiency of inbound supply chain of coffee products.

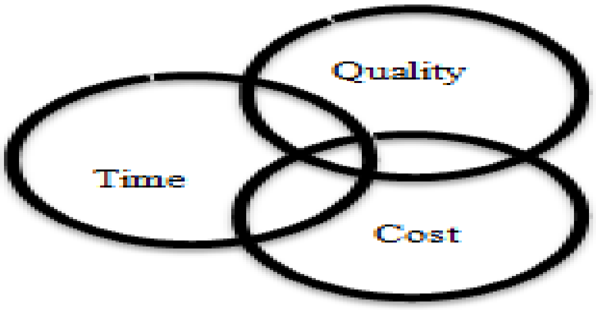


Figure 4.8 Relationship between three indicators

One of the critical aspects of a wet coffee inbound supply chain is time; any delivery delay to the processing plant implicates a loss in the economic value of the wet coffee because time directly influences coffee product quality. Formulate an MILP model in which a balance is found between capturing the impacts of lead time constraints on strategic design decisions while keeping a low level of detail of the operational aspects of lead time. An approach for dealing with a problem involving a number of conflicting objectives, all of which are considered simultaneously, is to translate each of them into a specific numeric target (goal) and to search for a solution that minimizes the deviations of the desired objectives from their targets. This can be achieved using the mathematical goal programming (GP) technique mention in section 4.2.2. The selected options have an influence on the delivery lead time, because delivery lead times should not exceed that assured to processor, which impose restrictions in the model on delivery lead times for maintain the quality of coffee product. Furthermore the analysis was performed based on costs and areas required for coffee drying to reach the target dryness values. Cost functions and an optimization model were utilized to calculate costs and area requirements. Coffee processors have problems drying their coffee product properly. According to metrological forecast data during harvest season (November, December and January) Yirgacheffe climate weather average rain day is 12, drying is delayed because it rains 40% of the time. Shortage of tables can arise from limited factory land and deterioration of the drying tables caused by failure to maintain and repair them as required. Congestion can also occur where the cherry delivery to a factory exceeds its design cherry intake capacity. Such adverse conditions can compromise the coffee quality perhaps by inducing mould formation. It is obvious that when coffee production increases, required cost, and dryer area would increase. Another critical issue in the optimization problem was the constraint on area requirement. The assumption in this study was that the area available for drying for coffee processing plant could not be more than the total facility area (including land without construction) estimated from Alemayhu Yiredaw and their family coffee processing plc. Coffee drying is the most critical phase of the coffee processing chain. Normally, it also imposes serious challenges to the processors for being highly dependent on the solar energy, an input whose reliability can be impaired sometime by occurrence of dark, cloudy and rainy periods. This can cause prolonged drying even at critical stages of high moisture content, which is detrimental to the production of high quality coffee. Generally, the drying tables require vast areas out of the limited available land besides being labour intensive. The objective function is subject to several system constraints including the limits on total area available for drying systems. Area limitation is a constraint in some regions of Ethiopia, especially in Gedeo Zone which is highly densely populated. Different area constraints are used to limit the area that can be allocated to the dryer. This area limitation constraint is used to understand the impact of the available area for coffee drying on costs and feasibility of coffee drying with dryer capacity.

Effects of GSD with solar panels

The use of greenhouse solar drier during sunny days reduced drying time of coffee parchments from seven days to five days when red cherries were depulped with the aid of the pulper. As mentioned (Idago and Cruz, 2015), over fermented green coffee bean results to high acidity that negatively affects the cupping quality of coffee. Cup tasting of coffee dried from all-weather solar dryer passed the quality standard of Nestle. This can be attributed to immediate drying of the coffee berries thereby eliminating possibility of over fermentation. Sundried berries for two weeks were also rejected due to over fermentation. Sundried berries for a week or less was accepted because it was immediately dried without undergoing excessive fermentation. Greenhouse solar dryer also prevented the coffee from rain, dust, dirty and animal contamination thereby preventing flavour. One of the measures of the quality of green coffee bean is an acceptable aroma based on cupping test. The drying method has an implication on the cupping quality of green coffee bean because drying duration affects the fermentation process of coffee. For drying operation that requires higher capacity and shorter drying period, the dryer can be coupled to a solar panel. This dryer is appropriate for farmers and traders or processors handling larger volume of coffee. The three main advantages that greenhouse dryers have over drying coffee in the sun are removing uncontrolled environmental variables which may affect coffee quality, improving accuracy, and minimizing delays. Furthermore, as greenhouse dryers protect coffee against all types of weather, they can also help to combat producers' anxiety about drying during adverse or unpredictable conditions. With greenhouse drying, parameters such as time and temperature can be controlled; this control means more consistency in quality, and fundamentally less risk in the drying process. In the long term, greenhouse dryers allow processors to maintain consistency over all harvesting season. While greenhouse dryers do require an investment in both equipment and solar panel/fuel/, these costs can be offset by the time and money that producers save in labour. This saving can actually lead to producers improving their productivity and profitability. By reducing the drying time and using less labour to revolve the coffees, producers will have more labour time available to process.

CHAPTER FIVE

CONCULUSION, RECOMMENDATION AND FUTURE WORK

5.1 Conclusions

Optimization model optimize the total cost of an integrated coffee drying process and transportation design problem in Alemayhu Yirdaw coffee processing company. Utilizing optimization for coffee processing in the coffee supply chain can have a positive economic impact for companies. The researcher introduce a two-stage coffee supply chain optimization problem involving coffee drying facility at coffee processer and transportation network for shipping coffee cherry from supplier to processing plant. The researcher developed a mixed integer linear programming model and solved using non preemptive goal (NPGP) programming to capture the realistic details of the problem, and the interactions with coffee drying facility at coffee processer. The optimization model to aid an Ethiopia coffee processing company in tactical decision making by selecting the best option to ship coffee cherry from suppliers to their facility and drying process at the lowest cost and area requirement. Suppliers located farthest from the plant frequently selected for cases with higher weights associated with costs as they quoted the lowest coffee cherry prices. Suppliers located closest to the plant were selected for cases with higher weights assigned to lead time. This shows that the model takes both criteria of cost and lead-time into account while selecting the most optimal assignment. The results of the optimization model suggest that the total production and transportation costs of the network can be reduced by 5.48% to 13.45% depending on the total demand of inbound supply chain of the case company. This improvement is mainly driven by the savings in transportation. To conclude, the inbound supply chain network design model would help Alemayhu Yirdaw and their family Plc. determines optimal shipping and drying option that minimize total production cost and delivery time plus improve the quality of product. In Ethiopia, majority of the processor preferred to dry their coffee by open sun dryer and this has produced the best quality coffee. However, though congestion due to shortage of drying tables sometimes causes a reduction in the quality of the dried coffee, since many factories do not have or unable to purchase the necessary land. If the coffee is on the table for so many days without attaining fully dry status during adverse weather conditions, the factory would be experiencing serious congestion and results to over fermentation that produces green coffee bean with high acidity are quality deteriorations that evident when coffee is exposed to cup tasting. Evaluating its effect on the processor income, if processors adapting the greenhouse solar dryer they will have a maximum incremental income of processor due to reduction in labor cost, dryer space, drying period and improvement in quality of green coffee bean.

5.2. Recommendation

These studies do well in achieving the optimal response utilizing minimum resources and time. Also important to know the quality of design can improve by improving the quality of product and productivity in companywide activities.

Recommendations for government

A first measure to improve the income of farmers would be to lower their costs. Presently, the insufficient road infrastructure many coffee producing kebeles make inputs and the transport of coffee expensive. Support to market infrastructure development to limit weight loss and reduce transport fees along the value chain. Government authorities have an important role to improve the present situation.

Recommendations for supplier

The suppliers collect and transport fresh and ripe red cherries to primary market center within a short time window, and handle in proper manner due preserve the economic value of the wet coffee cherry quality and might get high price.

Recommendations for processing company

The processing company should buy the red coffee cherries at the primary market and take care of the transport on own account. The company should consider shipping from suppliers and storing coffee cherry at the warehouse, to help reduce costs and lower delivery lead times. A warehouse of increased capacity or multiple warehouses could also be included in the network. Greenhouse solar drying method is especially suitable for processing company use for improving coffee product quality. Therefore, any evolution of suitable drying methods should estimate based on coffee processing method. A GSD was suitable for the large-scale parchments coffee drying. The land requirement could reduce compared to the sun drying.

5.3. Future work

The research demonstrates the opportunity to improve the Yirgacheffe coffee inbound supply chain through network design. This improvement has the potential to impact the life of intermediate actors that depend on coffee production. Therefore, I am see three areas for further research. First, expanding the model for more or bigger geographies and full supply chain network. Secondly, develop similar inbound supply chain network design models for other similar industries. Lastly, extended research in particular aspects of the inbound supply chain and further developing the drying technologies within the facilities.

6. REFERENCE

Abeba Gachen, Zewude Hirpesa, Lemi Negera Woyessa. (2020). Design and Construction of Indirect Solar Coffee dryer. International Journal of Innovative Technology and Exploring Engineering (IJITEE), 2278-3075.

Adams, F. H. (2020). Impact of supply chain relations on farmers income in Ethiopia . German Federal Ministry for Economic Cooperation and Development (BMZ) .

Alan Rushton, Phil Croucher, & Peter Baker . (2010). The Handbook of Logistics and Distribution. Daryaganj: Replika Press Pvt Ltd.

Amit Das, Tasminur Mannan Adnan, Md. Sajid Hasan, Kazi Mushfiqur Rahman. (2017). Analyzing logistics cost factors and developing cost optimization tools andtechniques for a cement industry (Case study: Lafarge Surma Cement Ltd). International Research Journal of Engineering and Technology (IRJET), 1504 - 1510.

Andri Ikhwana Sekolah Tinggi Teknologi Garut. (2018). Supply chain management of coffee commodities. MATEC Web of Conferences 197. Indonesia.

Antonio Mitsumasa Vieira Takita and Jandecy Cabral Leite. (2016). Inbound Logistics: A Case Study. Business Management Dynamics, 14-21.

Ather. (2020). http://www.pveducation.org/ .

Bahareh Vaisi, Reza Tavakkoli-Moghaddam. (2015). Designing A Nonlinear Integer ProgrammingModel For A Cross-Dock By A Genetic Algorithm. INTERNATIONAL JOURNAL OF SCIENTIFIC & TECHNOLOGY RESEARCH VOLUME 4.

Berhanu Tsegaye, Ali Mohammed, Tesfaye Shimber, Yehenew Getachew and Essubalew Getachew. (2015). Influence of sun drying methods and layer thickness on. Global Journal of Agriculture and Agricultural Sciences, 203-212.

Bladyka, E. (2013). Coffee Staling Report. Specialty Coffee Association of America.

Boot, W. J. (2011). Ethiopian Coffee Buying Manual. US Virgin Islands: Fintrac Inc.

Briceño-Martínez, Bryan; Castillo-Calderón, Jairo; Carrión-Jaura, Rubén; Díaz-Sinche, Diego. (2020). Proposal for implantation of coffee drying greenhouse with parabolic cover and adapted modular structure. Ingenius. Revista de Ciencia y Tecnología, núm. 24,, 36-46.

Briceño-Martínez, Bryan; Castillo-Calderón, Jairo; Carrión-Jaura, Rubén; Díaz-Sinche, Diego. (2020). Proposal for implantation of coffee drying greenhouse with parabolic cover and adapted modular structure. Ingenius. Revista de Ciencia y Tecnología, 1390-650X / 1390-860X.

Chen, Y. (2016). MULTI-CRITERIA APPROACHES TO SUPPLIER SELECTION AND ORDER ALLOCATION WITH QUANTITY DISCOUNTS.

Cruijssen, F. C. (2006). HORIZONTAL COOPERATION IN TRANSPORT AND LOGISTICS. Tilburg: CentER, Center for.

Daniela Bonassina, Mauro Andreolla Dal Pizzol, Uiliam Hahn Biegelmeyer, Maria Emilia Camargo, Lucas Teixeira Costa. (2018). The Importance of Logistics Costs for Organizations Applied toLogistics and Supply Chain through Sustainable Management. European Journal of Scientific Research, 252-264.

Daniels, N. (2009). Variations in Coffee Processing and Their Impact on Quality and Consistency.

Debela, F. M. (2013). Logistics Practices in Ethiopia.

Debelo, B. K. (2017). Constraints and Opportunities in the Coffee Supply. International Journal of Scientific and Research Publications, Volume 7, 626-632.

Dilebo, T. T. (2019). Prospectives of Coffee Production and Marketing (The Value Chain Approach): The Case of Yirgachefe District, Gedeo Zone, Southern Nation Nationalities and Peoples Regional State, Ethiopia. Global Journal of Science Frontier Research, 0975-5896.

Dong, Z. (2014). EFFICIENT DESIGN OF INBOUND LOGISTICS NETWORKS.

Dušan Malindžák, Peter Kačmáry, Grzegorz Ostasz, Andrzej Gazda, Beata Zatwarnicka-Madura and Marlena Lorek. (2015). Design of Logistic Systems(Theory and Applications). New York, NY: Open Science.

Ebangu Orari Benedict, Dintwa Edward, Motsamai Seraga Oboetswe. (2019). Development of a Cost-effective Design of a P-V Ventilated GreenhouseSolar Dryer for Commercial Preservation of Tomatoes in a Rural Setting. Advances in Technology Innovation, vol. 4, 222-233.

FAS staff. (2019). ASSESSMENTS OF COMMODITY AND TRADE ISSUES. Global agricultural information network.

Fasika Bete Georgise, Boru Bedeya Jarso & Alemayehu Tesfaye Mindaye. (2020). Model development for coffee processing plant location selection by using AHP method: Case of Guji Zone, Ethiopia. (7).

Ferguson, J. E. (2017). coffee quality, land use, and processing in the Cajamarca region of peru. Nebraska: Lincoln .

Flávio Meira Borém, Eder Pedroza Isquierdo, Guilherme Euripedes Alves,. (2013). QUALITY OF NATURAL COFFEE DRIED UNDER DIFFERENT TEMPERATURES Borém, F. M. et al. Coffee Science, Lavras, v. 13, n. 2, p. 159 - 167.

Gianpaolo Ghiani, Gilbert Laporte, & Roberto Musmanno. (2004). Introduction to logistics systems planning and control. Chichester: John Wiley & Sons Ltd, (Ed).

Gomes, A. C. (2016). Optimization of supply chain network design and.

HAQUE, S. N. (2013). A STUDY OF RADIATION AND NATURAL CONVECTIONOF AIR ON DRYING OF COFFEE BEANS IN A HEAT RECOVERY SOLAR DRYER. New South Wales.

HERNANDEZ, R. O. (2016). ENVIRONMENTAL ASSESSMENT AND OPTIMIZATION OF FACILITIES FOR COFFEE PROCESSING. Minas Gerais.

Hicks, A. (n.d.). Post-harvest Processing and Quality Assurance. FAO Regional Office for Asia and the Pacific.

III, B. W. (2013). Introduction to Management Science. New Jersey: Pearson Education, Inc.

John A. Duffie and William A. Beckman. (2013). solar engineering of thermal processes. New Jersey: John Wiley & Sons, Inc.

John W. Bartok, J. (2000). Greenhouses for Homeowners and Gardeners. New York: Natural Resource, Agriculture, and Engineering Service(NRAES).

Juan Quintanar Olguin and Refugio Roa Durán. (2017). Thermal and financial evaluation of the drying process of coffeebean in a active solar dryer type greenhouse. Revista Mexicana de Ciencias Agrícolas Vol.8, 321-331.

Juan Quintanar Olguinand Refugio Roa Durán. (2017). Thermal and financial evaluation of the drying process of coffee bean in a active solar dryer type greenhouse. Revista Mexicana de Ciencias Agrícolas Vol.8 , 321-331.

Juliana Puello-Mendeza, Pedro Meza-Castellar, Luis Cortésb, Luis Bossab,Emmanuel Sanjuan, Henry Lambis-Miranda, Leonardo Villamizar. (2017). Comparative Study of Solar Drying of Cocoa Beans: TwoMethods Used in Colombian Rural Areas. The Italian Associationof Chemical Engineering, 48-8.

Juliana Ventura Amaral & Reinaldo Guerreiro. (2014). Knowledge and Assessment of Logistics Cost Trade-offs: a Study withBrazilian Professionals. R. Cont. Fin. – USP, São Paulo (pp. 111-123). Rio de Janeiro,: Annual Congress of the European Accounting Association.

Kchaou-Boujelben, M. (2014). Modeling and solving a distribution network design problem with multiple operational constraints. Application to a case-study in the automotive industry. Ecole Centrale Paris: HAL .

Lysen, E. H. (2013). Pico Solar PV Systems for Remote Homes. INTERNATIONAL ENERGY AGENCY PHOTOVOLTAIC POWER SYSTEMS PROGRAMME.

Mercer, D. G. (2007). AN INTERMEDIATE COURSE IN FOOD DEHYDRATION AND DRYING. In D. G. Mercer.

Mercer, D. G. (2014). An Introduction to the Dehydration and Drying of Fruits and Vegetables. ontario.

Michael Watson, Sara Lewis,Peter Cacioppi, and Jay Jayaraman. (2014). APPLYING OPTIMIZATION AND. In Supply Chain Network Design. new jersey: Pearson Education, Inc.

Monrudee Boonyasri*, Charoerporn Lertsatitthanakorn, Lamul Wiset, Nattapol Poomsa-ad. (2011). Performance analysis and economic evaluation of a greenhouse dryer for pork drying. KKU Engineering Journal Vol.38 No.4 , 433-442.

Murry, M. (2020, December 04). www.the balancesmb.com/logistics. Retrieved Aug 5, 2021, from The dotdash publishing family : https:/www.google.com/search?clint

Musebe, R., C. Agwenanda and M. Mitiku. (2007). Primary coffee processing in Ethiopia: patterns,constraints and determinants. Afr. Crop Sci.Conference Proceed., 8, 1417-1421.

Nia Rosiana, Rita Nurmalina, Ratna Winandi, Amzul Rifin. (2017). Efficiency Analysis of Indonesian Coffee Supply Chain Network Using A New DEA Model Approach. Asian Social Science, 1911-2025.

OBIMPEH, L. O. (2018). THE DESIGN AND EVALUATION OF A GREENHOUSE TYPE SOLARDRYER AND ITS PERFORMANCE ON TWO FOOD COMMODITIES:CASSAVA AND COCOA.

Oded Berman and Qian Wang. (2006). Inbound Logistic Planning. TRANSPORTATION SCIENCE, 287–299.

Oloketuyi S Idowu, Oyewola M Olarenwaju and Odesola Ifedayo. (2013). Determination of optimum tilt angles for solar collectors in low-latitude tropical region. International Journal of Energy and Environmental Engineering, 4-29.

Oti, O. (2013). Hub and Spoke Network Design for the Inbound Supply Chain. Florida: The Leaders for Global Operations Program at the Massachusetts Institute of Technology.

P. Pankaew1, O. Aumporn, S. Janjai,*, T. Mundpookhiew, and B.K. Bala. (2019). Performance of parabolic greenhouse solar dryer equipped with rice husk burning system for banana drying. Journal of Renewable Energy and Smart Grid Technology, Vol. 14, 53-65.

Padmapriya R, Jenny Anne Tharian and Thirunalasundari T. (2013). Coffee waste management-An overview. INT J CURR SCI 2013, 9, 83-91.

Palmiro Poltronieri and Franca Rossi. (2016). Challenges in Specialty Coffee Processing and. Challenges , 7, 19.

Payel Ghosh and Dr. N. Venkatachalapathy. (2014). Processing and Drying of Coffee – A Review. International Journal of Engineering Research & Technology (IJERT), 784-794.

Petros Abebe Melerasha, Ratinder Kaur. (2020). Cost-Benefit Analysis Of Actors Involved In Coffee. INTERNATIONAL JOURNAL OF SCIENTIFIC & TECHNOLOGY RESEARCH VOLUME 9, 2277-8616.

Randall Salazar Esquivel,Mauricio Rodríguez Vindas, Pedro Casanova Treto,Kattia Solís Ramírez. (2018). Cfd Applied in the Optimization of A Dryer For ParchmentCoffee Drying (Coffeaarabica L.)By Forced Ventilation. American Journal of Engineering Research (AJER), 221-229.

Sahdev, R. K. (2014). Open Sun and Greenhouse Drying of Agriculturaland Food Products: A Review. Rohtak: International Journal of Engineering Research & Technology (IJERT).

Samaneh Sami, Amir Rahimi, Nasrin Etesami. (2014). Economical optimization of an indirect solar cabinet dryer based on mathematical model. Environmental Engineering and Management Journal 13, 2615-2623.

Santiago Botero López and Muhammad Salman Chaudhry. (2020). Designing an Efficient Supply Chain for Specialty Coffee from Caldas-Colombia.

SCHIAVONE, D. F. (2011). DEVELOPMENT AND EVALUATION OF A NATURAL-CONVECTION SOLAR DRYERFOR MANGO IN RURAL HAITIAN COMMUNITIES. FLORIDA: Drew Schiavone.

Sebastjan Škerlič, Robert Muha, Klavdij Logožar. (2016). A DECISION-MAKING MODEL FOR CONTROLLING LOGISTICS COSTS. Technical Gazette 23, 145-156.

Stiftung, H. R. (2019). Restoring degraded coffee landscapes, Ethiopia. German International Climate Initiative (IKI).

Subedi, R. N. (2010). COMPARATIVE ANALYSIS OF DRY AND WET PROCESSING OF COFFEE WITH RESPECT TO QUALITY IN KAVRE DISTRICT, NEPAL. Wageningen: Larenstein University of Professional Education.

Sunil Chopra and Peter Meindl. (2007). SUPPLY CHAINmanagement: strategy, planning, and operation. new jersey: Pearson Education, Inc.

Susila, W. R. (2005). ENHANCEMENT OF COFFEE QUALITY THROUGH PREVENTION OF MOULD FORMATION. Jacarta: FOOD AND AGRICULTURE ORGANIZATION(FAO).

TechnoServe team. (2013). The Coffee Initiative. TechnoServe business solution to poverty.

Tesfa, M. (2019). Review on Post-Harvest Processing Operations Affecting Coffee (Coffea Arabica L.) Quality in Ethiopia. International Journal of Research Studies in Science, Engineering and Technology,, 25-35.

UNIDO project team. (2016). UNIDO PROJECT FOR IMPROVING THE. Illycaffè S.p.A. and Ernesto Illy Foundation.

Wendelin Gross and Christian Butz. (2014). Design of Sustainable Transportation Networks.

Werner Weiss and Josef Buchinger. (2003). Solar drying. Glesdorf: AEE INTEC.

Yang, X. (2013). A Review of Distribution Related Problems in Logistics and Supply Chain Research. International Journal of Supply Chain Management, 2051-3771.

7. APPENDIX

Appendix 1

Determining Freight Transport

$$total\ cost\ = capital\ cost + operating\ cost$$

$$capital\ cost = deprecetion\ cost + rental\ cost\ or\ cost\ of\ buying + interest\ of\ payment$$

$$operating\ cost = labor\ cost + \ maintenance\ cost + traffic\ cost + tax + insurance\ cost + overhead\ cost + miscelloneous\ cost$$

Where Labor costs include Salaries, Bonuses, Overtime, and others expenses. Maintenance and repairs costs are a function of Lubricants, Tires, Parts and supplies, and others related expenses. Overhead costs are costs occurring from supporting activities such as accounting expenses, administration expenses, sales etc.

With above input variables, a model can be formulated suggesting that total transport cost per Kg per Km is derived from

$$Total\ transport\ cost = capital\ cost + operating\ cost$$

$$TTC = Cap + Cop$$

Average total transport cost per kilometer can be denoted as:

$$Average\ transport\ cost\ per\ kilo\ meter\ \frac{total\ transport\ cost}{total\ kilometer\ per\ period}$$

Table 1values of fixed and variable cost

Fixed cost	Birr	Variable costs	Birr
Salary of driver and assistance per a month	12300	Maintenance and Spare part cost per month	5362
Interest and depreciation/rent cost per a month	40000	Fuel consumption per a Km is 0.25 litter	
Tax	10%	Fuel price	20.75
Average fullness ratio	90%=0.9		

Monthly working days are 26 day/ period /

Assume a truck is average travel distance in Km is 200Km per period

Capital cost per month = 40000Birr/month →1538.45birr per period

$$total\ cost\ per\ Km = capital\ cost + operating\ cost$$

Capital cost per Km= $\frac{\text{capital cost per period}}{\text{Assume a truck is average travel distance in Km}} = \frac{\text{1538.45birr per period}}{\text{200Km per period}}$

=12.80 birr/Km

$operating\ cost = \frac{\text{679.30birr per period}}{\text{200Km per period}}$ + 5.20 birr = 4.65+ 5.20= 9.85

$$total\ cost\ per\ Km = 7.70 + 9.85 = 17.55\ Birr/Km$$

Average carriage of load track = average fullness ratio* loading capacity of truck

= 0.9 *3500Kg = 3150 Kg

Average transport cost of one Kg coffee cherry per Km of travel distance

$= \frac{total\ cost\ per\ Km}{\text{Average carriage of load track}} = \frac{17.55\ Birr/Km}{\text{3150Kg}}$ = 0.0056Birr/km kg

Table 2 Distance from supplier to plant warehouse in km

no	Supplier	Distance (in Km)	T. cost
		Edido	T.cost (birr/kg)
1	Gedeb	46	0.258
2	Chelelktu	32	0.179
3	Yirgachef	7.2	0.04
4	Wenago	25	0.14

Table 3 Distance from supplier to consolidation center (warehouse) in km

	supplier			
	1	2	3	4
Consolidation center	29	16	9.4	32
T. cost	0.162	0.09	0.053	0.179

Table 4 Distance from consolidation center (warehouse) to plant warehouse in km

	Distance from warehouse to plant in Km
Consolidation center(warehouse)	15
T. cost	0.084

Appendix 2

Table 5 Optimal option selected

Supplier						
1		2		3		4
Dir.	Via W	Dir.	Via W	Dir.	Via W	Dir.
3	2	1	4	4	1	5
5	0	1	4	4	1	5
5	0	2	3	3	2	5
13	2	4	11	11	4	15
86.67	13.33	26.67	73.33	73.33	26.67	100

Appendix 3

Table 5 Weight of water in wet coffee

wet coffee loading rate (kg/hr)	m_{p1}=142.5	177.52	110.78	58.8
m_{eGSDp}	$m_{p1}(1\text{-}0.4/DS_m)$	$m_{p2}(1\text{-}0.4/DS_m)$	$m_{p3}(1\text{-}0.4/DS_m)$	$m_{p4}(1\text{-}0.4/DS_m)$
m_{ewspp}	$m_{p1}*(1\text{-}1.13\ Ds_m)$	$m_{p2}*(1\text{-}1.13\ Ds_m)$	$m_{p3}*(1\text{-}1.13Ds_m)$	$m_{p4}*(1\text{-}1.13Ds_m)$
m_{wp}	85.5	106.512	66.47	35.28

Equal amount of coffee parchement sample with moisture content & temperature in Greenhouse type solar dryer and open sun dryer

Table 6 Experimental data

GTSD				OSD	
Days	Time (h)	Temperature (°F)	Moisture content (%)	Temperature(°F)	Moisture content (%)
1	3:00	69.9	57	66.6	57
	5:00	78.7	48.7	75.2	51
	7:00	81	34.7	77.4	42.7
	9:00	82.5	30.1	79.2	36.2
	11:00	77.8	28.3	75	33.3
2	3:00	72.6	28.9	69.3	34.8
	5:00	77	26.6	74.1	32.2
	7:00	84.1	24.2	80	31
	9:00	85.5	22.4	81.5	28.5

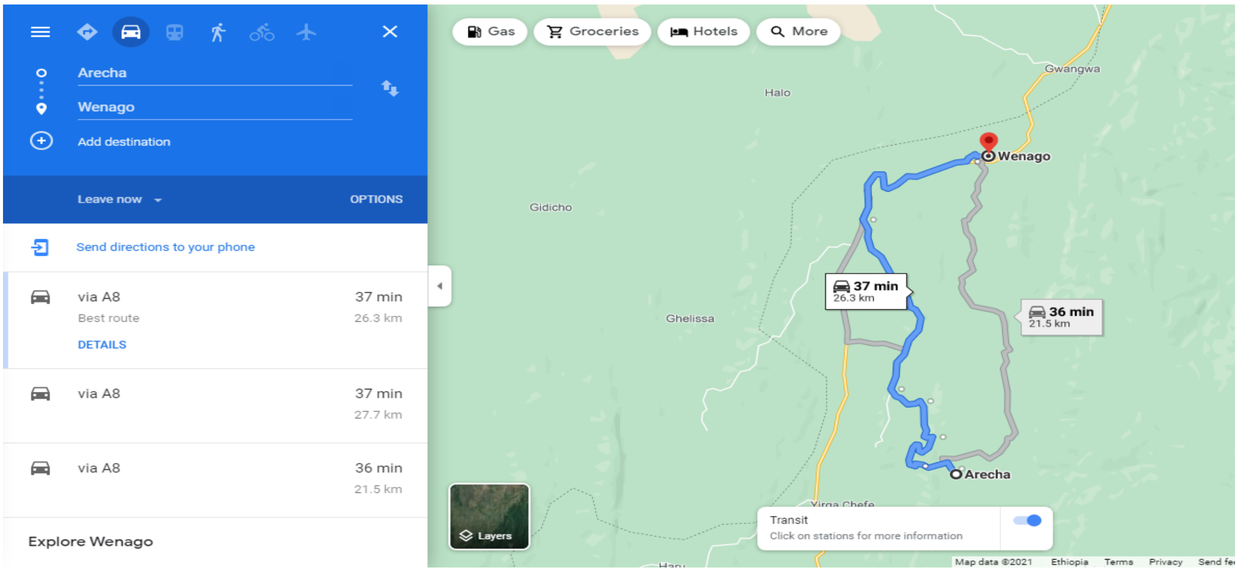
	11:00	76.7	20.1	73	27.2
3	3:00	71.6	20.3	68	28
	5:00	77.3	19.2	73.3	26.4
	7:00	81.5	18.4	77.4	25.2
	9:00	85	17.8	80	23.4
	11:00	76	17.1	72	22.4
4	3:00	72.6	17.1	70.3	22.8
	5:00	82.4	16.2	78	21.1
	7:00	85.8	15.3	82.9	20.3
	9:00	81.6	14.4	78.6	19.6
	11:00	72	13.8	71	18.8
5	3:00	72	13.9	68.9	18.9
	5:00	75.2	13.0	72.1	18.3
	7:00	85.9	12.2	83.9	17.5
	9:00	84.5	11.7	80.5	16.8
	11:00	73	11.4	70.9	16.2
6	3:00	70.5		67.3	15
	5:00	82.1		79.0	15
	7:00	88.7		85	14.4
	9:00	86		81.8	14.1
	11:00	73		72.9	13.4
7	3:00	67		65.4	14
	5:00	80.2		78	13.4
	7:00	85.3		82.9	12.6
	9:00	83.4		79.8	11.9
	11:00	75.2		73	11.5

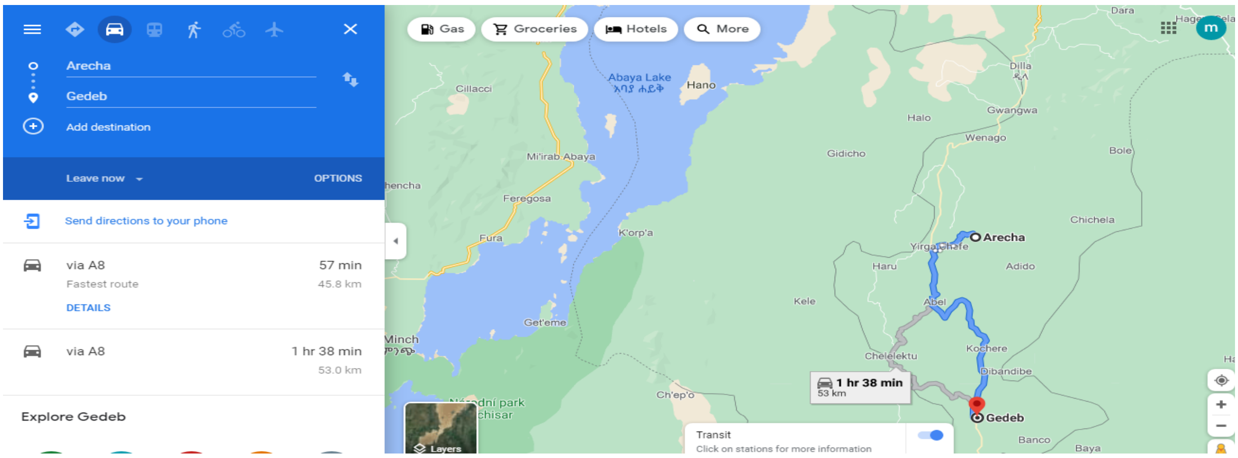
Model construction of greenhouse dryer

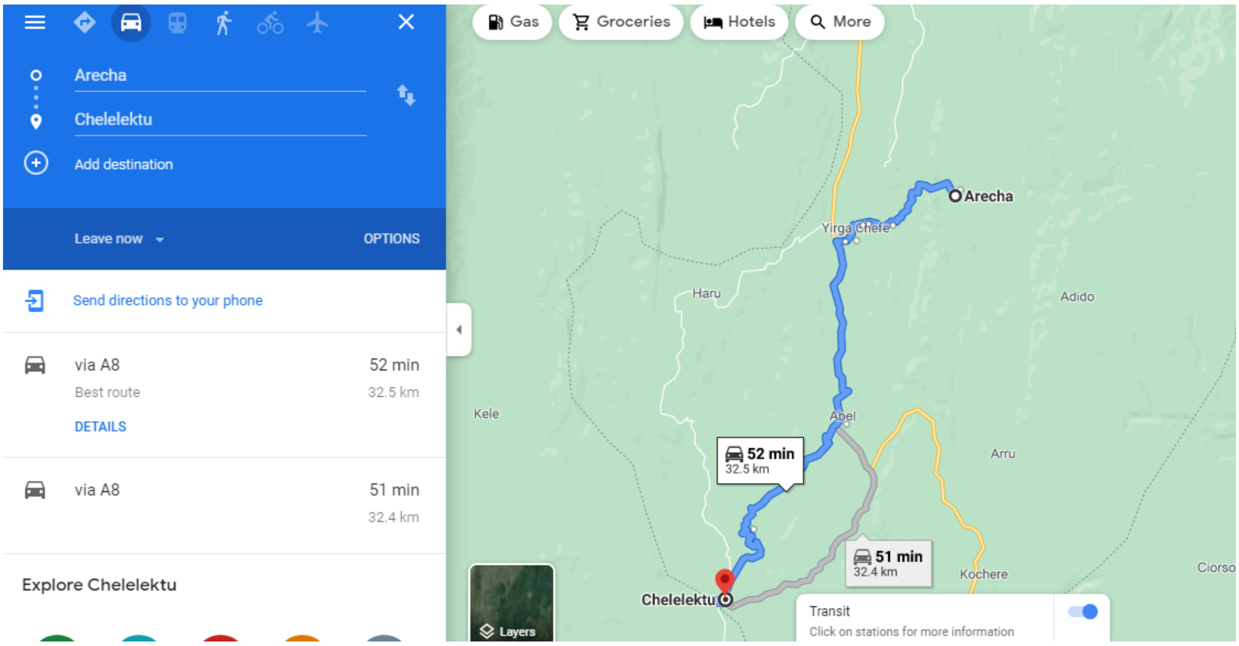
Test coffee parchment greenhouse solar dryer

Moisture and temperature meter

Field observations of open suns drying







Map of origin and destination point of study area