Adaptive Sequential Optimization Decision Making Approach to Procurement, Storage and Distribution of Perishable Food Items to Fast-Food Chain Restaurants at Regional Level

by

Meet Patel

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Abstract

The fast-food restaurant chain industry currently relies on frozen ingredients to reduce the cost of procurement of raw-material. In recent years, consumers are shifting their habit of eating out from fast-food chain restaurants due to its prevailing perception of unhealthy menu choices and the frozen-food ingredient concept.

This thesis addresses the problem of integrating sourcing, storage, and distribution strategies for a fast-food restaurant chain at the regional level. We present an adaptive sequential optimization decision-making approach for procurement, storage and distribution of perishable food products to multi-unit restaurants at the regional level. This solution approach uses shelf-life considerations in developing a procurement and distribution strategy for raw-materials. In this thesis, three models are developed using mixed integer linear programming (MILP). First, a procurement model is developed to find the cost-effective supplier for each produce category based on shelf-life. Second, a distribution model is developed to find the cost-optimal solution for distributing produce to multiple restaurant locations considering weight, volume, and operation hours. Finally, an integrated model is developed to optimally combine procurement and distribution options generated by the first two models to minimize costs while respecting total shelf-life constraints. A numerical example is developed based on realistic data to illustrate how the three models can be used sequentially to configure the fast-food supply chain. Other examples are presented to illustrate the effect of price, shelf-life, and demand changes on the supply chain.

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Chapter 1

1 Introduction

1.1 Current trends in the restaurant industry

Individuals in the contemporary era prefer to eat out more often to save their time and effort. Thus, the restaurant industry is contributing a large share to the economy of every nation. At the same time, consumers today demand more return on the money spent on eating out due to increased variety and sophistication in eating habits, choice and higher restaurant competition. The consumer essentially wants to consume quality and safe food at an affordable price with a variety of menu choices. As a result, each restaurant outlet tries to engage more and more consumers by competing on quality, menu price and service time.

The restaurant industry itself is classified into two categories: fine-dining and quick-serving. Each type of restaurant tries to satisfy consumer appetite differently. The fine-dining restaurant strategy is to serve specialized menu choices to fewer customers at a higher menu price. On the other hand, quick-serving restaurants serve a larger number of customers at a lower menu price. The food choice and quality at these restaurants is typically more basic. Generally, quick serving restaurants consume a higher quantity of ingredients due to the higher consumer demand. They are also operated in multi-unit chains and are often known as fast-food chain restaurants. For such restaurants, even a small reduction in procurement cost of raw material can significantly increase profit. Therefore, fast-food chain restaurants use more frozen and processed foods to reduce the procurement cost of raw-material, while fine-dining restaurants use fresher, locally sourced produce, since their chefs find it difficult to source quality field-mature fruits and vegetables from a longer distance.

1.2 Procurement in the Fast Food Chain Industry

As mentioned, fast food chain restaurants procure raw-material from local and global suppliers due to their comparatively higher demand and frozen food use. This procurement strategy facilitates lower customer food prices than in fine-dining restaurants. A genuine effort to deliver safe food to the customer by reducing wastage to compete with menu price using inventory management solutions is prevalent in the local restaurant industry. The level of inventory is a trade-off between bulk procurement costs and the cost of holding/perishability. The restaurant menu price is directly affected by raw material prices. Small and medium consumption restaurant units find it difficult to play a large role in deciding the price of raw material consumed at their facility. On the other hand, fast-food chain restaurants have sufficiently high demand to negotiate prices with their suppliers. In addition, the presence of nationwide outlets also helps them find a cost-effective solution to procure and distribute raw-materials at each outlet. Many consumers believe that frozen food served by quick-serving restaurants can have a deleterious effect on a person's health in the long run. Despite customer reluctance to consume frozen or globally procured food, most of the fast-food restaurant chain industry still fully or partially continues to use frozen food to lower costs.

Most of the fast-food industry uses the primary strategy of distributing raw-material to restaurants after centralizing it at one central regional warehouse. The fast-food industries strive to maintain their market by supplying their raw-materials in a cost-effective and timely manner. For instance, Subway has developed an independent purchasing co-operative (IPC) responsible for procuring and supplying raw-material used in their outlets. The franchise-owned and operated purchasing cooperative (IPC) negotiates low costs for food and services from suppliers while maintaining quality standards and ensuring the best value for Subway franchisees. In the fast-food restaurant chain industry, the economic ordering quantity (EOQ) model is used for inventory management at warehouse and outlets. This model optimizes the cost of ordering and holding raw-material in the warehouse. An individual supplier transports its products to a regional warehouse in most of the fast-food restaurant chain industry. It is indeed the best way of procurement when demand is high enough to fill an entire truck with one or more product. However, less than truck load (LTL) shipments from suppliers translate to higher transportation costs per kg of product. In general, the biggest problem faced by most of the fast-food restaurant chain industry is to reduce the use of frozen food and transportation cost while maintaining the same quality standards to all regional outlets. The problem can be reduced significantly by considering the perishability of each produce type and the average daily demand of each outlet at the regional level. Perishability of food can be understood by the service or utilization time after which produce cannot be stored or used for consumption.

The time from harvesting to the end of the consumption period (maximum ripened state) is also known as shelf-life. Degradation in quality of food produce begins after it achieves its maximum ripened state. The food industry relies upon refrigeration to decelerate the respiration rate of produce. Refrigeration delays deterioration of produce by preventing or slowing down the growth of microorganisms. It converts water in the food, required for the growth of microorganisms, into ice crystals and extends the shelf-life of produce.

1.3 Thesis Aims and Objectives

The aim of this thesis is to develop a sophisticated adaptive sequential decision-making optimization approach to procure, store and distribute fresh food items to fast-food restaurant chains at a regional level. This study is divided into several chapters. In Chapter 3, the product categorization method is discussed. Product categorization is used to cluster produce with the same shelf-life to increase cumulative demand of that category to obtain economies of scale in procurement and transportation and thereby reduce costs. In Chapter 4, a procurement model is developed to find the cost-effective supplier for each produce falling under the same category considering transportation cost, purchase price, packaging standard and remaining shelf-life of each produce. In Chapter 5, a distribution model is developed to find the cost-optimal solution for distributing produce to multiple restaurant locations considering weight, volume, and operation hours. Chapter 6 presents an integrated model to optimally combine several runs of the procurement and distribution models. The objective is to devise and implement a most cost-optimal combination of procurement, storage, and distribution by the trading off between procurement and utilization cycle and shipment frequency required for distribution considering holding the cost of each produce in the regional warehouse. This approach considers accessible information such as remaining shelf-life and price of each produce from suppliers and utilizes it to enforce the quality standards and reduce the procurement cost of fresh produce evaluating average daily demand at a regional level. Chapter 7 presents a numerical example is developed based on realistic data to illustrate how the three models can be used sequentially to configure the fast-food supply chain. Other examples are presented to illustrate the effect of price, shelf-life, and demand changes on the supply chain. Chapter 8 presents the conclusions of this thesis and outlines directions for future research.

Chapter 2

2 Literature review

In this section, we review the literature on various issues related to the fast-food industry, procurement strategy of retail chain for fresh produce, inventory terminology for raw- material in the restaurant industry. Since both procurement and distribution are based on vehicle routing, we briefly review the literature on the VRP problem with time-windows (VRPTW).

2.1 Various trends and issues related to fast-food industry

LaMarco (2018) discusses the various types of economic factors that can affect the fast-food industry and suggests that the cost of labour and fuel and the price of a commodity can adversely affect the prices consumer pay for menu items. It also suggests that the fast-food chain restaurants always insist on maintaining lower prices to attract more customers, even if commodity prices are high. Kara et el. (1995) suggests that fast-food restaurant menus reflect a marketing-oriented approach that looks at menu price, wholesomeness, healthiness and variety of foods. They reviewed eleven attributes targeted by fast-food restaurants to attract more consumers and to build brand perception. Among all discussed attributes, they suggest that the price, nutritional value, and promotional deals have higher importance to draw consumer attention along with menu variety and service time.

Min and Min (2013) discuss cross-cultural competitive benchmarking for the fast-food industry. Example of this includes the taste of food, service response time, cleanliness of restaurants, restaurant location, competitive price and the availability of a healthy menu. They classified these service factors into five main categories: service image, accessibility, food quality, location, and drawing power. After evaluating each factor based on the degree of importance, the study concludes that fast-food restaurants should avoid the prejudice of duplicating the same marketing and service strategy everywhere and adapt their menu offering based on local needs. As discussed by Ramadhan and Simatupang (2012), restaurants procure and hold inventory required by location considering shelf-life of produce with the fastest expiration cycle as the utilization time limit. This procurement practice ends up paying more on transportation cost for produce with longer expiration cycle due to more frequent delivery. It also gives an overview of inventory terminology and policies prevailing in the restaurant industry.

According to the *Oxford Dictionary*, fast food is defined as “Easily prepared or processed food served in snack bars and restaurants as quick as a meal or to be taken away”. Thus, frozen food and ready to eat meals are also considered as fast food. To avail of quicks service at their outlets and to reduce procurement cost, the fast-food industry traditionally relies upon preservation methods and the frozen food serving concept. Brissette (2018) suggests that fast food is highly processed, has high calories and is of low nutritional value. Fast-food usually has high sugar, salt and saturated or trans fats for preservation. Thus, the consumption of fast-food can result in a higher risk of obesity, digestive issue, heart disease and stroke, cancer and early death. Alter andd Eny (2005) and Bahadoram et el. (2015) supports the claim that fast-food consumption can result in cardiovascular disease, obesity problems and other metabolic abnormalities in individuals. In general, the cumulative amalgamation of all discussed studies concludes that it is difficult for the fast-food industry to compete with menu price by serving fresh and local food.

The consumer shift toward a healthy lifestyle is becoming a major threat to the survival of the fast-food industry. *Fast Food Industry Analysis Report (2018)* claims that consumer perception toward the fast-food industry as having an unhealthy menu is making them consider healthier options. As a result, the trend to use locally-sourced ingredients in fresh condition has gathered momentum in the fast-food industry distribution model. In this thesis, an adaptive sequential decision making optimization approach is developed to help alleviate this fundamental problem related to the fast-food industry by considering fresh and healthy substitutes and a more reliable method of procurement, storage, and distribution.

2.2 Supply market in the food industry

The fast-food industry as well as the food retail industry depends on farmers, distributors, and wholesalers for raw-material procurement. Thus, it is extremely important to understand supply chain models of all market players involved in raw material manufacturing and supply. McCluskey and O’Rourke (2000) and Pullman and Wu

(2012) mentioned that buying any produce from farm to consumer involves the entire supply chain. The distributors purchase produce from manufacturers (farmers) and supply a large amount of quantity to wholsalers. Retailers procure small shipments either from wholesalers or distributors. Sihariya et el. (2013) discuss three successful models for supplying perishable food products to retail locations as shown in Figure 1. The most common procurement technique found among all retail store chain models is that they procure material daily and transportation cost from the collection center to distribution center is borne by vendors and other costs are borne by the store. Vegetables are transported from a buying center to a distribution center. Among the three discussed models, Reliance serves its retail stores from one distribution center only. In the case of Benison, it is from wholesaler markets, while in the case of Hypercity, it is from vendors.

Blackburn and Scudder (2009) examine the complication in designing and monitoring the supply chain for perishable fresh produce, and discuss that product value deteriorates significantly over time for fresh produce. Some articles in the literature were reviewed to understand the relationship between produce firms and distributors, data management in the food industry and pricing strategy in the food industry based on quantitative and qualitative analysis. Charlebois et el. (2019) in *Canada's Food Report* discusses macro-level drivers for fresh food prices in Canada. According to the report, food retail and distribution landscape have major signicance on food price at the sectoral level. Thus, transportation cost must be considered to reduce the price of raw material for the restaurant industry.

2.3 Technical aspects of problem and solution strategies

The problem addressed in this thesis is to find an optimal procurement, storage, and distribution strategy for the fast-food chain restaurant industry at the regional level. As discussed in Chapter 1, the fast-food industry operates multi-unit restaurant units and the raw material is sourced to a centralized warehouse and then distributed to the restauratns. Thus, the industry needs an optimal strategy for procurement, storage, and distribution to reduce transportation and the holding cost of raw materials.

An optimal strategy for procurement and distribution can be developed using exact or

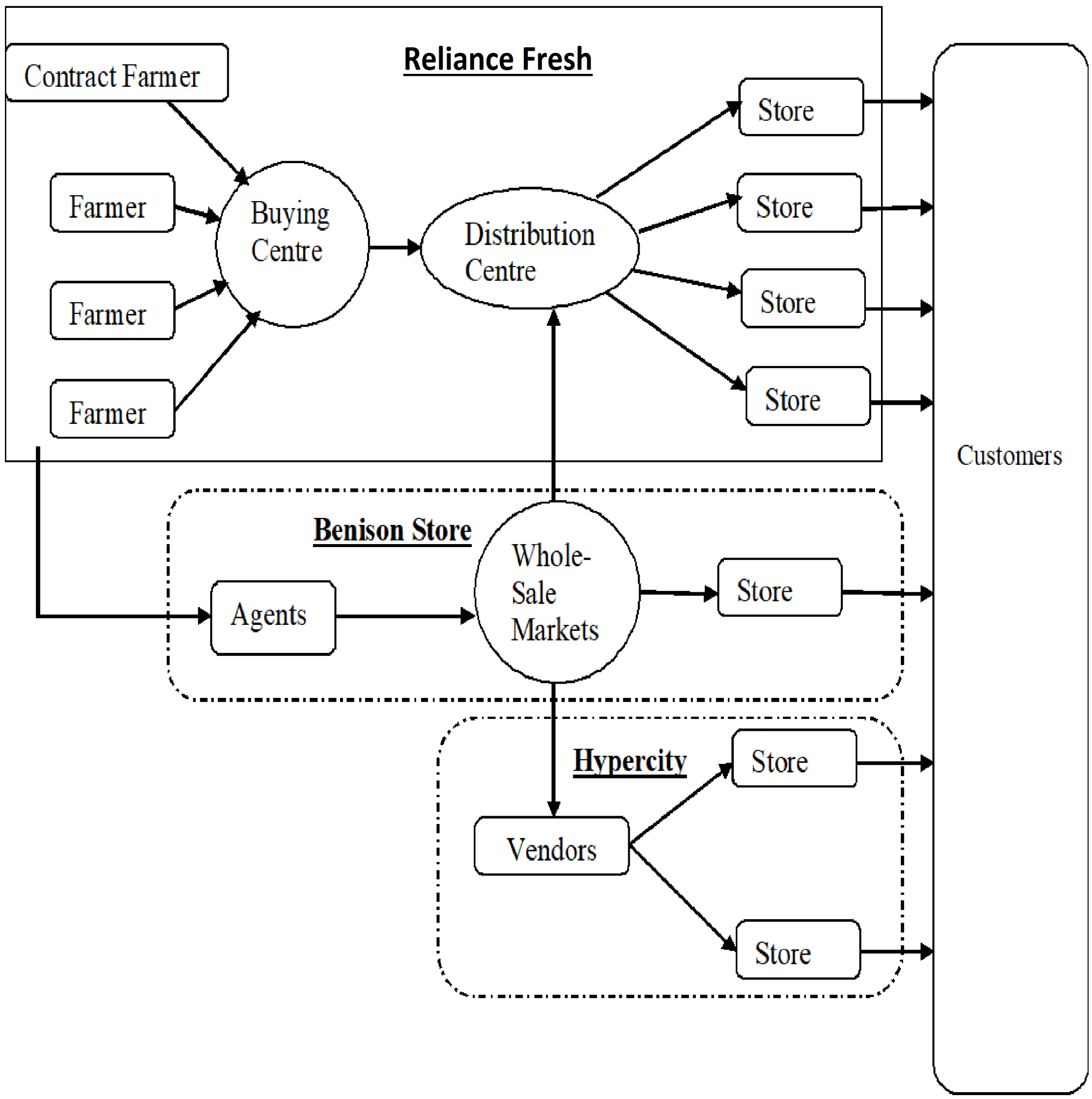

Figure 1: Organization of retail chain models in the food industry

heuristic methods of solving the vehicle routing problem (VRP). Song and Ko (2016) model the supply of perishable food products using general and refrigerated vehicle types. The goal is to maximize the level of customer satisfaction. It is assumed that the volume of ordered food products for each customer, capacity of the vehicle and available numbers of vehicles are known. Here, a non-linear model and heuristic algorithm is being used to maximize the total level of customer satisfaction. The given study is devoted to generating a routing network for an online perishable food shopping store where the required order size and customer location is known.

Suppliers, as well as restaurants operation hours are limited, and it is desired to procure or distribute products within time-windows. Koskosidis et el. (1992) considered soft-time window constraints in transportation such that the violation of a time window constraint incurs a penalty cost on the supplier. It also includes a mixed integer linear programming formulation to calculate the arrival time of the vehicle at a given location in a routing network by minimizing the total cost of transportation.

Hsu et el. (2007) considered the spoilage of food with elapsed time from a distribution center to a given location. They use a decreasing linear price function of elasped time associated with the spoilage of food. However, they assume a single product and a homogeneous fleet. Their objective is to minimize the fixed cost of dispatching vehicles, variable costs of transportation and energy and a penalty cost for violating a time-window. Borcinova (2017) discussed the hard-time window as well as soft time window constraints for a vehicle routing problem. In addition to that, multiple suppliers for a similar product might exist at the local and global level. Thus, transportation cost and purchase cost needed to be considered in the objective function to reduce procurement cost. Amorim et al. (2014) and Azi et el. (2010) discussed vehicle routing problems associated with revenues from consumers. In both articles, routes are defined over customers with demand and time-windows. In these articles, customers are chosen based on their associated revenue minus the traveling cost to reach them. Laarhoven et el. (1987) discussed a simulated annealing approach for solving vehicle routing problem with time window (VRPTW) and Lin et el. (2011) devoted their study for reducing the transportation cost of the truck and trailer routing problem (TTRP). In the study by Lin et el. (2011), truck and trailer routing problems with time windows were introduced. Two experiments also included in that article results to show that the simulated annealing is an effective method to get near to the optimal solution within a reasonable time.

While much research has been done on the fast food industry, a gap in the literature is the development of a sourcing and distribution model for restaurant chains with perishability constraints.

Chapter 3

3 Product categorization

3.1 Product categorization requirements

Ramadhan and Simatupang (2012) classify food material according to the restaurant industry terminology as wet and dry material.

1. **Wet material:** Wet material has a shorter expiration life cycle. Examples of wet material include fruits and vegetables with short shelf-life such as tomatoes, dairy products, and other ingredients such as sauces. The industry uses the Just-in-time (JIT) model to procure wet materials. In the JIT model, the system procures required by the restaurant locations with very little holding.
2. **Dry material:** Dry material is food material which has a longer expiration life cycle. Examples of dry material include vegetables with long shelf life such as potatoes or ginger, ketchup, salt, pepper, cooking oil, etc. The industry uses the economic ordering quantity (EOQ) model to procure dry materials. The EOQ trades-off the cost of ordering and holding raw materials in a warehouse.

The economic ordering quantity (EOQ) model appears to be a valid strategy for the procurement of dry material. In this thesis, we are only concerned about the procurement and distribution strategy of wet material. In the restaurant industry, the shelf-life of fresh-produce for procurement and distribution is important. Restaurants usually place their orders after the inventory level reduces to the reordering point following which a centralized warehouse distributes the product. The raw materials should be procured cyclically to reduce transportation costs, obtain economies of scale, and be consistent. But, the demand at each restaurant is triggered at a different time. Thus, the industry faces a challenge in supplying raw materials with the same remaining shelf-life at each restaurant; as a result, raw-material sometimes get spoiled at a restaurant facility before they are used.

The second and more crucial problem is that in current industry practice, the warehouse only procures and holds inventory required by the restaurant locations consid-

Table 1: Shelf-life of fresh produce and dairy products

Index	Fresh produce	Shelf-life (in days)	Condition
1	Tomato	7	Non-refrigerated
2	Eggplant	7	Non-refrigerated
3	Green Beans	7	Non-refrigerated
4	Corn	7	Non-refrigerated
5	Cucumber	7	Non-refrigerated
6	Spinach	7	Non-refrigerated
7	Chilli	7	Non-refrigerated
8	Milk (Dairy)	7	Refrigerated
10	Beet	15	Non-refrigerated
11	Cilantro	15	Non-refrigerated
12	Brocoli	15	Non-refrigerated
13	Cauliflower	15	Non-refrigerated
14	Kale	15	Non-refrigerated
15	Mushrooms	15	Non-refrigerated
16	Lemon	15	Non-refrigerated
17	Capsicum	21	Non-refrigerated
18	Cabbage	30	Non-refrigerated
19	Carrot	30	Non-refrigerated
20	Onion	30	Non-refrigerated
21	Ginger root	30	Non-refrigerated
22	Squash	30	Non-refrigerated

ering remaining shelf-life of produce with the fastest expiration cycle as the utilization time limit. This implies that produce with a longer shelf-life are procured and distributed in the same cycle as produce with a shorter life-cycle. This practice makes it difficult to optimize procurement and distribution of produce with different life cycles. Further, when longer life-cycle produce is sourced, suppliers further away from the warehouse could be considered.

3.2 Method of product categorization

Every fruit, vegetable, or other products such as dairy, have different shelf-life. Some fruits and vegetables can last for a week while others can last more than a month. Depending on their shelf-life, product categorization can take place. Table 1 shows the shelf-life of fresh produce and dairy products in a refrigerated or non-refrigerated condition. This list includes typical fresh produce out of many such used in the restaurant industry.

Using a refrigerated environment prolongs produce shelf-life (e.g. tomatoes). But refrigeration also has a down side. Some types of produce lose their flavour at the genetic level (Klein, 2016). Whether a product should be refrigerated or or not can be chosen based on the quality standard required by the industry. After enlisting all the produce required at each restaurant location, those having almost similar shelf-lives could be clustered within the same category.

As illustrated in Table 1, the types of produce with the same shelf-life have been clustered together, except for product 17, which for simplifcation could be classified as having a shelf-life of 15 days. The reason behind clustering these produces is to procure, store and distribute them in the same cycle.

3.3 The function of product categorization

Product categorization can be shown to be an appropriate alternative method of procurement and distribution. However, It is important to define several terminologies to understand the function of product categorization.

1. **Procurement cycle:** Procurement cycle is defined as the total time a produce spends after harvesting from the farm to arrival at the regional warehouse. Every produce spends some time at a supplier facility (such as a distributor or wholesaler) as well as in transportation before arriving into the warehouse. The procurement time can be defined as the elapsed shelf-life of produce when it arrives into the warehouse from a farm.
2. **Utilization cycle:** Utilization cycle is defined as the total remaining shelf-life of produce after its arrival in the warehouse. It implies that the produce must be consumed within that time to avoid spoilage of food.

The produce shelf-life can be defined by the following formula:

Produce shelf-life (fixed) = Procurement cycle (variable) + Utilization cycle (variable)

As illustrated in the formula, the produce shelf-life is fixed, while the procurement and utilization cycles can be variable. If a produce is procured quickly, then a higher utilization time for consumption can be allowed. Therefore, the restaurant outlets can hold produce for a longer period of time (i.e., they can hold more inventory). However, a distant supplier cannot be considered in the case of a shorter procurement cycle.

On the other hand, if the produce is procured with a longer duration, then the utilization time available for product consumption reduces. Thus, the restaurant outlets need to order more frequently since they cannot hold a large amount of produce in inventory.

Therefore, the functions of product categorization are:

1. **Increase in demand:** Clustering produce with a similar shelf-life increases the cumulative demand of each produce category. Therefore, the demand can be met from a distant supplier, if beneficial in terms of total purchase and transportation cost.

2. **Supplier location consideration:** Product categorization can offer the flexibility to consider an appropriate supplier for each produce category. Each category can be purchased allocating different procurement time limits. Thus, a more distant supplier can be considered for procurement of a category with longer shelf-life. On the contrary, a less distant supplier should be considered for procurement of a category with shorter shelf-life. Short shelf-life produce can be purchased from a regional or national supplier, while global suppliers can be considered for longer shelf-life produce.

Chapter 4

4 Procurement model

4.1 Constraints for Procurement model

There are two kinds of procurement techniques: supplier distribution and customer pick up. In supplier distribution, a supplier is responsible for bringing produce to the client warehouse. In the consumer pickup method, a consumer is responsible for picking up their shipments from the supplier facility. We will begin with the customer pick up method and show how the model can be generalized to use supplier distribution also.

The characteristics of the procurement model are:

1. **Supplier facility business hours:** Each supplier has a specific time-window for their business operation. Some supplier facility might be operated longer hours than others. There are two kinds of time-window restrictions that can be considered. If a supplier has specific business hours for their operation, then the vehicle must visit the supplier within that time-window only. This is a hard constraint. On the other hand, some suppliers can accomdate any arrival time so long as it is communicated in advance. Therefore, the model needs to be able to estimate arrival time at the supplier.

2. **Selling price of produce:** The selling price of produce may differ from supplier to supplier. Retailers generally have a higher selling price than wholesalers and distributors. In addition, retailers cannot provide distribution making consumer pick-up the only option.

3. **Elapsed Shelf-life of Product:** It is assumed that a supplier consistently has the same elapsed shelf-life of produce since procurement is done daily. In other words, the elapsed shelf life for a given category of produce does not vary from day to day. However, there can be differences in the elapsed shelf life of a produce category from supplier to supplier based on their location or type. For example, a supplier close to the farm will have a lower elapsed shelf

life. Similarly, a retailer supplier might have a higher elapsed shelf-life than a distributor. Regardless of the distribution method, the transportation time from the distributor to the regional warehouse is added to obtain the elapsed shelf-life of produce at a facility.

4. **Packaging standard:** Every produce falling under the same produce category might require a different packaging configuration according to the weight and volume of product. It also needs to comply with the common footprint of packaging standards. Thus, the volume and weight capacity constraints according to the packaging standard of each produce type must be considered in the procurement model.

4.2 Objectives of Procurement model

The objectives of the procurement model can be stated as follow:

1. **Supplier selection:** The primary objective of the model is to find the most appropriate and cost-effective supplier for each type of produce falling under the same category considering its purchase and transportation cost. The remaining shelf-life of each produce at the supplier facility needs to fall within an allocated procurement time limit. This then determines the demand rate at the supplier facility. Distributors, wholesalers and retailers play a significant role in in the food supply chain, and the selling price of each produce and the distance of a supplier from the warehouse is different for each supply facility. In addition, suppliers can have one or more types of produce available at their facility.

2. **Route of procurement**: Every supplier facility operates during different business hours. Thus, it is desired to find out most cost-effective route for procurement based on the purchase and transportation cost subject to the supplier facility business hours. The model should also consider the routing for procurement based on daily operating hours. Overnight breaks are allowed in the model. It also ensures the procurement of every produce category in a cycle by one or more routes.

3. **Vehicle requirement**: Every produce has different packaging standards as discussed. The input data can contain vehicles of different sizes. The model

should find the most suitable and cost-effective vehicle based on the packaging standard and demand of each type of produce.

4. **Arrival time and overnight stopover time of vehicles**: The model should find the estimated arrival time and the overnight stopover time of a vehicle at a supplier location. This finding can help the supplier manage its workforce for loading operations in advance. A constant loading time can be considered at the suppliers.

4.3 Linear Formulation

4.3.1 Sets

The sets for the procurement model are as follows:

W = 0 (Warehouse)

A = $1, 2..., a$ (Supplier locations for product A)

B= $a + 1, a + 2..., a + b$ (Supplier locations for Product B)

$\vdots$

N = $a + b + ... + 1, a + b + ... + 2..., a + b + ... + n$ (Supplier locations for Product N)

U = W ∪ A ∪ B ∪....N (Set of depot and all supplier locations)

Days = $1, 2..., L$ (indexed by t for days)

Vehicles = $1, 2..., M$(indexed by k for vehicles)

Following the traditional VRP problem formulation, this problem contains node sets. Here, W represents the regional warehouse and set A represents suppliers for product A. Suppliers with multiple produce type are represented by creating a dummy node and considering them as individual suppliers at the same location. For example, if S3 is selling six products as indicated in Figure 2, then six individual suppliers are considered at location L3 shown in Figure 3. Every vehicle k has a different payload and cubic load capacity configuration. The procurement cycle is of length L and up to L days are allowed to complete the pickups and delivery to the regional warehouse. Vehicles and Days are also embedded as decision variable in procurement model.

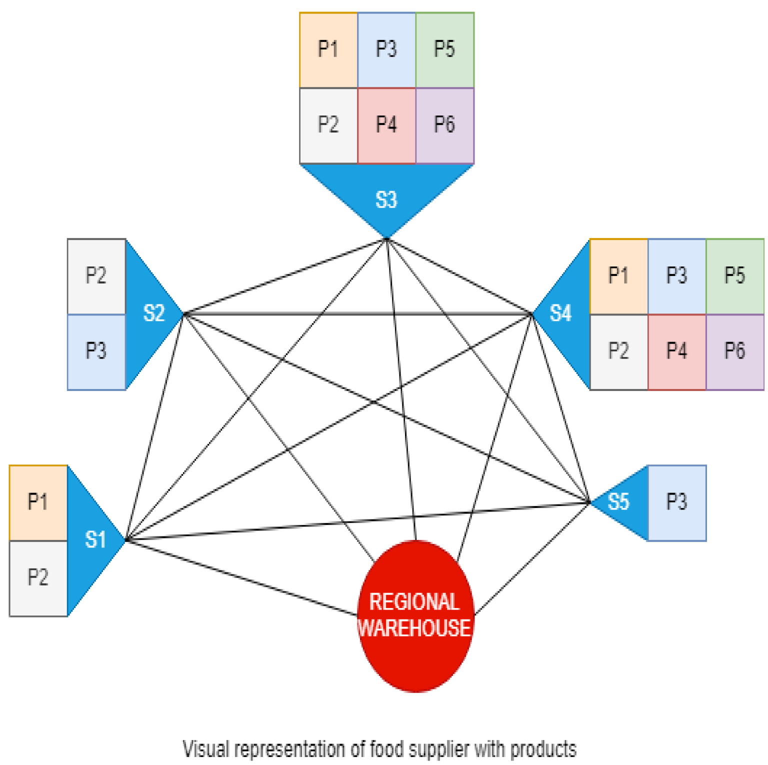

Figure 2: Visual representation of suppliers

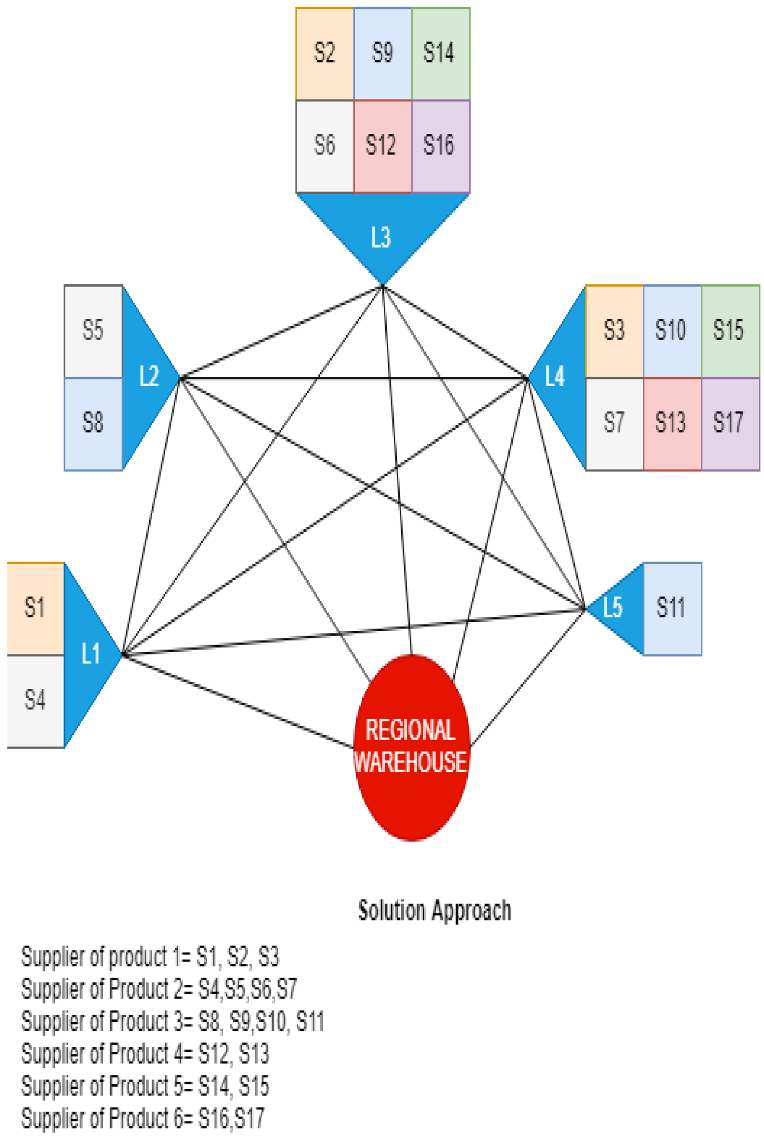

Figure 3: Supplier coding approach

4.3.2 Parameters

d_{ij}= travel distance from supplier location i to supplier location j

t_{ij}= travel time from supplier location i to supplier location j

s_i= Supply of given product from supplier i

v_i= Shipment volume of given product from supplier location i

p_i= Selling price of given product from supplier location i

lt_i= loading time required at supplier location i

W_k=Payload capacity of vehicle k

V_k=Cubic load capacity of vehicle k

F_k=Fixed cost of oprating vehicle k

O_k=Operating cost of vehicle k per km

S_k=Stopover cost of vehicle k per hour

EL_i=Elapsed shelf-life of product at supplier location i

TC_i=Travel time consideration constant for supplier location i

E_{ti}=Earliest arrival time of vehicle at supplier location i in day t

L_{ti}=Latest arrival time of vehicle at supplier location i in day t

P_{limit}=Procurement time limit

SL= Shelf-life of produce category

M= Big constant number

$Tf_1 = 60, Tf_2 = 1440$ (conversion factor of hours to minutes and days to minutes respectively)

4.3.3 Decision variables

L_{ijk}=1 if arc i , j transversed by vehicle k , 0 otherwise

X_k=1 if vehicle k is used, 0 otherwise

Y_i=1 if product is being procured from supplier facility i , 0 otherwise

T_{ti}=1 if a vehicle visits supplier location i in day t , 0 otherwise

D_t=1 if day is being utilized, 0 otherwise

Ar_{ik}=Arrival time of vehicle k at supplier location i

SO_{ik}=Stopover time at supplier location i by vehicle k

Pr_{0k}=Total procurement time by vehicle k

Z_{ik}= Sub-tour elimination variable

4.3.4 Objective function

The problem is to find the most appropriate supplier for each category of produce by using one or many vehicle types to meet demand.

Minimize Z: $\sum_{k=1}^{m} F_k{*}X_k{+} \sum_{k=1}^{m}\sum_{i=0}^{n}\sum_{j=0,i\neq j}^{n} L_{ijk}{*}d_{ij}{*}O_k{+} \sum_{i=1}^{n} Y_i{*}p_i{*}s_i{*}(SL{-}P_{limit}){+} \sum_{k=1}^{m}\sum_{i=0}^{n}$ $SO_{ik} * \frac{S_k}{Tf_1}{+} \sum_{k=1}^{m}\sum_{i=0}^{n} Ar_{ik} * \frac{1}{M}{+} \sum_{k=1}^{m} Pr_{0k} * \frac{1}{M}$

The objective function is to minimize total procurement cost by considering the fixed cost of vehicle dispatch, transportation cost, purchase cost, and the stopover cost of vehicles (these are the first four terms in the objective function). The last two terms are simply accounting variables to make sure that arrivals and procurements are shifted as early as possible.

$$\sum_{k=1}^{m} F_k * X_k \qquad \text{(OF4-1)}$$

F_k in above term represents the fixed cost of operating vehicle k . X_k is a binary variable, which indicates that if vehicle i serves any given route during procurement then X_k =1; otherwise X_k=0.

$$\sum_{k=1}^{m}\sum_{i=0}^{n}\sum_{j=0,i\neq j}^{n} L_{ijk} * d_{ij} * O_k \qquad \text{(OF4-2)}$$

L_{ijk} in (OF4-2) is a binary varible, which indicates that if vehicle k serves supplier j after supplier i in a sequence then L_{ijk} =1; otherwise L_{ijk} =0. In term (OF2) ,d_{ij} is the distance between supplier i and supplier j and $O_k$is the vehicle operating cost per km.

$$\sum_{i=1}^{n} Y_i * p_i * s_i * (SL - P_{limit}) \tag{OF4-3}$$

p_i and $s_i$in (OF4-3) are the selling cost and total supply of produce from supplier i respectively. Y_i is a binary veriable, which indicates that if produce is purchased from supplier i , then $Y_i = 1$;otherwise $Y_i = 0$. The demand is calculated by the length of the procurement cycle which is represented by $SL - T_{limit}$.

$$\sum_{k=1}^{m}\sum_{i=0}^{n} SO_{ik} * \frac{S_k}{Tf_1} \tag{OF4-4}$$

The problem is formulated in a way that a vehicle can use a route of any length less than the procurement time limit. Thus, the overnight stopover penalty cost is considered in the objective function. This could also include the parking cost of vehicle k at supplier facility. SO_{ik} is stopover time required at supplier facility i for vehicle k in minutes. S_k stopover cost for vehicle k per hour. Term (OF4) is divided by TF_1 to convert minutes into hours.

$$\sum_{k=1}^{m}\sum_{i=0}^{n} Ar_{ik} * \frac{1}{M} \tag{OF4-5}$$

$$\sum_{k=1}^{m} Pr_{0k} * \frac{1}{M} \tag{OF4-6}$$

Terms (OF4-5) and (OF4-6) in the objective function are added to ensure that the arrivals and procurement time are as small as possible. Both functions are divided by big constant number to reduce their impact in the objective function - these are accounting variables only.

4.3.5 Model constraints

$$\sum_{i=1, i \neq j}^{n} L_{ijk} = \sum_{i=1, i \neq j}^{n} L_{jik}, \forall j \epsilon 1, 2 \ldots, n, \forall k \epsilon 1, 2 \ldots, m \tag{4-1}$$

$$\sum_{k=1}^{m} \sum_{i \epsilon U \cap A} \sum_{j \epsilon A, i \neq j} L_{ijk} = 1 \tag{4-2}$$

$$\sum_{k=1}^{m} \sum_{i \epsilon U \cap B} \sum_{j \epsilon B, i \neq j} L_{ijk} = 1 \tag{4-3}$$

$\vdots$

$$\sum_{k=1}^{m} \sum_{i \epsilon U \cap N} \sum_{j \epsilon N, i \neq j} L_{ijk} = 1$$

$$\sum_{k=1}^{m} \sum_{i \epsilon U \cap A} L_{ijk} = Y_j, \, \forall j \epsilon A \tag{4-4}$$

$$\sum_{k=1}^{m} \sum_{i \epsilon U \cap B} L_{ijk} = Y_j, \, \forall j \epsilon A$$

$$\vdots$$

$$\sum_{k=1}^{m} \sum_{i \epsilon U \cap N} L_{ijk} = Y_j \, , \forall j \epsilon N$$

$$\sum_{i=1}^{n} \sum_{j=1, i \neq j}^{n} L_{ijk} \leq M * X_k \; \forall k \epsilon 1, 2 \ldots, m \tag{4-4}$$

$$\sum_{j=1}^{n} L_{0jk} - X_k = 0 \, , \forall k \epsilon 1, 2 \ldots, m \tag{4-5}$$

$$\sum_{i=1}^{n} L_{i0k} - X_k = 0 \, , \forall k \epsilon 1, 2 \ldots, m \tag{4-6}$$

$$Z_{ik} - Z_{jk} + W_k * (1 - L_{ijk}) \leq (SL - P_{limit}) * s_i * L_{ijk} + M * (1 - X_k), \, \forall i, j \epsilon 1, 2 \ldots, n, i \neq j, \forall k \epsilon 1, 2 \ldots, m \tag{4-7}$$

$$s_i * (SL - P_{limit}) * L_{ijk} \leq Z_{ik} \leq W_k X_k \, , \forall i \epsilon 1, 2 \ldots, n, j \epsilon 1, 2 \ldots, n, , i \neq j, \forall k \epsilon 1, 2 \ldots, m \tag{4-8}$$

$$V_k - \sum_{j=1}^{n} ((SL - P_{limit}) * v_j * \sum_{i=0, i \neq j}^{n} L_{ijk}) \geq 0 \, , \forall k \epsilon 1, 2 \ldots, m \tag{4-9}$$

$$Pr_{0k} \geq \frac{\sum_{i=0}^{n} \sum_{j=0, i \neq j}^{n} L_{ijk} * (t_{ij} + lt_i) + \sum_{i=1}^{n} SO_{ik}}{Tf_2} \, , \forall k \epsilon 1, 2 \ldots, m \tag{4-10}$$

$$Pr_{0k} + EL_i * L_{ijk} \leq P_{limit} \, , \forall i, j \epsilon 1, 2 \ldots, n, i \neq j, \forall k \epsilon 1, 2 \ldots, m \tag{4-11}$$

$$Pr_{0k} \leq \sum_{t=1}^{l} D_t \, , \forall k \epsilon 1, 2 \ldots, m \tag{4-12}$$

$$Ar_{jk} \geq Ar_{ik} + t_{ij} * TC_i + lt_i - (1 - L_{ijk}) * M \; , \, \forall i, j \epsilon 1, 2 \ldots, n, i \neq j, \forall k \epsilon 1, 2 \ldots, m \tag{4-13}$$

$$SO_{ik} \geq (Ar_{jk} - Ar_{ik}) - t_{ij} - (1 - L_{ijk}) * M \, , \forall i, j \epsilon 1, 2 \ldots, n, i \neq j, \forall k \epsilon 1, 2 \ldots, m \tag{4-14}$$

$$\sum_{t=1}^{l} E_{ti} * T_{ti} \leq Ar_{ik} \leq \sum_{t=1}^{l} L_{ti} * T_{ti} \, , \forall j \epsilon 1, 2 \ldots, n, i \neq j, \forall k \epsilon 1, 2 \ldots, m \tag{4-15}$$

$$\sum_{t=1}^{l} T_{ti} \leq 1 \, , \forall i \epsilon 1, 2 \ldots, n \tag{4-16}$$

$$L_{ijk}, \, X_k, \, Y_i, \, T_{ti}, \, D_t, \, Ar_{ik}, \, SO_{ik}, \, Pr_{0k}, \, Z_{ik} \geq 0 \tag{4-17}$$

Constraint (4-1) is a flow -balance constraint, which ensures that vehicle k enters and exits supplier location j.

Constraint (4-2) ensures that the vehicle visits only one location from a given list of suppliers for each produce type. Set $i \epsilon U \cap A$ suggests that the vehicle can arrive from any supplier except for supplier group of products A. In the same constraint, set $j \epsilon A, i \neq j$ suggests that it must enter into supplier group A for procurement.

Constraint (4-3) is included to consider the selling price of every given produce type from a visited supplier in the objective function. Constraints (4-2) and (4-3) need to repeated for every produce type.

All route variables L_{ijk} are 0 for vehicles which are not used (Constraint 4-4). Constraints (4-5) and (4-6) ensure that no vehicle can use a route disconnected from the depot. All used vehicles must leave the depot and renter it after procurement.

Constraints (4-7) and (4-8) are the subtour elimination constraints along with maximum capacity (payload) .

Constraint (4-9) is the maximum volume (cubic load) constraint.

Constraint (4-10) calculates the procurement time, i.e., total time of each used vehicle from the regional warehouse and back.

Constraint(4-11) ensures that model can not procure a produce with elapsed shelf life including total transportation time which is greater than the allocated procurement limit.

Constraint (4-12) is a valid inequality which defines the days of operation of each vehicle (the days are opened consecutively). This constraint is strictly not necessary but reduces the execution time.

Constraint (4-13) calculates the arrival time of vehicle at each supplier facility visited.

Constraint (4-14) calculates the stopover time of vehicle at each supplier facility if overnight stopovers are required during procurement.

Constraints (4-15) and (4-16) cumulatively enforce hard-time window constraints in the model.

Constraints (4-17) defines the variable domains (continuous, binary, integer).

4.4 Execution of the procurement model

In this thesis, the main objective is to find the cost-effective combination of procurement, storage and distribution to restaurants. The procurement model represents the first stage of delivery. The procurement model can therefore be run by varying the procurement time limit P_{limit}. The utilization time limit described in the next chapter (for the second stage of delivery) should be such that the sum of procurement and utilization time is less than the total shelf life.

The GUSEK programming code of the procurement model is included in Appendix I.

Chapter 5

5 Distribution model

5.1 Constraints for the distribution model

The characteristics of the distribution models are:

1. **Restaurant service hours:** Like supplier facilities, restaurants also have specific time window for their business operation. Restaurant service hours might be diffferent based on locations, selling potential and consumer requirements. It is very crucial to consider restaurant service time-windows to distribute demanded shipment from the regional warehouse. Therefore, hard time-window constraints needs to be considered in the distribution model as well.
2. **Packaging standard:** Every restaurant may have different demands for each produce. Shipment will require different packaging configurations based on weight and volume of demanded produce. Thus, weight and volume consraints according to the common footprint of packaging standards also needs to considered in the distribution model as well.

5.2 Objective of distribution model

1. **Route of distribution:** Every restaurants operates during different service hours. Thus, it is desired to find out most cost-effective route for distribution based on the demand and transportation cost subject to the restaurant business hours. It also ensures the distribution of every demanded shipment in utilization cycle by one or more routes.
2. **Vehicle requirement:** Every shipment has a different packaging configuration. The input data can contain different sizes of vehicles. The model should find the most suitable and cost-effective vehicles considering payload and cubic load capacity.
3. **Arrival time of vehicles:** The model should find the estimated arrival time of vehicles at restaurants. This can help the restaurants manage its workforce for

unloading operations in advance. A constant unloading time can be considered at the restaurants.

5.3 Linear Formulation

5.3.1 Sets

The sets for a distribution model are as follow:

W = 0

N = $1, 2..., n$

U = W $\cup$ N

V = $1, 2..., m$

Following the traditional VRP problem notation, this problem contains node sets. W represent the regional warehouse. N represents restaurant locations. V denotes the different vehicles.

5.3.2 Parameters

d_{ij}= travel distance from nodel i to node j

t_{ij}= travel time from node i to node j

D_i= Demand at node i (in kg)

v_i= Demanded shipment volume at node i

ut_i=Unload time required at node i

W_k=Payload capacity of vehicle k

V_k= Cubic load capacity of vehicle k

F_k= Fixed cost of operating vehicle k

O_k= Operating cost of vehicle k per km

U_{limit}=Allocated utilization time limit

E_i=Earliest arrival time at location i

L_i=Latest arrival time at location i

5.3.3 Decision Variables

L_{ijk}= 1 if arc i, j is transversed by vehicle k , 0 otherwise

X_k=1 if vehicle k is used, 0 otherwise

Ar_{ik}= Arrival time of vehicle k at supplier location i

Z_{ik}= Subtour elimination variable

5.3.4 Objective function

Minimize Z: $\sum_{k=1}^{m} F_k * X_k + \sum_{k=1}^{m}\sum_{i=0}^{n}\sum_{j=0,i\neq j}^{n} L_{ijk} * d_{ij} * O_k$

The primary goal of objective function is to minimize total fixed cost and the transportation cost of distribution. It also finds the most cost-effective and suitable vehicles for procurement considering payload and cubic load capacity.

$$\sum_{k=1}^{m} F_k * X_k \tag{OF5-1}$$

F_k in above term represents the fixed cost of operating vehicle k . X_k is a binary variable, which indicates that if vehicle i serves any given route during procurement then X_k =1; otherwise X_k=0.

$$\sum_{k=1}^{m}\sum_{i=0}^{n}\sum_{j=0,i\neq j}^{n} L_{ijk} * d_{ij} * O_k \tag{OF5-2}$$

L_{ijk} in (OF5-2) is a binary varible, which indicates that if vehicle k serves supplier j after supplier i in a sequence then L_{ijk} =1; otherwise L_{ijk} =0. In term (OF5-2) ,d_{ij} is the distance between supplier i and supplier j and $O_k$is the vehicle operating cost per km.

5.3.5 Model constraints

$$\sum_{i=1,i\neq j}^{n} L_{ijk} = \sum_{i=1,i\neq j}^{n} L_{jik},\ \forall j \epsilon 1, 2 \ldots, n, \forall k \epsilon 1, 2 \ldots, m \tag{5-1}$$

$$\sum_{k=1}^{m}\sum_{i=0}^{n} L_{ijk} = 1\ \ ,\forall j \epsilon N \tag{5-2}$$

$$\sum_{i=1}^{n}\sum_{j=1,i\neq j}^{n} L_{ijk} \leq M * X_k \ \ ,\forall k\epsilon 1,2\ldots,m \tag{5-3}$$

$$\sum_{j=1}^{n} L_{0jk} - X_k = 0 \ \ ,\forall k\epsilon 1,2\ldots,m \tag{5-4}$$

$$\sum_{i=1}^{n} L_{i0k} - X_k = 0 \ \ ,\forall k\epsilon 1,2\ldots,m \tag{5-5}$$

$$Z_{ik} - Z_{jk} + W_k * (1 - L_{ijk}) \leq U_{limit} * D_i * L_{ijk} + M * (1 - X_k),\ \forall i,j\epsilon 1,2\ldots,n \ \ ,i \neq j,\ \forall k\epsilon 1,2\ldots,m \tag{5-6}$$

$$U_{limit} * D_i * L_{ijk} \leq Z_{ik} \leq W_k X_k \ \ ,\forall i\epsilon 1,2\ldots,n, j\epsilon 1,2\ldots,n, i\neq j, \forall k\epsilon 1,2\ldots,m \tag{5-7}$$

$$V_k - \sum_{j=1}^{n} (U_{limit} * v_j * \sum_{i=0,i\neq j}^{n} L_{ijk}) \geq 0 \ \ ,\forall k\epsilon 1,2\ldots,m \tag{5-8}$$

$$Ar_{jk} \geq Ar_{ik} + t_{ij} * TC_i + ut_i - (1 - L_{ijk}) * M \ \ ,\ \forall i,j\epsilon 1,2\ldots,n, i \neq j, \forall k\epsilon 1,2\ldots,m \tag{5-9}$$

$$E_i \leq Ar_{ik} \leq L_i \ \ ,\forall k\epsilon 1,2\ldots,m, \forall i\epsilon 1,2\ldots,n \tag{5-10}$$

$$L_{ijk},\ X_k,\ Ar_{ik},\ Z_{ik} \geq 0 \tag{5-11}$$

Constraint (5-1) is a flow-balance constraint, which ensures that if vehicle k enters and restaurant location j , it must then leave.

Constraint (5-2) states that each restaurant is visited exactly once.

(Constraint 5-3) specifies that all route variables L_{ijk} are 0 for vehicles which are not used .

Constraints (5-4) and (5-5) ensure that no vehicle can use a route disconnected from the depot. All used vehicles must leave the depot and renter it after delivery.

Constraints (5-6) and (5-7) are subtour elimination constraints which also act as maximum capacity (payload) constraints.

Constraint (5-8) is the maximum volume (cubic load) constraint.

Constraint (5-9) calculates the arrival time of vehicle at each restaurant facility visited.

Constraint (5-10) enforces the service time-window constraints in the model.

Constraint (5-11) defines the variable domains (continuous, binary, integer).

5.4 Execution of Distribution model

The distribution model represents the second stage of delivery. It can therefore be run by varying the utlization time limit U_{limit}. The procurement time limit described in the previous chapter (for the first stage of delivery) should be such that the sum of the procurement and utilization time is less than the total shelf life.

The GUSEK programming code of the distribution model is included in Appendix II.

Chapter 6

6 Integrated model for procurement, storage and distribution

6.1 Requirements for the integrated model for procurement, storage and distribution

As discussed in chapters 4 and 5, the length of the procurement and utilization cycle have a major impact on the cost of each produce utilized by restaurants. The demand for each produce is inversely proportional to the procurement cycle length. Therefore, the storage needs of each produce at regional warehouse changes with the procurement cycle length. When the procurement cycle length is short, the inventory level at the warehouse will be high and the delivery to the restaurants can be done within a longer time window. Conversely, when it is long, the inventory level will be low and the delivery to the restaurants is within a shorter time window. Also, the suppliers chosen for delivery depend on the procurement time. When it is higher, distant suppliers may be considered if they are cheaper.

The storage cost at the warehouse is different according to the weight and volume of produce. The holding for per kilogram for each produce should be considered individually as a parameter.

Therefore, the integrated model is developed to find the most cost-effective procurement and utilization cycle grouping to minimize total supply chain costs. The procurement and distribution models discussed in the previous chapters can be run with different procurement and utilization limits. The integrated model finds the best combination of both.

6.2 Linear Formulation

6.2.1 Sets

The sets for distribution model are as follow.

U= $1, 2..., M$ (indexed by i)

DO= $1, 2..., N$ (indexed by j)

R=$1, 2..., K$(indexed by k)

Set U=$1, 2, ..., m$ represents the utilization time limit. The value of M can not be more than the produce shelf-life. Set DO=1, 2, ..., n represent delivery options for these utilization time limits. In this model, the value of M and N must be equal. However, all delivery options are not possible for each utilization time. R=$1, 2, ..., K$ represents the produce types.

6.2.2 Parameters

Parameters for distribution model are as below.

P_i=Total procurement cost of raw-materials considering utilization cycle length i (objective function value of the procurement model with $P_{limit} = SL - i$)

D_i= Total distribution cost of raw-material considering utilization cycle length i (objective function value of the distribution model with $U_{limit} = i$)

O_{ij}= 1, if the shipment combination with utilization time i and delivery option j is possible, 0 otherwise

f_{ij}= Shipment frequency implicit in the shipment combination O_{ij}

d_k= Average daily demand of produce k

h_k= Daily holding cost per kg of produce k

I_{ij}= Inventory carried for shipment combination O_{ij} in daily units (this can be pre-calculated based on shipment combination O_{ij}

6.2.3 Decision variables

X_{ij}=1 if shipment combination O_{ij} is chosen, 0 otherwise

6.2.4 Objective function

The objective function is to minimize given equation, which is the sum total of procurement, distribution, and holding costs per day.

Minimize Z: $\sum_{i=1}^{m}\sum_{j=1}^{n} \frac{P_i}{i} * X_{ij} + \sum_{i=1}^{m}\sum_{j=1}^{n} \frac{D_j}{i} * f_{ij} * X_{ij} + \sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{p} I_{ij} * O_{ij} * d_k * h_k$

The primary goal of objective function is to find the cost optimal shipment combination which represents the best procurement and utlization cycle lengths. It also decides the frequency of distribution required after procurement considering the holding cost of produce in the warehouse.

$$\sum_{i=1}^{m}\sum_{j=1}^{n} \frac{P_i}{i} * X_{ij} \tag{OF6-1}$$

P_i in term (OF6-1) represents the total cost of procurement of raw-material for a utilization time limit of i. Therefore, P_i is divided by utilization time i to calculate the procurement cost based on average daily demand.

$$\sum_{i=1}^{m}\sum_{j=1}^{n} \frac{D_j}{i} * f_{ij} * X_{ij} \tag{OF6-2}$$

Term (OF6-2) in the objective function calculates the total distribution cost for shipment combination O_{ij}. The divison by i and multiplication by shipment frequency f_{ij} is done to calculate the distribution cost based on average daily demand. Since X_{ij} is a binary variable indicating whether shipment combination O_{ij} is used, both terms are multiplied by this variable.

$$\sum_{i=1}^{m}\sum_{j=1}^{n}\sum_{k=1}^{p} I_{ij} * O_{ij} * d_k * h_k \tag{OF6-3}$$

Term (OF6-3) in the objective function calculates the total holding cost for shipment combination O_{ij}.

6.2.5 Model constraints

$$\sum_{i=1}^{m}\sum_{j=1}^{n} O_{ij}X_{ij} = 1 \tag{6-1}$$

Constraint (6-1) ensures that only one out of the allowable shipping options is selected.

A mixed integer linear program is not necessary for this model. The total cost of the feasible shipment combinations can be calculated by adding the inventory cost to the procurement and distribution models and the lowest cost option can be obtained.

The GUSEK programming code of the integrated model is included in Appendix III.

Chapter 7

7 Numerical example and results

This chapter illustrates the adaptive sequential decision making approach for procurement and distribution in fast-food restaurant chains using the models developed in chapters 4, 5, and 6.

7.1 Basic data for example

It is assumed that the locations of the fresh produce suppliers (25 suppliers for 8 produce types) are known as shown in Table 2. Table 3 shows which produce is available at which supplier facility by indexing all supplier produce combinations. It can be observed from Table 3 that suppliers may have one or more produce types available at their facility. Table 4 shows the range of suppliers available for each produce type. Therfore, as discussed in Chapter 4, 100 supplier-produce combinations are considered after creating a dummy node for each produce type available at each supplier facility. It is assumed that the warehouse is located in the Toronto harbourfront area.

The distance matrix between suppliers and the warehouse are generated using Google Distance Matrix API and the relative travel time is calculated considering an average transportation speed 80 km/hr considering a combination of highway and non-highway conditions.

To generate the distance matrix, Python code was developed to call Google Distance Matrix API (Appendix IV). Hooper and Murray (2018) and Manaadiar et el. (2017) provide information related to logistical needs such as the fixed and operating cost of vehicles with different payloads and cubic load capacities. Table 5 shows the values for 4 different vehicle types used in this numerical example based on these articles.

Suppliers in the example are located in Figure 4. Each supplier has a specific time-window for their business operation (Appendix V).

7.2 Numerical examples

The sequential decision-making optimization approach was discussed using three numerical examples. Between examples 1 and 2, the selling price and elapsed shelf-life of

Table 2: Fresh produce supplier locations in the examples

Index	Physical Address	Latitude/Longitude
1	1020 Malkin Ave, Vancouver, BC V6A 3S9	49.27261° N, 123.08234° W
2	9751 Bottom Wood Lake Rd, Lake Country, BC V4V 1S7	50.02344° N, 119.39749° W
3	221 BC-16, Burns Lake, BC V0J 1E0	54.2312° N, 125.76308° W
4	5470 76 Ave SE, Calgary, AB T2C 4S3	50.98516° N, 113.95633° W
5	10300 100 Ave, High Level, AB T0H 1Z0	58.52035° N, 117.14289° W
6	1450 Park St, Regina, SK S4N 2G2	50.45659° N, 104.57365° W
7	950 Boardman St, La Ronge, SK S0J 1L0	55.112869° N, 105.292664° W
8	1200 King Edward St, Winnipeg, MB R3H 0R5	49.91272° N, 97.207321° W
9	3109 School St, Terrace, BC V8G 5T4	54.51507° N, 128.5762° W
10	1000 Lakeshore Rd E, Mississauga, ON L5E 1E4	43.57667° N, 79.55913° W
11	22 Maitland St, London, ON N6B 3L2	42.99329° N, 81.24° W
12	1481 Michael St, Gloucester, ON K1B 3R5	45.415001° N, 75.628059° W
13	165 The Queensway, Etobicoke, ON M8Y 1H8	43.6298° N, 79.48573° W
14	355 Elmira Rd N, Guelph, ON N1K 1S5	43.531311° N, 80.304466° W
15	205 165 The Queensway,Toronto, ON M8Y 1H8	43.6298° N, 79.48573° W
16	500 terminal Ave A-05,ottawa, ON K1G 0Z3	45.414299° N, 75.647133° W
17	3335 Banwell Rd, Windsor, ON N8R 2K9	42.31578° N, 82.90174° W
18	83 Erb St W, Building two, Waterloo, ON N2L 6C2	43.46328° N, 80.52691° W
19	2072 Walkley Rd, Ottawa, ON K1G 3V3	45.37716° N, 75.64687° W
20	698 Rue Melançon, Saint-Bruno, QC G0W 2L0	48.46678° N, 71.63885° W
21	9210 Pie-IX Blvd, Montreal, QC H1Z 4H7	45.57384° N, 73.60806° W
22	1370 Rue de Beauharnois O #200, Montreal, QC H4N 1J5	45.52967° N, 73.65145° W
23	032 Fairville Blvd, Saint John, NB E2M 5T5	45.24629° N, 66.10815° W
24	528 Windmill Rd, Dartmouth, NS B3B 1B3	44.69204° N, 63.59959° W
25	6 Industry Ave, Yarmouth, NS B5A 4B2	43.83359° N, 66.09512° W

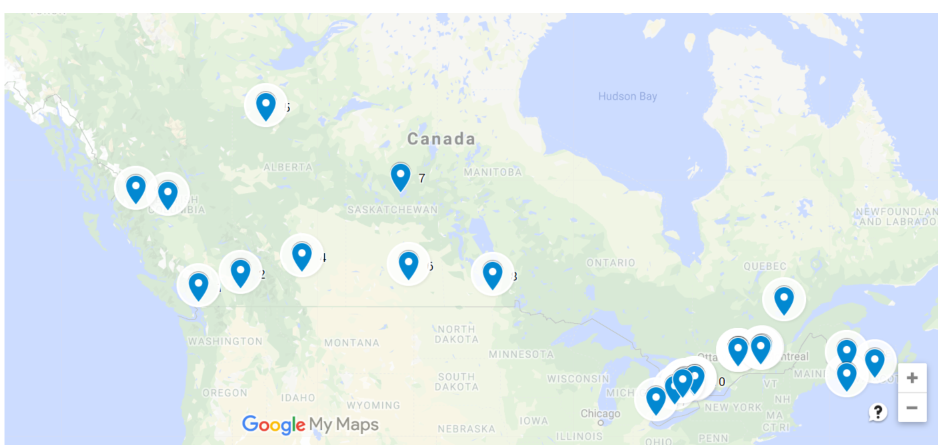

Figure 4: Fresh food supplier locations for example

Table 3: Fresh produce availability at supplier facilities

Supplier	Eggplant	Tomato	Green Beans	Corn	Cucumber	Spinach	Chilli	Milk
1	-	9	28	-	57	67	-	93
2	-	10	29	-	-	-	-	-
3	1	-	30		-	68	-	-
4	2	-	31	45	-	69	-	94
5	3	11	-	46	-	-	79	-
6	-	12	32	-	-	-	80	-
7	-	13	33	47	58	70	81	-
8	-	14	34	48	59	71	82	-
9	-	15	35	-	-	-	83	95
10	4	-	-	-	60	72	-	-
11	-	16	36	49	-	-	84	-
12	5	17	37	-	-	73	-	
13	-	-	38	-	-	74	-	96
14	6	-	-	50	-	-	85	-
15	-	18	-	-	61	-	-	-
16	7	19	39	51	62	75	86	-
17	-	20	40	52	63	76	87	-
18	-	21	-	53	-	-	-	
19	-	22	41	-	-	-	-	97
20	-	23	42	-	64	-	-	98
21	8	-	43	-		-	88	99
22	-	24	44	54	65	-	89	-
23	-	25	-	55	66	-	90	-
24	-	26	-	56	-	77	91	100
25	-	27	-	-	-	78	92	-

Table 4: Fresh produce supplier list

Index	Fresh produce	List of Dummy Suppliers
1	Eggplant	1 to 8
2	Tomato	9 to 27
3	Green Beans	28 to 44
4	Corn	45 to 56
5	Cucumber	57 to 66
6	Spinach	67 to 78
7	Chilli	79 to 92
8	Milk	93 to 100

Table 5: Vehicle information

Index	Payload Capacity	Cubic Load Capacity	Fixed Cost	Operating Cost ($/km)
1	1000 kg	1.72 m^3	$100	$1
2	3000 kg	5.16 m^3	$120	$1.2
3	5000 kg	10.4 m^3	$150	$1.5
4	10000 kg	20.6 m^3	$200	$1.8

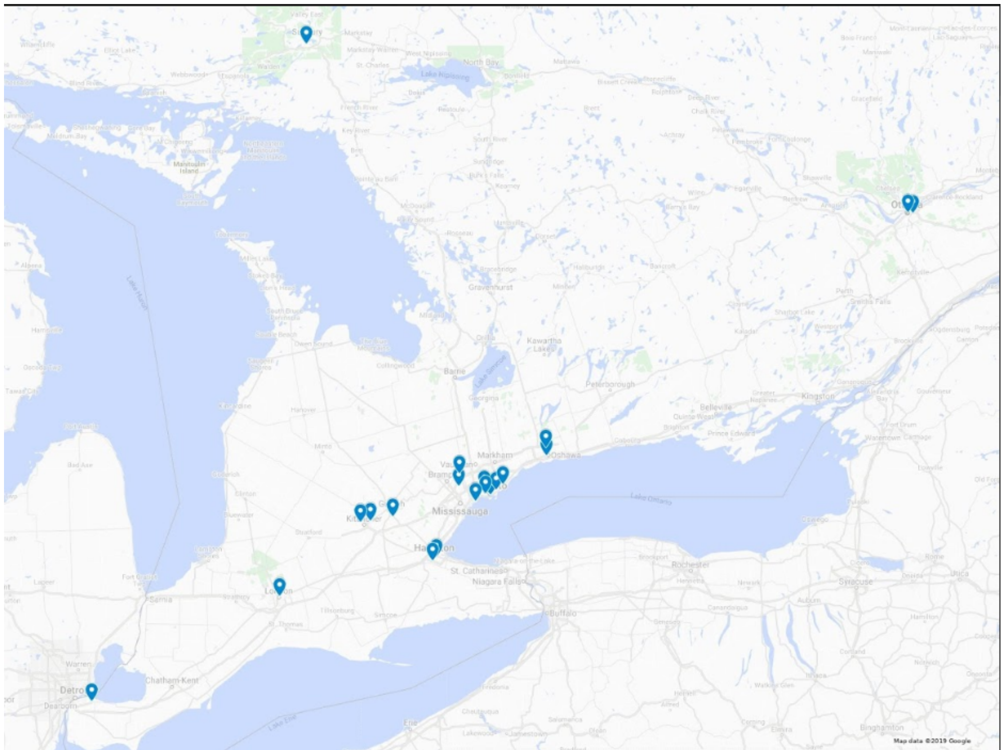

Figure 5: Restaurant locations for example 1

each produce type are different but the regional demands remain the same. Between examples 1 and 3, the selling price and and elapsed shelf-life for each produce type remain the same, while the regional demands are different.

7.2.1 Numerical example 1

In this example, a hypothetical multi-unit restaurant chain located in Ontario with 20 outlets as shown in Figure 5 is considered. The geographical location of each restaurant is included in Table 6. It is desired to procure and utilize each produce from the same supplier to maintain brand reputation and quality consistency in all restaurant outlets. In addition, all restaurants must be able to consume each produce within its shelf-life. Thus, it is assumed that the chain has established a regional warehouse located in the Toronto harbourfront area. Produce type with average daily demands are as shown in Table 7. The average daily demand for each produce type is calculated in Appendix VI. The elapsed shelf-life and selling price of each produce is shown in Table 8.

Table 6: Restaurant locations for example 1

Index	Physical Address	Latitude/Longitude
1	810 St Clair Ave W, Toronto, ON M6C 1B6	43.6809° N,79.4303° W
2	1150 Queen St W, Toronto, ON M6J 1J3	43.6432° N,79.4246° W
3	226 Greenwood Ave, Toronto, ON M4L 2R2	43.6717° N,79.3285° W
4	480 Danforth Rd, Scarborough, ON M1K 1C7	43.7086° N,79.2677° W
5	92 Ossington Ave, Toronto, ON M6J 2Z4	43.6462° N,79.4198° W
6	3003 Lake Shore Blvd W, Etobicoke, ON M8V 1K2	43.6° N,79.5077° W
7	7171 Torbram Rd, Mississauga, ON L4T 3W4	43.6976° N,79.6565° W
8	8920 Hwy 50, Brampton, ON L6P 3A3	43.7752° N,79.6536° W
9	3335 Banwell Rd, Windsor, ON N8R 2K9	42.3055° N,82.8998° W
10	500 Terminal Ave A-05, Ottawa, ON K1G 0Z3	45.4145° N,75.6484° W
11	296 Elgin St, Ottawa, ON K2P 1M3	45.4166° N,75.6895° W
12	44 Stevenson Rd S, Oshawa, ON L1J 2K6	43.8918° N,78.8831° W
13	1889 Regent St, Sudbury, ON P3E 3Z7	46.4518° N,81.0047° W
14	465 Dundas St, London, ON N6B 1W1	42.9871° N,81.2373° W
15	522 Concession St, Hamilton, ON L8V 1A6	43.2413° N,79.8539° W
16	1170 Upper James St, Hamilton, ON L9C 3B1	43.2172° N,79.8873° W
17	1812 Simcoe St N #4, Oshawa, ON L1G 4Y2	43.9429° N,78.8895° W
18	115 Downey Rd, Guelph, ON N1C 1A2	43.4994° N,80.2379° W
19	1595 Victoria St N, Kitchener, ON N2B 3E6	43.4734° N,80.4352° W
20	83 Erb St W, Building Two, Waterloo, ON N2L 6C2	43.4631° N,80.5267° W

As discussed in Chapter 3, the overall produce shelf-life is broken up into the procurement and utilization cycles. Thus every possible combination of procurement and utilization cycles must be considered to find the most optimal cost-effective strategy for procurement and distribution. The produce types considered in this example have a shelf-life of 7 days, as consistent with Table 1 in Chapter 3. It is assumed that each produce is already a day old by the time it reaches the supplier from the farm. Therefore, for the example, the total produce shelf-life has to be 6 days or less (*i.e.*, SL=6),

Table 7: Fresh produce suppliers for example 1

	Avg. daily demand	No of suppliers	Holding cost per day
Eggplant	332 kg	8	$0.15
Tomatoes	973 kg	19	$0.10
Green Beans	214 kg	17	$0.05
Corn	144 kg	12	$0.10
Cucumber	69 kg	10	$0.10
Spinach	82 kg	12	$0.25
Chilli	93 kg	14	$0.05
Milk	722 kg	8	$0.10

Table 8: Selling price and elapsed shelf-life of produce by supplier for example 1

Supplier	p_i	EL_i	Supplier	p_i	EL_i	Supplier	p_i	EL_i
1	7.19	1	36	2.88	3	71	7.19	3
2	6.39	3	37	3.3	2	72	7.42	1
3	6.46	1	38	3.89	3	73	8.18	2
4	5.91	2	39	4.32	1	74	8.43	1
5	5.95	1	40	5.3	3	75	7.77	3
6	5.4	3	41	5.26	3	76	8.75	1
7	7.75	3	42	2.95	2	77	7.29	1
8	6.87	3	43	4.02	1	78	8.87	1
9	3.4	3	44	4.77	1	79	7.48	1
10	4.79	3	45	3.72	2	80	11.96	3
11	2.85	2	46	3.98	3	81	13.77	1
12	3.85	1	47	3.8	3	82	13.94	3
13	4.91	2	48	4.46	1	83	14.44	1
14	3.52	3	49	4.86	2	84	13.98	3
15	3.85	2	50	3.91	3	85	11.19	3
16	4.89	2	51	3.5	1	86	13.54	3
17	4.34	1	52	4.46	2	87	12.05	3
18	3.9	2	53	4.38	2	88	12.37	2
19	3.66	1	54	4.01	2	89	12.87	1
20	4.2	2	55	3.5	3	90	12.48	1
21	3.54	3	56	4.35	2	91	14.78	3
22	3.7	3	57	4.59	1	92	11.82	2
23	4.7	3	58	5.2	1	93	1.45	2
24	4.12	1	59	6.48	1	94	1.35	2
25	2.42	1	60	5.87	3	95	1.45	2
26	2.3	1	61	5.58	1	96	1.1	1
27	2.6	2	62	5.05	2	97	1.24	1
28	4.5	1	63	4.79	1	98	1.16	2
29	2.9	2	64	4.62	3	99	1.57	2
30	3.64	2	65	5.94	2	100	1.27	1
31	3.38	2	66	7.64	1			
32	4.09	3	67	8.14	3			
33	3.05	1	68	8.63	2			
34	5.35	3	69	7.63	3			
35	3.91	2	70	7.09	1			

Note : Prices are in dollars and EL_i is in days

Table 9: Alternative combinations for procurement and utilization in days

Alternative	Procurement Cycle	Utilization Cycle
1	2	4
2	3	3
3	4	2
4	5	1

Table 10: Arrival time (in minutes) after running the procurement model for example 1

P_{limit}	Vehicle		Fresh Produce							
			1	2	3	4	5	6	7	8
5	3000 kg	Y_i	6	21	38	50	61	72	85	96
		Ar_{ik}	124	171	30	109	0	257	139	15
4	5000 kg	Y_i	6	21	36	50	-	72	85	-
		Ar_{ik}	88	135	236	103	-	0	73	-
	3000 kg	Y_i	-	-	-	-	61	-	-	96
		Ar_{ik}	-	-	-	-	0	-	-	15
3	5000 kg	Y_i	-	25	37	51	62	-	88	-
		Ar_{ik}	-	0	1440	1457	1472	-	1281	-
	3000 kg	Y_i	4	-	-	-	-	72		96
		Ar_{ik}	24	-	-	-	-	39		0
2	5000 kg	Y_i		25	-	-	-	-	90	-
		Ar_{ik}		0	-	-	-	-	15	-
	5000 kg	Y_i	-	-	-	-	61	72		96
		Ar_{ik}	-	-	-	-	0	39		15
	3000 kg	Y_i	5	-	39	51	-	-	-	-
		Ar_{ik}	32	-	15	0	-	-	-	-

as shown in Table 9.

Table 10 shows the arrival times of the vehicles used in the procurement model solution (an arrival time of 0 corresponds to 9 AM). Produce types are illustrated by index assigned in Table 4.

Table 11 shows the routes used for different procurement time limit values. The total payload and cubic load of freight for each route are also included in the results.

Table 12 shows the cost of procurement which includes purchase cost and transportation. It can be observed that the total procurement costs increase as the procurement cycle time decreases. However, the quantity purchased is also higher with the lower procurement cycle time, and in general, the impact on the unit purchase cost varies and will be discussed. The transportation costs are also higher as the procurement cycle time decreases because the distance travelled is higher and the quantity procured is also higher.

Table 11: Procurement routes used for example 1

P_{limit}	Feasible Route	Vehicle used	Vehicle Payload	Vehicle Cubicload
5	0-96-38-50-6-85-21-72-0	3000 kg	2629 kg	4.66 m^3
4	0-72-6-85-50-21-36-0	5000 kg	3636 kg	7.67 m^3
	0-96-61-0	3000 kg	1582 kg	1.65 m^3
3	0-25-88-37-51-62-0	5000 kg	4479 kg	7.43 m^3
	0-96-4-72-0	5000 kg	3408 kg	6.56 m^3
2	0-25-90-0	5000 kg	4264 kg	7.84 m^3
	0-61-96-72-0	5000 kg	3492 kg	5.90 m^3
	0-51-39-5-0	3000 kg	2760 kg	4.92 m^3

Table 12: Cost of procurement in example 1

Fresh Produce	Procurement cycle (in days)							
	5		4		3		2	
	Unit	Total	Unit	Total	Unit	Total	Unit	Total
Eggplant	5.4	1792	5.4	3585	5.91	5886	5.95	7901
Tomatoes	3.54	3444	3.54	6888	2.42	7063	2.42	9418
Green beans	3.89	832	2.88	1232	3.3	2118	4.32	3639
Corn	3.91	445	3.91	891	3.5	1197	3.5	1596
Cucumber	5.58	385	5.58	770	5.05	1045	5.58	1540
Spinach	7.42	608	7.42	1216	7.42	1825	7.42	2433
Chilli	11.19	1040	11.19	2081	12.37	3451	12.48	4642
Milk	1.1	794	1.1	1588	1.1	2382	1.1	3176
Total Purchase Cost	9343		18255		24790		34007	
Transportation Cost	416		946		4909		5965	
Total Procurement Cost	9760		19202		29880		40373	

Note : Prices are in dollars

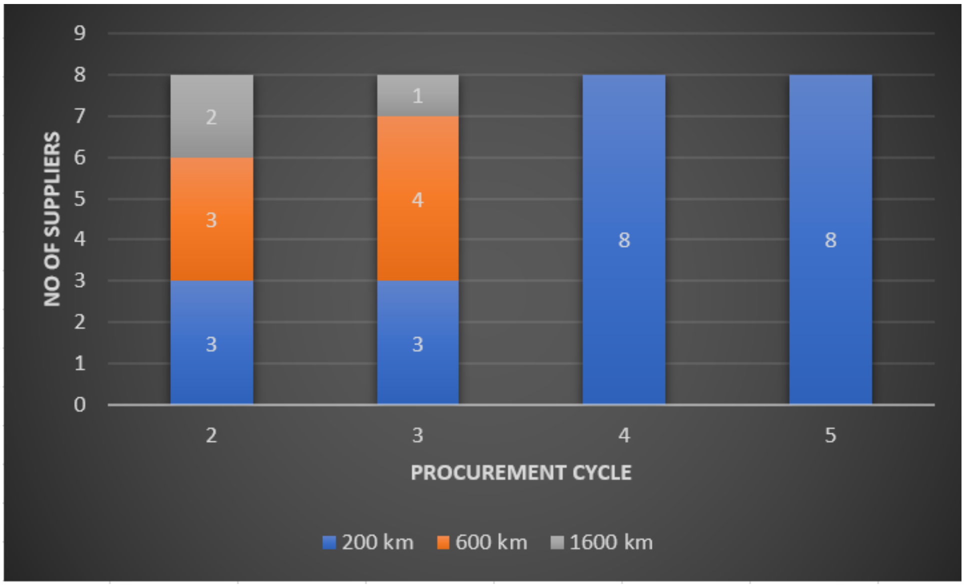

Figure 6: Procurement distance and suppliers for example 1

Figure 6 shows the breakdown of supplier distance associated with the solution for each procurement cycle length. For example, for procurement cycle length of 2, 3 suppliers are within 200 km distance, 3 suppliers are within 200 and 600 km distance, while 2 suppliers are as far away as 600 to 1600 km. travel vehicle travel. It is clear that there is the suppliers chosen are nearer as the procurement cycle length (P_{limit}) decreases. When P_{limit} is large, there is very little time for distribution. Therefore, the shipment size is smaller and a distant supplier even with a cheaper unit price may not be attractive. On the other hand, when this value is small, the distribution time and the shipment size are both large, making a distant supplier more attractive.

It may be observed that the procurement solution is a trade-off between elapsed shelf-life, purchase price, and the transportation cost.

1. **Elapsed shelf-life of produce at supplier facility:** If supplier is unable to supply a produce with shelf-life less than or equal to procurement time limit including transportation time, then model decides to procure a produce at a higher price from another supplier.

2. **Transportation cost:** As the procurement time limit decreases, the demand for each produce incresaes because produce needs to be procured for a longer utilization time limit. Thus, produce may purchased from a distant supplier if beneficial in terms of purchase and transportation and costs, provided there is

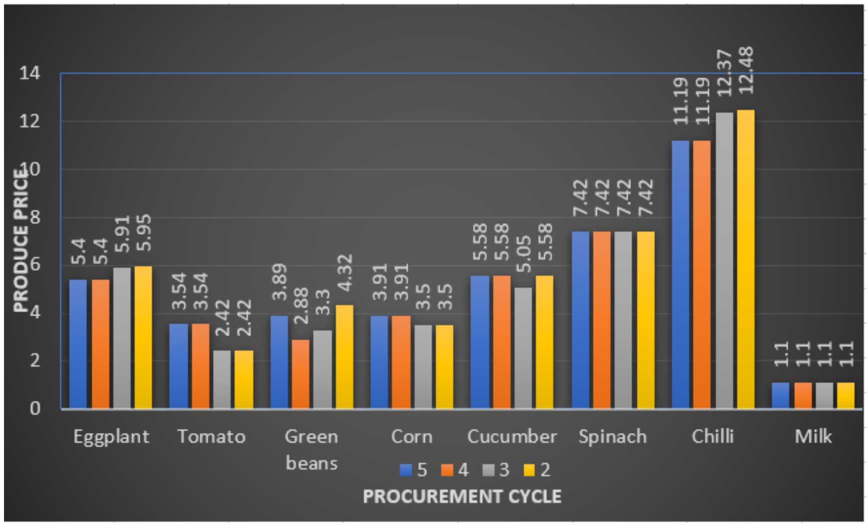

Figure 7: Produce purchase cost for example 1

enough time to travel a longer distance and procure the produce within the time limit for procurement.

Figure 7 shows procurement trend for produce associated with different procurement time limits. There are four different types of procurement price trends (incerasing, decreasing, irregular, and constant). For eggplant and chilli, the purchase cost increases with decrease in P_{limit}. This is because as P_{limit} reduces from 5 to 2, the same low cost supplier is not able to supply produce with the freshness level demanded by the corresponding higher utlization time limit. For example, in the case of eggplant the cheapest price per unit is \$5.4 (Table 8) from supplier 6 (Table 10). Supplier 6 has an elapsed shelf-life of eggplant of 3 days. The procurement model is able to choose this supplier when P_{limit} =5 and deliver it to the warehouse within 1 day and subsequently to the restaurants within the 1 day utilization corresponding to the P_{limit} value. For the case of eggplant with P_{limit}=2, it requires a supplier with a much shorter elapsed shelf-life and as a result, supplier 5 with an elapsed shelf-life of 1 day is chosen with a unit price of \$5.95 (Tables 8 and 10).

The purchase cost of tomatoes and corn, on the other hand, decrease with decreasing P_{limit} . For these produce types, the demand (as with all produce) increases with a decrease in P_{limit}. When this limit is 5, procurement happens from supplier 21 with an elapsed shelf-life of 3 for a unit price of \$3.54 (Tables 8 and 10). However, when the limit drops to 2, supplier 25 with an elapsed shelf-life 1 with a unit price of

$2.42 becomes economically viable (Tables 8 and 10). Supplier 21 is within a 200-km radius of the warehouse whereas supplier 25 (which is cheaper per unit) is further away (within 1600 km) and therefore, covering a greater distance to purchase a larger quantity of produce is such that the the fixed and variable transportation costs are offset by the lower unit cost of purchase.

Green beans and cucumbers show an irregular trend in procurement. In the case of green beans, it can be noticed that, changing P_{limit} from 5 to 4 days is reduces the purchase cost of produce, which is result of increase in demand. The elapsed shelf-life at the suppliers 38 and 36 in the respective solutions are the same (3 days, as seen in Table 8). However, since the demand increases, the distant supplier (supplier 36) is chosen to take advantage of the lower unit price ($2.88 instead of $3.89). When P_{limit} changes from 4 to 3 days, which is due to the inability of supplier 36 with an elapsed shelf-life for the produce to 3 days to deliver the produce within 3 days. Therefore, supplier 37 is chosen with a elapsed shelf-life of 2 days and an unit cost of $3.3, an increase from $2.88 (Tables 8 and 10). This upward trend in unit price continues for P_{limit}=2.

Suppliers for spinach and milk remain the same for all values of P_{limit}. These are procured from suppliers with a short elapsed shelf life.

After the distribution model in chapter 5 is run, the arrival time of vehicles at restaurants are seen as in Table 13..

Table 14 shows the routes, vehicles used, payload, volume (cubic) load, and the total costs of the distribution model for different utilization cycle time limits.

Table 15 shows the different shipping combination O_{ij} based on the value of U_{limit} which varies from 1 to 4. When U_{limit}=1, the only delivery option is 1 and and O_{ij} =(1,1). When U_{limit}=2, two possible delivery options are possible: deliver twice in two days, i.e., O_{ij} =(2,1) or deliver once in two days, i.e, O_{ij} =(2,2). Similarly, for U_{limit}=4, deliveries can be made once, twice, or four times in 4 days. The inventory level required in days for each shipping combination O_{ij} is I_{ij}, whose values are shown in Table 16 .

The procurement and distribution cost combinations for the values of P_{limit} and U_{limit} (the optimal objective function values of the solutions to the procurement and distribution models) are shown in Table 17. These are entered into the integrated model with associated inventory costs for each of the options.

Table 13: Arrival time (in minutes) after running the distribution model for example 1

U_{limit}	Vehicle	Restaurant location											
1	1000 kg	Y_i	4	3	1	8	7	6	2	5	-	-	-
		Ar_{ik}	0	22	46	87	113	146	171	187	-	-	-
	1000 kg	Y_i	12	17	10	11	13	-	-	-	-	-	-
		Ar_{ik}	0	22	321	341	764	-	-	-	-	-	-
	3000 kg	Y_i	18	19	20	14	9	16	15	-	-	-	-
		Ar_{ik}	0	35	58	169	339	599	619	-	-	-	-
2	3000 kg	Y_i	5	2	1	17	12	4	3	-	-	-	-
		Ar_{ik}	0	16	36	109	131	183	205	-	-	-	-
	3000 kg	Y_i	7	18	19	20	14	9	16	9	6	-	-
		Ar_{ik}	0	69	104	127	238	408	668	688	754	-	-
	1000 kg	Y_i	10	11	13	8	-	-	-	-	-	-	-
		Ar_{ik}	0	20	443	766	-	-	-	-	-	-	-
3	5000 kg	Y_i	4	3	1	8	7	6	2	5	-	-	-
		Ar_{ik}	0	22	46	87	113	146	171	187	-	-	-
	3000 kg	Y_i	12	17	10	11	13	-	-	-	-	-	-
		Ar_{ik}	0	22	321	341	764	-	-	-	-	-	-
	3000 kg	Y_i	18	19	20	14	16	15	-	-	-	-	-
		Ar_{ik}	0	35	58	169	599	619	-	-	-	-	-
4	5000 kg	Y_i	1	7	18	19	20	14	9	16	15	-	-
		Ar_{ik}	0	38	107	142	165	276	446	706	726	-	-
	3000 kg	Y_i	5	2	6	8	4	3	-	-	-	-	-
		Ar_{ik}	0	16	43	81	135	157	-	-	-	-	-
	3000 kg	Y_i	12	17	10	11	13	-	-	-	-	-	-
		Ar_{ik}	0	22	321	341	764	-	-	-	-	-	-

Table 14: Distribution route and cost for example 1

U_{limit}	Feasible Route	Vehicle used	Payload	Cubicload	Total Cost
1	0-4-3-1-8-7-6-2-5-0	3000 kg	1030 kg	1.82 m^3	$2540
	0-12-17-10-11-13-0	1000 kg	636 kg	1.16 m^3	
	0-18-19-20-14-9-16-15-0	1000 kg	963 kg	1.67 m^3	
2	0-5-2-1-17-12-4-3-0	3000 kg	1868 kg	3.36 m^3	$2828
	0-7-18-19-20-14-9-16-6-0	3000 kg	2218 kg	3.89 m^3	
	0-10-11-13-8	1000 kg	946 kg	1.71 m^3	
3	0-4-3-1-8-7-6-2-5-0	5000 kg	3090 kg	5.48 m^3	$3061
	0-12-17-10-11-13-0	3000 kg	1908 kg	3.50 m^3	
	0-18-19-20-14-9-16-15-0	3000 kg	2889 kg	5.01m^3	
4	0-1-7-18-19-20-14-9-16-15-0	5000 kg	4980 kg	8.65 m^3	$3271
	0-5-2-6-8-4-3-0	3000 kg	2992 kg	5.34 m^3	
	0-12-17-10-11-13-0	3000 kg	2544 kg	4.67 m^3	

Table 15: Shipping Combinations for distribution

P_{limit}	U_{limit}	Delivery option			
		1	2	3	4
5	1	1	0	0	0
4	2	1	1	0	0
3	3	1	0	1	0
2	4	1	1	0	1

Table 16: Inventory holding required for the shipment combinations (in days)

U_{limit}	Delivery opt.			
	1	2	3	4
1	0	0	0	0
2	1	0	0	0
3	3	0	0	0
4	6	4	0	0

Table 17: Data for the integrated model for example 1

P_{limit}	U_{limit}	Procurement Cost	Distribution Cost
5	1	9760	2540
4	2	19202	2828
3	3	29880	3061
2	4	40373	3271

Note : Cost is in dollars

```
CPLEX 12.8.0.0: optimal integer solution; objective 10911
0 MIP simplex iterations
0 branch-and-bound nodes
ampl: display X;
X :=
1 1   0
1 2   0
1 3   0
1 4   0
2 1   0
2 2   0
2 3   0
2 4   0
3 1   0
3 2   0
3 3   0
3 4   0
4 1   0
4 2   0
4 3   0
4 4   1
;
```

Figure 8: Results of the integrated model for example 1

Figure 8 shows the results of the integrated model in which O_{ij} =(4,4). This means that a 2-day procurement cycle, a 4-day utlization cycle, with one delivery every 4 days to the restaurants is the optimal configuration. The total cost for this solution is \$10,911 per day.

7.2.2 Numerical Example 2

As the seasons change, the produce available in any regional landscape also changes. This reflects changes in the selling price and elapsed shelf-life for each produce at each supplier. The selling price and elapsed shelf-life data in Table 8 of example 1 was generated using the Uniform distribution between certain upper and lower bounds. A different series of prices and elasped shelf-life using the same bounds were generated again, as shown in Table 18. The average produce price in example 2 is \$6.30 per unit, slightly higher than in example 1, where it is \$5.78. The elapsed shelf life in example is slightly higher 2.05, compared with example 1, where it is 1.97.

Table 19 shows the arrival times of the vehicles used in the procurement model solution.

Table 20 shows the routes used for different procurement time limit values. The total payload and cubic load of freight for each route are also included in the results.

Table 21 shows the unit and total costs of procurement which includes purchase cost and transportation.The transportation costs are lower for the all procurement cycle lenths compared to example 1 because the distance travelled is lower, as seen in Figure 9.

Figure 9 shows the breakdown of supplier distance associated with the solution for each procurement cycle length. For all different P_{limit} values, the cost-optimal suppliers for each produce are located within radius of 600 km, which is within a reach of one day in all routes (as seen in Table 19).

Figure 10 shows that, the unit procurement price of each produce is once again affected by demand, supplier distance and elapsed shelf-life. Three out of the four trends discussed in the procurement prices in example 1 apply to this case (with the exception of irregular). In example 2, the unit price of eggplant increases, just as in example 1. The unit price of tomato decreases, as in example 1. The unit price of corn, however, increases unlike in example . The unit price of milk increases (it is constant in example 1). Further analysis reveals the same conceptual trends, i.e., the interaction between cost, distance, elaspsed shelf-life, demand, and the procurement cycle limit.

In example 2, since the demand of each produce type remained unchanged, the results of the distribution model remain the same as example 1, as already shown in Table

Table 18: Selling price and elapsed shelf-life of produce by supplier for example 2

Supplier	p_i	EL_i	Supplier	p_i	EL_i	Supplier	p_i	EL_i
1	4.16	3	36	3.31	1	71	7.24	3
2	7.05	2	37	4.97	2	72	8.46	1
3	4.76	1	38	3.52	2	73	7.36	3
4	6.81	3	39	4.4	1	74	7.16	1
5	6.33	1	40	3.29	3	75	7.07	3
6	4.12	2	41	4.73	2	76	8.02	2
7	7.21	1	42	3.06	2	77	8.46	1
8	6.41	3	43	3.76	1	78	7.12	3
9	2.89	2	44	4.57	3	79	7.5	1
10	3.69	1	45	6.02	1	80	17.09	2
11	3.02	3	46	6.31	2	81	14.58	3
12	2.9	1	47	7.42	3	82	15.12	3
13	3.64	3	48	7.75	3	83	15.66	2
14	3.94	3	49	7.00	3	84	13.60	3
15	2.53	3	50	4.61	3	85	14.09	2
16	4.61	2	51	6.00	2	86	17.51	1
17	3.63	3	52	5.98	3	87	17.34	1
18	2.71	1	53	5.22	1	88	16.45	2
19	2.59	1	54	6.75	3	89	14.26	2
20	4.78	1	55	6.78	3	90	15.93	3
21	4.15	1	56	4.53	1	91	13.56	1
22	3.23	1	57	6.17	1	92	17.85	3
23	4.52	1	58	6.51	3	93	1.12	1
24	3.37	3	59	5.94	1	94	1.37	3
25	2.79	2	60	4.82	3	95	1.04	2
26	4.82	2	61	4.91	1	96	1.02	2
27	4.22	1	62	6.65	2	97	1.72	1
28	4.93	2	63	6.84	1	98	1.7	1
29	4.53	2	64	5.7	3	99	1.45	2
30	4.66	3	65	4.75	2	100	1.63	2
31	3.33	2	66	7.31	3			
32	2.5	3	67	7.81	2			
33	4.66	3	68	7.98	2			
34	4.7	3	69	7.91	2			
35	3.82	2	70	7.1	1			

Note : Prices are in dollars and EL_i is in days

Table 19: Arrival time (in minutes) after running the procurement model for example 2

P_{limit}	Vehicle		Fresh Produce							
			1	2	3	4	5	6	7	8
5	3000 kg	Y_i	6	18	38	50	60	74	85	96
		Ar_{ik}	154	45	15	139	227	30	124	0
4	3000 kg	Y_i	-	18	38	-	-	-	-	-
		Ar_{ik}	-	15	0	-	-	-	-	-
	3000 kg	Y_i	6	-	-	50	60	74	85	96
		Ar_{ik}	109	-	-	94	197	0	124	15
3	10000 kg	Y_i	6	18	38	53	61	74	85	96
		Ar_{ik}	139	66	0	186	15	45	154	30
2	10000 kg	Y_i	5	19	-	-	-	-	86	97
		Ar_{ik}	19	15	-	-	-	-	0	52
	3000 kg	Y_i	-	-	36	53	61	74	-	-
		Ar_{ik}	-	-	209	108	15	0	-	-

Table 20: Procurement routes used for example 2

P_{limit}	Feasible Route	Vehicle used	Vehicle Payload	Vehicle Cubicload
5	0-96-38-74-18-85-50-6-60-0	3000 kg	2629 kg	4.66 m^3
4	0-38-18-0	3000 kg	2374 kg	4.16 m^3
	0-74-96-50-6-85-60-0	3000 kg	2884 kg	5.17 m^3
3	0-61-96-74-18-6-85-53-0	10000 kg	7887 kg	14.00 m^3
2	0-86-19-5-52-0	10000 kg	8480 kg	14.01 m^3
	0-74-61-53-36-0	3000 kg	2036 kg	4.65 m^3

Table 21: Cost of procurement in example 2

Fresh Produce	Procurement cycle (in days)							
	5		4		3		2	
	Unit	Total	Unit	Total	Unit	Total	Unit	Total
Eggplant	4.12	1367	4.12	2736	4.12	4103	6.33	8406
Tomatoes	2.71	2636	2.71	5273	2.71	7910	2.59	10080
Green beans	3.52	753	3.52	1506	3.52	2259	3.31	2833
Corn	4.61	664	4.61	1327	5.22	2255	5.22	3006
Cucumber	4.82	333	4.82	665	4.91	1016	4.91	1355
Spinach	7.16	587	7.16	1174	7.16	1761	7.16	2348
Chilli	14.09	1310	14.09	2620	14.09	3931	17.51	6513
Milk	1.02	736	1.02	1472	1.02	2209	1.72	2945
Total Purchase Cost	8250		16500		24977		38884	
Transportation Cost	368		509		679		2514	
Total Procurement Cost	8618		17009		25665		41399	

Note : Prices are in dollars

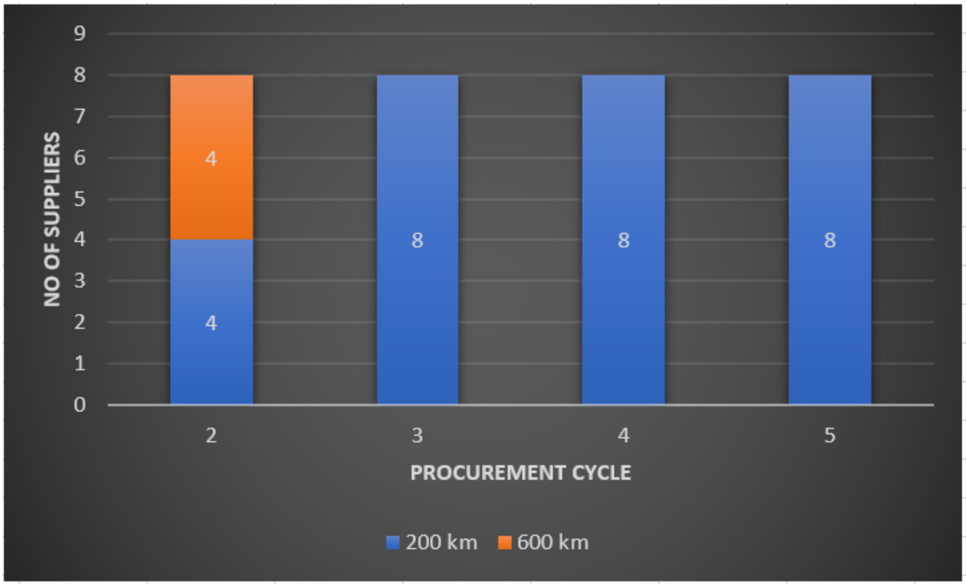

Figure 9: Procurement distance and suppliers for example 2

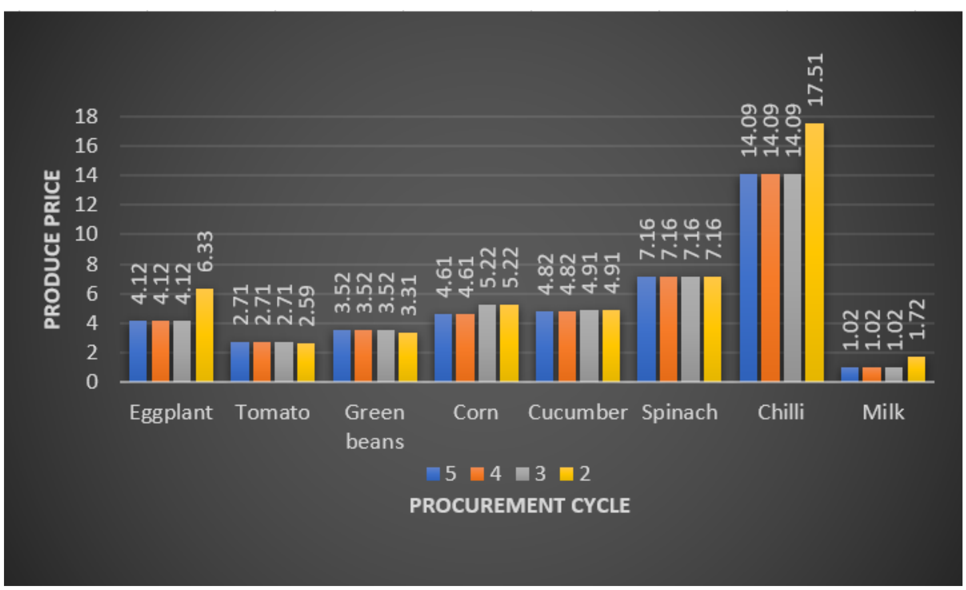

Figure 10: Produce purchase cost for example 2

Table 22: Data for the integrated model for example 2

P_{limit}	U_{limit}	Procurement Cost	Distribution Cost
5	1	8618	2540
4	2	17009	2828
3	3	25665	3061
2	4	41399	3271

Note : Cost is in dollars

13 and Table 14 .

The procurement and distribution cost combinations for the values of P_{limit} and U_{limit} (the optimal objective function values of the solutions to the procurement and distribution models) are shown in Table 22. The procurement costs are lower for the first two combinations and higher for the last two combinations, as compared to example 1. The distribution costs remain unchanged.

Figure 11 shows the result of the integrated model. This time, the optimal solution changes to 3 days for procurement, 3 for utilization, with one shipment to the restaurants every 3 days. The total cost for this solution is \$9575.33 per day, contrasted with \$10,911 per day in example 1. So even though the price and elapsed shelf-life were slightly higher than in example 1, the optimal solution is lower. This again is a complex trade-off between supplier price, distance, and elapsed shelf-life.

```
CPLEX 12.8.0.0: optimal integer solution; objective 9575.333333
0 MIP simplex iterations
0 branch-and-bound nodes
ampl: display X;
X :=
1 1   0
1 2   0
1 3   0
1 4   0
2 1   0
2 2   0
2 3   0
2 4   0
3 1   0
3 2   0
3 3   1
3 4   0
4 1   0
4 2   0
4 3   0
4 4   0
;
```

Figure 11: Results of the integrated model for example 2

7.2.3 Numerical example 3

In example 3, a restaurant chain located in Ontario with only 10 outlets is considered (these 10 are arbitrarily chosen from those in Table 6), with the procurement network remaining the same as in example 1. The selling price and elapsed shelf-life of each produce type is also the same as in example 1 (Table 8).

The geographical location of each restaurant is shown in Table 23.

Table 23: Restaurant locations for example 3

Index	Physical Address	Latitude/Longitude
1	1150 Queen St W, Toronto, ON M6J 1J3	43.6432° N,79.4246° W
2	226 Greenwood Ave, Toronto, ON M4L 2R2	43.6717° N,79.3285° W
3	92 Ossington Ave, Toronto, ON M6J 2Z4	43.6462° N,79.4198° W
4	3003 Lake Shore Blvd W, Etobicoke, ON M8V 1K2	43.6° N,79.5077° W
5	7171 Torbram Rd, Mississauga, ON L4T 3W4	43.6976° N,79.6565° W
6	3335 Banwell Rd, Windsor, ON N8R 2K9	42.3055° N,82.8998° W
7	44 Stevenson Rd S, Oshawa, ON L1J 2K6	43.8918° N,78.8831° W
8	1889 Regent St, Sudbury, ON P3E 3Z7	46.4518° N,81.0047° W
9	522 Concession St, Hamilton, ON L8V 1A6	43.2413° N,79.8539° W
10	1812 Simcoe St N #4, Oshawa, ON L1G 4Y2	43.9429° N,78.8895° W

Table 24: Fresh produce suppliers for example 3

	Avg. daily demand	No of supplier	Holding Cost
Eggplant	174 kg	8	$0.15
Tomatoes	483 kg	19	$0.10
Green Beans	100 kg	17	$0.05
Corn	76 kg	12	$0.10
Cucumber	36 kg	10	$0.10
Spinach	40 kg	12	$0.25
Chilli	45 kg	14	$0.05
Milk	348 kg	7	$0.10

Table 25: Arrival time (in minutes) after running the procurement model for example 3

P_{limit}	Vehicle		Fresh Produce							
			1	2	3	4	5	6	7	8
5	3000 kg	Y_i	6	21	38	50	61	72	85	96
		Ar_{ik}	154	45	15	139	227	30	124	0
4	3000 kg	Y_i	6	21	38	50	61	72	85	96
		Ar_{ik}	139	171	15	109	30	257	124	0
3	3000 kg	Y_i	-	19	37	51	62	72	88	-
		Ar_{ik}	-	0	47	15	30	646	206	-
	3000 kg	Y_i	4	-	-	-	-	-	-	96
		Ar_{ik}	0	-	-	-	-	-	-	24
2	5000 kg	Y_i	5	17	43	51	-	-	89	-
		Ar_{ik}	1440	17	191	0	-	-	212	-
	3000 kg	Y_i	-	-	-	-	61	72	-	96
		Ar_{ik}	-	-	-	-	15	39	-	0

The total average daily demand of each produce type is different from example 1, as shown in Table 24. The total average daily demand for produce is 1302 kg, as opposed to 2629 kg in example 1 (about 51.47% lower).

Table 25 shows the arrival times of the vehicles in the optimal solution to the procurement model.

Table 26 shows the unit and total costs of procurement for example 3.

Figure 12 shows procurement distances in the optimal solution. The difference from example 1 (Figure 6) is the reduced travel distance to suppliers because of lower of demand.

A comparison of results between Figures 7 and 13 shows how demand affects supplier selection for each produce type. It can be observed from the case of tomatoes, that the demand is not high enough for procurement from same distant supplier as in example 1. Specifically, for procurement cycle limits of 5 and 4 days, the supplier

Table 26: Cost of procurement for example 3

Fresh Produce	Procurement cycle (in days)							
	5		4		3		2	
	Unit	Total	Unit	Total	Unit	Total	Unit	Total
Eggplant	5.4	939	5.4	1879	5.91	3085	5.91	4113
Tomatoes	3.54	1709	3.54	3419	3.66	5303	4.34	4675
Green beans	3.89	389	3.89	778	3.3	990	4.02	1608
Corn	3.91	297	3.91	594	3.5	798	3.5	1064
Cucumber	5.58	200	5.58	401	5.05	545	5.58	803
Spinach	7.42	296	7.42	593	7.42	890	7.42	1187
Chilli	11.19	503	11.19	1007	12.37	1670	12.48	2246
Milk	1.1	382	1.1	765	1.1	1148	1.1	1531
Total Purchase Cost	4719		9439		14430		21036	
Transportation Cost	415		415		1785		1141	
Total Procurement Cost	5135		9855		16216		22178	

Note : Prices are in dollars

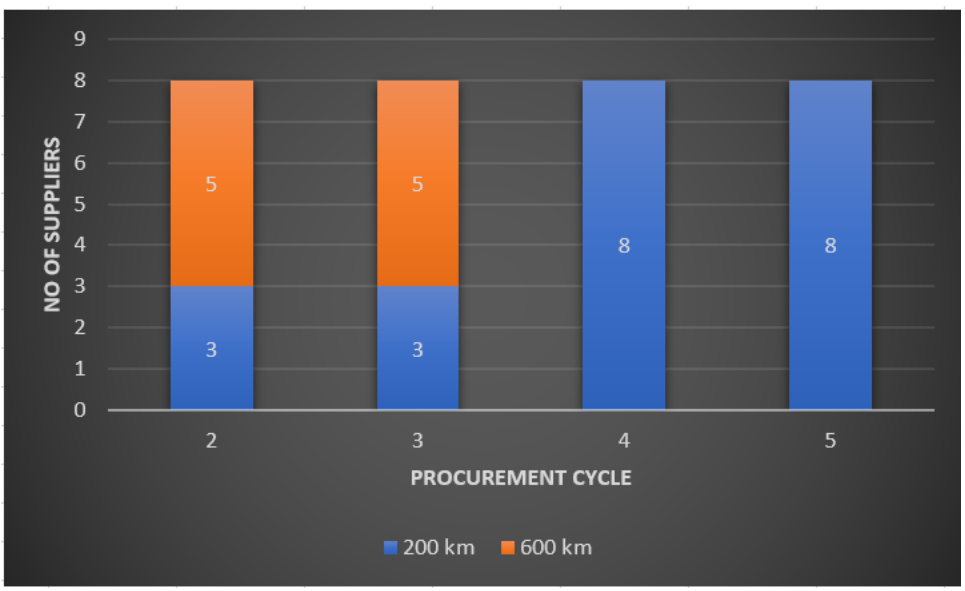

Figure 12: Procurement distance and suppliers for example 3

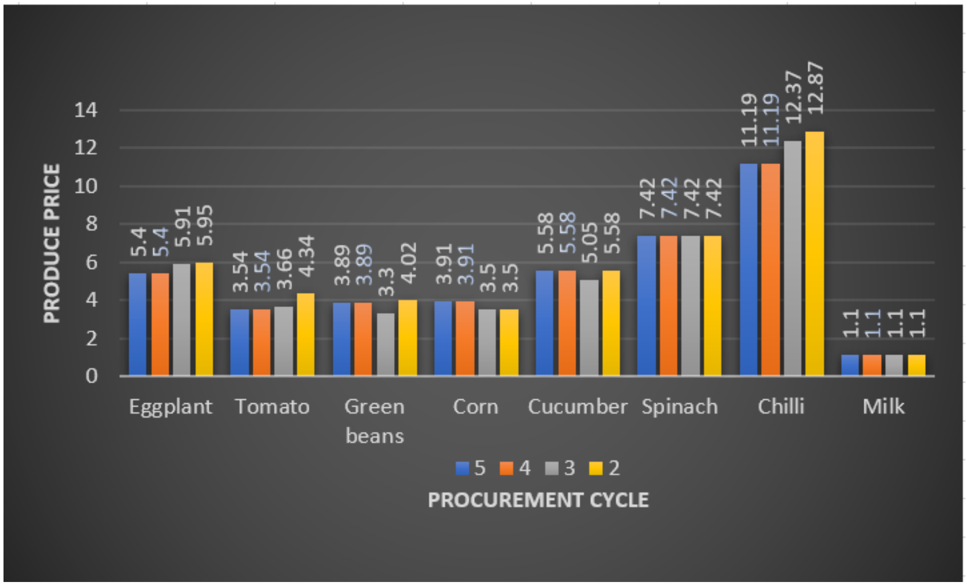

Figure 13: Produce purchase cost for example 3

doesn't change between examples 1 and 3. However, since the demand is lower, the model solution chooses a closer more example supplier in example 3 for procurement cycle limits of 3 and 2 days. The effect on supplier selection is observed for all other produce types.

The arrival time of vehicles at restaurants after running the distribution model are seen as in Table 27.

Table 28 shows the routes, vehicles used, payload, volume (cubic) load, and the total costs of the distribution model for different utilization cycle time limits. The distribution costs are all lower than in example 1 because of the reduced number of restaurants and consequently the reduced demand.

The shipment combinations for this example is the same as in example 1. The procurement and distribution cost combinations for the values of P_{limit} and U_{limit} (the optimal objective function values of the solutions to the procurement and distribution models) are as shown in Table 29.

Figure 14 shows the result of the integrated model with a 4-day procurement and 2-day utlization cycle, with distribution to restaurants once every 2 days. The total cost of the configuration is \$5893.5 per day, which is approximately 54% of the total cost in example 1 (\$10,911). It may be noted that the demand in example 3 is approximately

Table 27: Arrival time (in minutes) after running the distribution model for example 3

U_{limit}	Vehicle	Restaurant location							
1	1000 kg	Y_i	1	3	8	10	7	2	-
		Ar_{ik}	0	16	314	643	664	720	-
	1000 kg	Y_i	9	6	5	4	-	-	-
		Ar_{ik}	0	239	508	540	-	-	-
2	3000 kg	Y_i	3	1	5	10	7	2	-
		Ar_{ik}	0	16	52	128	149	205	-
	1000 kg	Y_i	6	9	4	8	-	-	-
		Ar_{ik}	0	239	300	604	-	-	-
3	3000 kg	Y_i	2	7	10	5	4	1	-
		Ar_{ik}	0	56	77	153	185	209	-
	1000 kg	Y_i	3	8	-	-	-	-	-
		Ar_{ik}	0	298	-	-	-	-	-
	1000 kg	Y_i	6	9	-	-	-	-	-
		Ar_{ik}	0	239	-	-	-	-	-
4	5000 kg	Y_i	2	7	10	5	4	1	3
		Ar_{ik}	0	56	77	153	185	209	225
	1000 kg	Y_i	6	9	-	-	-	-	-
		Ar_{ik}	0	239	-	-	-	-	-
	1000 kg	Y_i	8	-	-	-	-	-	-
		Ar_{ik}	0	-	-	-	-	-	-

Table 28: Distribution routes and costs for example 3

U_{limit}	Feasible Route	Vehicle used	Payload	Cubicload	Total Cost
1	0-1-3-8-10-7-2-0	1000 kg	811 kg	1.46 m^3	1811
	0-9-6-5-4-0	1000 kg	491 kg	0.86 m^3	
2	0-3-1-5-10-7-2	3000 kg	1626 kg	2.91 m^3	1932
	0-6-9-4-8-0	1000 kg	978 kg	1.73 m^3	
3	0-2-7-10-5-4-1-0	3000 kg	2412 kg	4.35 m^3	2048
	0-3-8-0	1000 kg	798 kg	1.42 m^3	
	0-6-9-0	1000 kg	696 kg	1.20 m^3	
4	0-2-7-10-5-4-1-0	5000 kg	3216 kg	5.80 m^3	2145
	0-6-9-0	1000 kg	928 kg	1.60 m^3	
	0-8-0	1000 kg	548 kg	0.98 m^3	

Table 29: Data for the integrated model for example 3

P_{limit}	U_{limit}	Procurement Cost	Distribution Cost
5	1	5135	1811
4	2	9855	1932
3	3	16216	2048
2	4	22178	2145

Note : Cost is in dollars

```
CPLEX 12.8.0.0: optimal integer solution; objective 5893.5
0 MIP simplex iterations
0 branch-and-bound nodes
ampl: display X;
X :=
1 1   0
1 2   0
1 3   0
1 4   0
2 1   0
2 2   1
2 3   0
2 4   0
3 1   0
3 2   0
3 3   0
3 4   0
4 1   0
4 2   0
4 3   0
4 4   0
;
```

Figure 14: Results of Integrated model for example 3

49.53% of the demand in example 1. However, the distribution option changes to 4-day procurement and 2-day utilization instead of the reverse in example 1. The difference is mainly due to lower demand at restaurants which makes distribution possible in lower time and gives the chain the ability to use the extra time for lower cost procurement.

Table 30: Procurement model performance and execution time

Example	P_{limit}	Nodes explored	Simplex Iteration	Execution time
1	2	15035	408687	112.04
	3	114116	7161381	2042.99
	4	336717	10303077	16609.99
	5	196884	5521578	6884.5
2	2	5656	229264	325.07
	3	4163	153267	572.47
	4	44062	1841728	1849.2
	5	19162	801692	1136.76
3	2	175024	4781959	2097
	3	37575	940002	1583.22
	4	230266	8004493	8204.73
	5	107149	3038638	5336.43

Note: Execution time is in seconds.

7.3 Model performance and execution time

The procurement model is more complex than the other two models. The computational time requirement of the procurement model depends on various factors such as demand, elapsed shelf-life, selling price of each produce, and more importantly the procurement time limit.

In this thesis, the modelling platform was GLPK/GUSEK and the solution platform Gurobi optimizer 8.1.1. Models were programmed using GLPK/GUSEK and the problems were written in .lp format. Gurobi optimizer was used to optimize the model outputs. All models were run using a 20-core Intel 4114 CPU with 2.20 Ghz processor speed and 63.67 GB RAM. The execution time of the procurement model for different procurement time limits are shown in Table 31.

It can be inferred from Table 31 that the execution time for the same P_{limit} value differs significantly between the examples. Example 1 with similar P_{limit} takes much longer than example 2. Therefore, it can be stated that data such as shelf-life and selling price have a huge impact on the execution time of the procurement model. In addition, a comparison of execution time between examples 1 and 3 shows thatthe demand of each produce type also affects the execution time. The procurement time for a 4-day P_{limit} value seems to take the longest solution time for each example. When the limit is higher or lower, it appears that the problem becomes easier due to constraints on demand and elapsed shelf-life.

7.4 Effect of perishability on configuration

In this thesis, perishability of produce is the main driver of the supply chain configuration. In the numerical examples, a shelf-life of 7 days was used, considering Canada-wide suppliers only. As observed from the integrated model, there are 8 different combinations of procurement, storage and distribution for a shelf-life of 7 days. This combination goes up to 35 for a shelf-life of 15 days. The procurement model and distribution models need to be executed 13 times each for different procurement and utilization time limits. For 15 day procurement, suppliers from the US or Mexico can also be considered. Alternatively, air and ship transportation modes can be included in future work.

Chapter 8

8 Conclusions and Future Research

This thesis focused on developing a strategic method to procure, store and distribute raw-materials (produce) in the fast-food restaurant chain industry. The thesis considers a two-stage procurement and distribution supply chain with perishability constraints with a centralized warehouse between suppliers of produce and the fast-food restaurant units. The approach suggested in this thesis is to repeatedly run two models, i.e., the procurement model and the distribution model, each for different procurement and utlization time limits respectively. The integrated model looks at several distribution options such that the produce shelf life constraint is respected. Both the procurement and distribution models are based on vehicle routing formulations with multiple vehicle sizes, capacities (on payload and volume), time-window constraints at stops, and overnight stopover (for the procurement model only). The procurement model is useful in finding the most appropriate (cost-optimal) supplier for every produce. When the procurement time limit is increased, sourcing can take place from distant suppliers in order to minimize costs. On the other hand, the utilization time reduces placing a greater challenge on the distribution phase. Inventory costs are also considered in each procurement and distribution option.

This approach is adaptive in that the optimal supply chain configuration can be changed based on season, demand, selling price, and shelf-life. Restaurants must have historical data to estimate the average daily consumption of each produce at their facility. The data collection process remains the same for any procurement and distribution region.

In conclusion, this approach helps the fast-food restaurant chain industry maintain standards for produce freshness to serve its customers.

This work can be extended in several ways. As mentioned, other modes of transportation can be considered. The optimization models are currently feasible for relatively short shelf-lives. For longer shelf-lives, there are more shipment combination options which may limit the computational efficiency of the current approach. Therefore, metaheuristics may be used to speed up solution of these models. The procurement and distribution models can be enhanced to accommodate multiple procurement and utlilzation cycles (currently, only one cycle can be accommodated for each phase). Refrigerated vehicles were not modelled in this thesis. This is a natural extension. The freshness of produce also impacts customer satisfaction. The approach can be extended to use freshness as a criteria in the optimization. Either freshness costs can be added to the optimization models, or a Pareto cost-freshness trade-off frontier can be developed using a bi-objective framework. Since demand can be probabilistic, either sample average approximation or some other stochastic programming method can be developed for this problem. Supplier contracts with associated fixed and variable costs, economies of scale in procurement, multiple warehouses, etc. can also be considered.

References

Alter, D. A., & Eny, K. (2005). The relationship between the supply of fast-food chains and cardiovascular outcomes. Canadian Journal of Public Health, 96(3), 173-177.

Amorim, P., Parragh, S. N., Sperandio, F., & Almada-Lobo, B. (2014). A rich vehicle routing problem dealing with perishable food: a case study. Top, 22(2), 489-508.

Azi, N., Gendreau, M., & Potvin, J. Y. (2010). An exact algorithm for a vehicle routing problem with time windows and multiple use of vehicles. European Journal of Operational Research, 202(3), 756-763.

Bahadoran, Z., Mirmiran, P., & Azizi, F. (2015). Fast food pattern and cardiometabolic disorders: a review of current studies. Health promotion perspectives, 5(4), 231.

Blackburn, J., & Scudder, G. (2009). Supply chain strategies for perishable products: the case of fresh produce. Production and Operations Management, 18(2), 129-137.

Borcinová, Z. (2017). Two models of the capacitated vehicle routing problem. Croatian Operational Research Review, 8(2), 463-469.

Brissette, C. (2018, March 01). This is your body on fast food. Retrieved July 31, 2019, from https://www.washingtonpost.com/lifestyle/wellness/sneaking-a-little-junk-food-doesnt-mean-all-is-lost/

Chebolu-Subramanian, V., & Gaukler, G. M. (2015). Product contamination in a multi-stage food supply chain. European Journal of Operational Research, 244(1), 164-175.

Cindy. (n.d.). Fresh Vegetables - How Long Do Fresh Vegetables Last? Shelf Life. Retrieved July 31, 2019, from http://www.eatbydate.com/vegetables/fresh-vegetables/

Fast food Industry Analysis(2018).(n.d). Retrieved July 31, 2019, from https://www.franchisehelp.com/industry-reports/fast-food-industry-analysis-2018-cost-trends/

Folinas, D., Manikas, I., & Manos, B. (2006). Traceability data management for food chains. British Food Journal, 108(8), 622-633.

Golden, B. L., Raghavan, S., & Wasil, E. A. (Eds.). (2008). The vehicle routing problem: latest advances and new challenges (Vol. 43). Springer Science & Business Media.

Hanaysha, J. (2016). Testing the effects of food quality, price fairness, and physical environment on customer satisfaction in fast food restaurant industry. Journal of Asian Business Strategy, 6(2), 31-40.

Hooper, A., & Murray, D. (2018). An Analysis of the Operational Costs of Trucking: 2018 Update.

Hsu, C. I., Hung, S. F., & Li, H. C. (2007). Vehicle routing problem with time-windows for perishable food delivery. Journal of food engineering, 80(2), 465-475.

Kara, A., Kaynak, E., & Kucukemiroglu, O. (1995). Marketing strategies for fast-food restaurants: a customer view. International Journal of Contemporary Hospitality Management, 7(4), 16-22.

Klein, J. (2016, October 17). In Refrigerators, Tomatoes Lose Flavor at the Genetic Level. Retrieved July 31, 2019, from https://www.nytimes.com/2016/10/18/science/tomato-flavor-refrigerator.html

Koskosidis, Y. A., Powell, W. B., & Solomon, M. M. (1992). An optimization-based heuristic for vehicle routing and scheduling with soft time window constraints. Transportation science, 26(2), 69-85.

LaMarco, N. (2018, December 10). Types of Economic Factors That Can Affect the Fast Food Industry. Retrieved July 31, 2019, from https://smallbusiness.chron.com/types-economic-factors-can-affect-fast-food-industry-36923.html

Lin, S. W., Vincent, F. Y., & Lu, C. C. (2011). A simulated annealing heuristic for the truck and trailer routing problem with time windows. Expert Systems with Applications, 38(12), 15244-15252.

Manaadiar, H., Jayasekhar, Gueguen, F., & Austin. (2017, June 16). 20' container vs 40' container. Retrieved July 31, 2019, from https://shippingandfreightresource.com/20-container-vs-40-container/

McCluskey, J. J., & O'Rourke, A. D. (2000). Relationships between produce supply firms and retailers in the new food supply chain. Journal of Food Distribution Research, 31(856-2016-56391), 11-20.

Meindl, S. C. P. (2016). Supply Chain Management--Strategy, Planning and Operation. Tsinghua University Press. wheat soybean others land for no use.

Min, H., & Min, H. (2013). Cross-cultural competitive benchmarking of fast-food restaurant services. Benchmarking: An International Journal, 20(2), 212-232

Moen, O. (2016). The five-step model–procurement to increase transport efficiency for an urban distribution of goods. Transportation Research Procedia, 12, 861-873.

Miranda, S. (2017, June). A qualitative and quantitative analysis of vegetable pricing in supermarket. In IOP Conference Series: Materials Science and Engineering (Vol. 215, No. 1, p. 012042). IOP Publishing.

Miranda, S. (2017, June). A qualitative and quantitative analysis of vegetable pricing in supermarket. In IOP Conference Series: Materials Science and Engineering (Vol. 215, No. 1, p. 012042). IOP Publishing.

Oxford Dictionaries[Internet]. (n.d.). Retrieved July 31, 2019, from -https://www.oxfordlearnersdictionaries.com/definition/english/fast-food

Pullman, M., & Wu, Z. (2012). Food supply chain management: Economic, social and environmental perspectives. Routledge.

Ramadhan, A. N., & Simatupang, T. M. (2012). Determining inventory management policy for perishable materials in Roemah Keboen restaurant. Procedia-Social and Behavioral Sciences, 65, 992-999.

Sihariya, G., Hatmode, V. B., & Nagadevara, V. (2013). Supply chain management of fruits and vegetables in India. Int. J. Oper. Quant. Manag, 19(2), 113-122.

Song, B. D., & Ko, Y. D. (2016). A vehicle routing problem of both refrigerated- and general-type vehicles for perishable food products delivery. Journal of Food Engineering, 169, 61-71.

Sylvain Charlebois, Simon Somogyi, Eamonn McGuinty, Vlado Keselj, Catherine Mah, Andrea Guisto, . . . Joon Soon. (2018). Canada's Food Price Report 2019.

Toth, P., & Vigo, D. (Eds.). (2002). The vehicle routing problem. Society for Industrial and Applied Mathematics.

Van Laarhoven, P. J., & Aarts, E. H. (1987). Simulated annealing. In Simulated annealing: Theory and applications (pp. 7-15). Springer, Dordrecht.

Appendix I: Procurement model in GUSEK

set Warehouse; #Centralized regional warehouse

set Product_1; #Supplier set for product_1

set Product_2; #Supplier set for product_2

set Product_3; #Supplier set for product_3

set Product_4; #Supplier set for product_4

set Product_5; #Supplier set for product_5

set Product_6; #Supplier set for product_6

set Product_7; #Supplier set for product_7

set Product_8; #Supplier set for product_8

set Vehicles; #different size vehicles

set U:= Warehouse union Product_1 union Product_2 union Product_3 union Product_4 union Product_5 union Product_6 union Product_7 union Product_8; #union set

set Index;

#--Parameters---# param Distance{i in U,j in U:i!=j}; #Distance between location i to j

param travel_time{i in U,j in U:i!=j}; #avrage travel time between location i to j <In minute>

param Demand{U}; # total demand needed to procure from location i <in KG>

param Volume{U}; #Total Volume of vehicle

param Sell_Price{U}; #Selling price of product at location i

param lt{U}; #loading time at location i.

param TC{U};

param Vehicle_Capacity{Vehicles}; #Weight capacity of vehicle k

param Max_Volume{Vehicles};

param F_Cost{Vehicles}; #Fixed Cost for oprating vehicle k param Oprating_Cost{Vehicles}; #Oprating cost of vehicle k <travelling cost/km>

param Lapse_SL{U}; #Lapse shelf-life of product at Location i

param P_Limit; #Maximum time allowed for procurement <In Days>

param SL:= 6;

param T_Fraction_1:= 60; #Fraction Value to convert travel time in hours

param T_Fraction_2:= 1440; # Fraction value to convert travel time in Days

param M:=10000; # Big Constant Value

param Stay_Cost:=10;

param Ear_Time{Index,U diff Warehouse}; #Earliest arrival time-window for vehicle k in day t.

param Lat_Time{Index,U diff Warehouse}; #Latest arrival time-window for vehicle k in day t.

param Num{Index};

#---Variables---#

var L{i in U,j in U,Vehicles:i!=j} binary; # 1 if arc i,j transversed by truck k,0 otherwise

var Y{i in U:i>=1} binary; #1 if product procured from location i, o otherwise var El{U,Vehicles}>=0; #Subtour-Elimination Variable

var V{Vehicles} binary; #1 if vehicle k is used,0 otherwise

var Day{Index} binary; #1 if day is being considered,0 otherwise

var T_Ar{U,Vehicles}>=0 integer; #Arrival time of vehicle at facility

var Arival_Time{Warehouse,Vehicles}>=0; #Arrival time of vehicle in Warehouse after procurement

var Time_window{Index,U diff Warehouse} binary; #Time window consideration variable

var StayOver{U,Vehicles}>=0; #Stopover time of vehicle at location i.

var TW{Index,U diff Warehouse} binary;

#---Objective Function---#

minimize Z: sum{k in Vehicles}F_Cost[k]*V[k] #Fixed Cost of oprating vehicle k if used for transportation,

+sum{i in U,j in U,k in Vehicles:i!=j}L[i,j,k]*Oprating_Cost[k]*Distance[i,j] #Total Cost of transportation

```
+sum{i in U:i>=1}Sell_Price[i]*Y[i]*(SL-P_Limit)*Demand[i]

+sum{i in U,k in Vehicles}Stay_Cost*StayOver[i,k]/T_Fraction_1

+sum{j in U,k in Vehicles}(T_Ar[j,k]*1/M)

+sum{i in Warehouse,k in Vehicles}(Arival_Time[i,k]*1/M); #+sum{i in Index}Num[i]*Day[i]+sum{j in U}(T_Ar[j]*1/M); #Total shipment cost incurred by procuring a product from supplier i,

#--------------------------------------------------Constraints--------------------------------------------------------#

subject to con_1{j in U,k in Vehicles:j>=1}:sum{i in U:i!=j}L[i,j,k]=sum{i in U:i!=j} L[j,i,k]; ##Constraints sets condition of flow-balance. Total number of vehicle going into node j must be equal to number of vehicle going out from same node.

#----------------------------------------------------------Con_2----------------------------------------------------------------------------------------#

subject to con_2A:sum{i in U diff Product_1,j in Product_1,k in Vehicles:i!=j}L[i,j,k]=1;

subject to con_2B:sum{i in U diff Product_2,j in Product_2,k in Vehicles:i!=j}L[i,j,k]=1;

subject to con_2C:sum{i in U diff Product_3,j in Product_3,k in Vehicles:i!=j}L[i,j,k]=1;

subject to con_2D:sum{i in U diff Product_4,j in Product_4,k in Vehicles:i!=j}L[i,j,k]=1;

subject to con_2E:sum{i in U diff Product_5,j in Product_5,k in Vehicles:i!=j}L[i,j,k]=1;

subject to con_2F:sum{i in U diff Product_6,j in Product_6,k in Vehicles:i!=j}L[i,j,k]=1;

subject to con_2G:sum{i in U diff Product_7,j in Product_7,k in Vehicles:i!=j}L[i,j,k]=1;

subject to con_2H:sum{i in U diff Product_8,j in Product_8,k in Vehicles:i!=j}L[i,j,k]=1; #vehicle can only visit one supplier location from all given suppliers of each food item.This constraints needed to repeat for every product as illustrated above.

#------------------------------------------------------------Con_3--------------------------------------------------------------------------------------#

subject to con_3A{j in Product_1}:sum{i in U diff Product_1,k in Vehicles:i!=j}L[i,j,k]=Y[j];

subject to con_3B{j in Product_2}:sum{i in U diff Product_2,k in Vehicles:i!=j}L[i,j,k]=Y[j];

subject to con_3C{j in Product_3}:sum{i in U diff Product_3,k in Vehicles:i!=j}L[i,j,k]=Y[j];

subject to con_3D{j in Product_4}:sum{i in U diff Product_4,k in Vehicles:i!=j}L[i,j,k]=Y[j];

subject to con_3E{j in Product_5}:sum{i in U diff Product_5,k in Vehicles:i!=j}L[i,j,k]=Y[j];

subject to con_3F{j in Product_6}:sum{i in U diff Product_6,k in Vehicles:i!=j}L[i,j,k]=Y[j];

subject to con_3G{j in Product_7}:sum{i in U diff Product_7,k in Vehicles:i!=j}L[i,j,k]=Y[j];
```

subject to con_3H{j in Product_8}:sum{i in U diff Product_8,k in Vehicles:i!=j}L[i,j,k]=Y[j]; #Constraint included to consider Cost of given items from visited supplier in an objective function.This constraints needed to repeat for every product as illustrated above.

#--#

subject to con_4{k in Vehicles}:sum{i in U, j in U:i!=j}L[i,j,k]<=M*V[k];

subject to con_5{k in Vehicles,i in Warehouse}:sum{j in U:j>=1}L[i,j,k]-V[k]=0;

subject to con_6{k in Vehicles,j in Warehouse}:sum{i in U:i>=1}L[i,j,k]-V[k]=0; #Constraints (6),(7) and (8) are included to consoder fixed cost of vehicle k in objective function if its being used in transportation.

#--Sub-tour---#

subject to con_7{i in U diff Warehouse, j in U diff Warehouse, k in Vehicles:i!=j}:El[i,k]-El[j,k]+ Vehicle_Capacity[k]*L[i,j,k]<=Vehicle_Capacity[k]- (SL-P_Limit)*Demand[j]*L[i,j,k]+ M*(1-V[k]);

subject to con_8{i in U ,j in U diff Warehouse,k in Vehicles:i!=j}:El[i,k]>=(SL-P_Limit) *Demand[i]*L[i,j,k];

subject to con_9{i in U diff Warehouse,k in Vehicles}:El[i,k]<= Vehicle_Capacity[k] *V[k];

subject to con_10{k in Vehicles}:Max_Volume[k]-(sum{j in U diff Warehouse} ((SL-P_Limit)* Volume[j]*sum{i in U:i!=j}L[i,j,k]))>=0;

#--Time-window---#

subject to con_11{k in Vehicles,m in Warehouse}:Arival_Time[m,k]>=(sum{i in U,j in U:i!=j} L[i,j,k]* (travel_time[i,j]*TC[i]+lt[i]) +sum{i in U diff Warehouse} StayOver[i,k])/T_Fraction_2; #Arrival_Time Calculation of vehicle k

subject to con_12{m in Warehouse,i in U,j in U,k in Vehicles:i!=j}:Arival_Time[m,k] +Lapse_SL[i] * L[i,j,k]<=P_Limit; #Procurement time Constarint

subject to con_13{m in Warehouse,k in Vehicles}:Arival_Time[m,k]<=sum{i in Index} Day[i]; #Allowance for days.

subject to con_14{i in U, j in U,k in Vehicles:i!=j and j>=1}:T_Ar[j,k]>=T_Ar[i,k]+ travel_time[i,j]*TC[i] + lt[i]-(1-L[i,j,k])*M; #Arrival time calculation of vehicle k at supplier facility i.

subject to con_15{j in U diff Warehouse,k in Vehicles}:T_Ar[j,k]>=sum{m in Index} Ear_Time[m,j] *TW[m,j];

subject to con_16{j in U diff Warehouse,k in Vehicles}:T_Ar[j,k] <=sum{m in Index} Lat_Time[m,j]

```
*TW[m,j];

subject to con_17{j in U diff Warehouse}:sum{i in Index}TW[i,j]<=1;

subject to con_18{i in U diff Warehouse,j in U diff Warehouse,k in Vehicles:i!=j}:StayOver[i,k]>=
(T_Ar[j,k]- T_Ar[i,k])- travel_time[i,j]-(1-L[i,j,k])*M;

solve; display L,Y,Z,T_Ar,TW,StayOver,V,Day,Arival_Time;
```

Appendix II: Distribution model in GUSEK

set Warehouse;

set Locations;

set Vehicles; #Same size vehicles

set U:= Warehouse union Locations;

param travel_time{i in U,j in U:i!=j}; #Travel travel from Node i to Node j

param distance{i in U,j in U:i!=j}; #Distance from Node i to node j

param Demand{U}; #Demand at each restaurent

param Unload_time{U}; #Unloading time at each restaurent

param Ear_time{Locations};

param Lat_time{Locations};

param T_con{U};

param Volume{U}; #Volume of demanded shipment by node i

param Payload{Vehicles}; #Vehicle Capacity

param Cubicload{Vehicles}; #Max Volume capacity of vehicle

param F_Cost{Vehicles}; #Fixed cost of vehicle k

param O_Cost{Vehicles}; #Oprating cost of vehicle k

param U_Limit;

param M:=10000;

var X{Vehicles} binary; #1 if vehicle is being oprated, 0 otherwise

var L{i in U,j in U,Vehicles:i!=j} binary; #1 if arc i,j transversed by vehicle k, 0 otherwise

var Z{U,Vehicles}>=0; #Sub-tour elimination constraint

var Y{U,Vehicles}>=0 integer; #Arrival time at node j

minimize z: sum{k in Vehicles}F_Cost[k]*X[k] #Fixed Cost of oprating vehicle k if used for transportation,

+sum{i in U, j in U, k in Vehicles:i!=j}(O_Cost[k]*L[i,j,k]*distance[i,j])

+sum{i in Locations,k in Vehicles}1/M*Y[i,k]; ##Total Cost of transportation

subject to con_1{j in Locations,k in Vehicles}:sum{i in U:i!=j}L[i,j,k]=sum{i in U:i!=j}L[j,i,k];

#Flow-balance Constraint

subject to con_2{j in Locations}:sum{i in U,k in Vehicles:i!=j}L[i,j,k]=1; #Demand at restaurant j is satisfied by exactly one vehicle.

subject to con_3{k in Vehicles}:sum{i in U, j in U:i!=j}L[i,j,k]<=M*X[k];

subject to con_4{k in Vehicles,i in Warehouse}:sum{j in Locations}L[i,j,k]-X[k]=0;

subject to con_5{k in Vehicles,j in Warehouse}:sum{i in Locations}L[i,j,k]-X[k]=0;

#Constraints (5),(6) and (7) are included to consoder fixed cost of vehicle k in objective function if its being used in transportation.

subject to con_6{i in Locations, j in Locations, k in Vehicles:i!=j}:Z[i,k]-Z[j,k]+Payload[k]*L[i,j,k]<= Payload[k]- U_Limit*Demand[j]*L[i,j,k]+M*(1-X[k]);;

subject to con_7{i in Locations,j in Locations, k in Vehicles:i!=j}:Z[i,k]>=U_Limit* Demand[i]*L[i,j,k];

subject to con_8{i in Locations,k in Vehicles}:Z[i,k]<=Payload[k]*X[k];

#Constraints (9),(10) and (11) are subtour elimination and capacity constraints. It confirms that Vehicle can not genrate route having cumulative demand more than weight bearing capacity of vehicle k.

subject to con_9{k in Vehicles}:Cubicload[k]-sum{j in Locations,i in Locations:i!=j}(U_Limit* Volume[j]* L[i,j,k])>=0; #Maximum Volume constraint

subject to con_10{i in U,j in Locations,k in Vehicles:i!=j}:Y[j,k]>=Y[i,k]+ travel_time[i,j]*T_con[i] + Unload_time[i]-(1-L[i,j,k])*M;

#Constraint calculate arrival time of vehicle k at a given restaurant j.

subject to con_11{i in Locations,k in Vehicles}:Y[i,k]>=Ear_time[i];

subject to con_12{i in Locations,k in Vehicles}:Y[i,k]<=Lat_time[i];

Appendix III: An integrated model in GUSEK

```
set U_time;

set Deleivery_Option;

set n;

set Products;

param Demand{Products};

param h{Products};

param Procurement_Cost{U_time};

param Distribution_Cost{U_time};

param ship_option{U_time,Deleivery_Option};

param I{U_time,Deleivery_Option};

var X{U_time,Deleivery_Option} binary;

var Y{U_time,Deleivery_Option}>=0;

minimize Z: sum{i in U_time,j in Deleivery_Option} (Procurement_Cost[i]/i)*X[i,j] + sum {i
in U_time, j in Deleivery_Option} (Distribution_Cost[j]/i)* I[i,j]*X[i,j] +sum{i in U_time,j in
Deleivery_Option,k in Products}Y[i,j]* Demand[k]*h[k];

subject to con_1:sum{i in U_time,j in Deleivery_Option}ship_option[i,j]*X[i,j]=1;
```

Appendix IV: Python code for distance matrix calculation

```
# imports the Google Maps API
import googlemaps
import copy
import time
# Set-up your API key
gmaps = googlemaps.Client(key='AIzaSyCqjuvnDsDGa93aQo_1kc2Y8nthkqQ9dgM')

#List of cities
cities =[ Latitude/Longitude
i.e (43.6412,- 79.3774) ,
          mention all latitude/longitude

]
def DistanceMatrix(cities):
    to = copy.deepcopy(cities)
    distancematrix = []
    for city in cities:
        newtablerow = []
        for city_to in to:
            if city == city_to:
                newtablerow.append(9999999)
            else:
                try:
                    query = gmaps.distance_matrix(city, city_to)
                    newtablerow.append(query['rows'][0]['elements'][0]['distance']['value'])
                    #newtablerow.append(query['rows'][0]['elements'][0]['duration']['value'])
                except:
                    newtablerow.append(float('inf'))
        distancematrix.append(newtablerow)
        print('Just finished city: {}'.format(cities.index(city)))
    return (distancematrix)

timestr = time.strftime("%Y%m%d-%H%M%S")
shit = DistanceMatrix(cities)
f = open('distance'+timestr+'.txt', 'w')
f.write(str(shit))
f.close()
```

Appendix V: Time windows at Supplier and Restaurant Locations

Supplier facility operation time

Supplier location	Operating time	Operating time (in min)
1	9 A.M to 9 P.M.	0 to 720
2	9 A.M to 7 P.M.	0 to 600
3	9 A.M to 7 P.M.	0 to 600
4	9 A.M to 7 P.M.	0 to 600
5	9 A.M to 7 P.M.	0 to 600
6	9 A.M to 9 P.M.	0 to 720
7	9 A.M to 7 P.M.	0 to 600
8	9 A.M to 7 P.M.	0 to 600
9	9 A.M to 9 A.M.	0 to 1440
10	9 A.M to 9 P.M.	0 to 720
11	9 A.M to 9 P.M.	0 to 720
12	9 A.M to 9 P.M.	0 to 720
13	9 A.M to 9 P.M.	0 to 720
14	9 A.M to 9 P.M.	0 to 720
15	9 A.M to 9 P.M.	0 to 720
16	9 A.M to 9 P.M.	0 to 720
17	9 A.M to 9 A.M.	0 to 1440
18	9 A.M to 9 A.M.	0 to 1440
19	9 A.M to 7 P.M.	0 to 600
20	9 A.M to 7 P.M.	0 to 600
21	9 A.M to 9 A.M.	0 to 1440
22	9 A.M to 9 P.M.	0 to 720
23	9 A.M to 7 P.M.	0 to 600
24	9 A.M to 9 P.M.	0 to 720
25	9 A.M to 9 A.M.	0 to 1440

Restaurant location operation time

Restaurant location	Oprating time	Oprating time (in min)
1	9 A.M to 10 P.M.	0 to 780
2	9 A.M to 10 P.M.	0 to 780
3	9 A.M to 10 P.M.	0 to 780
4	9 A.M to 10 P.M.	0 to 780
5	9 A.M to 10 P.M.	0 to 780
6	9 A.M to 10 P.M.	0 to 780
7	9 A.M to 10 P.M.	0 to 780
8	9 A.M to 10 P.M.	0 to 780
9	9 A.M to 10 P.M.	0 to 780
10	9 A.M to 10 P.M.	0 to 780
11	9 A.M to 10 P.M.	0 to 780
12	9 A.M to 10 P.M.	0 to 780
13	9 A.M to 10 P.M.	0 to 780
14	9 A.M to 10 P.M.	0 to 780
15	9 A.M to 10 P.M.	0 to 780
16	9 A.M to 10 P.M.	0 to 780
17	9 A.M to 10 P.M.	0 to 780
18	9 A.M to 10 P.M.	0 to 780
19	9 A.M to 10 P.M.	0 to 780
20	9 A.M to 10 P.M.	0 to 780

Appendix VI: Average Daily Demand Calculation for Examples

Demand calculation (example 1 and 2)

	Fresh produce and its demand (in kg)							
Restaurant Location	1	2	3	4	5	6	7	8
1	21	45	14	9	3	5	4	42
2	10	44	9	5	4	5	6	40
3	11	62	15	9	3	5	3	30
4	16	51	12	8	3	5	5	37
5	18	51	7	6	4	3	6	34
6	13	39	13	8	6	6	3	32
7	18	53	6	6	2	3	4	47
8	12	38	8	8	2	2	4	27
9	17	52	6	5	5	3	6	25
10	13	48	11	7	2	6	5	25
11	10	37	11	6	5	6	3	40
12	25	47	7	5	2	5	6	35
13	23	54	8	9	3	3	5	32
14	14	57	9	7	2	6	5	46
15	12	38	13	10	2	2	3	33
16	25	48	15	5	5	3	5	30
17	16	42	11	9	6	5	5	38
18	23	64	13	10	2	2	6	48
19	13	62	11	6	4	4	4	47
20	22	41	15	6	4	3	5	34
Average daily demand	332	973	214	114	69	82	93	722

Demand calculation (example 3)

	Fresh produce and its demand (in kg)							
Restaurant Location	1	2	3	4	5	6	7	8
1	10	44	9	5	4	5	6	40
2	11	62	15	9	3	5	3	30
3	18	51	7	6	4	3	6	34
4	13	39	13	8	6	6	3	32
5	18	53	6	6	2	3	4	47
6	17	52	6	5	5	3	6	25
7	25	47	7	5	2	5	6	35
8	23	54	8	9	3	3	5	32
9	12	38	13	10	2	2	3	33
10	16	42	11	9	6	5	5	38
Average daily demand	174	483	100	76	36	40	45	348