

**A Novel Location-Inventory-Routing Problem in a Two-Stage Red Meat Supply Chain with Logistic Decisions: Evidence from an Emerging Economy**

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# A Novel Location-Inventory-Routing Problem in a Two-Stage Red Meat Supply Chain with Logistic Decisions: Evidence from an Emerging Economy

## Abstract

**Purpose.** This study focuses on a specific method of meat production that involves carcass purchase and meat production by packing facilities with a novel two-stage model that simultaneously considers location-routing and inventory-production operating decisions. The considered problem aims to reduce variable and fixed transportation and production costs, inventory holding cost, and the cost of opening cold storage facilities.

**Method.** The proposed model encompasses a two-stage model consisting of a single-echelon and a three-echelon many-to-many network with deterministic demand. The proposed model is a mixed-integer linear programming (MILP) model tested with the General Algebraic Modeling System (GAMS) software for a real-world case study in Iran. A sensitivity analysis was performed to examine the effect of retailers' holding capacity and supply capacity at carcass suppliers.

**Findings.** The number of products transferred at each level, the number of products held, the amount of red meat produced, the required cold storage facilities, and the required vehicles were optimally specified. The outcomes indicated a two percent (2%) decrease in cost per kg of red meat. Eventually, the outcomes of the first and second sensitivity analysis indicated that reduced retailers' holding capacity and supply capacity at carcass suppliers lead to higher total costs.

**Originality.** This research proposes a novel multi-period location-inventory-routing problem for the red meat supply chain in an emerging economy with a heterogeneous vehicle fleet and logistics decisions. The proposed model is presented in two stages and four echelons including carcass suppliers, packing facilities, cold storage facilities, and retailers.

**Keywords.** Two-Stage Supply Chain; Location-Inventory-Routing Problem; Transportation and Logistic Decisions; Mixed Integer Linear Programming.

## 1. Introduction

Agricultural and livestock products are the most important sources of protein, and inadequate consumption of these products is likely to cause serious health problems (Adesogan *et al.*, 2020). One of the reasons for inadequate protein intake is the high cost of these products, which could limit people's access (van Huis and Oonincx, 2017; Hajiagha *et al.*, 2018). Red meat is a key source of animal protein (Bergeron *et al.*, 2019). Based on the *World Statistics Portal for Market Data*, red meat consumption in Iran as an emerging economy is 20-40 kg per person. Further, it has been discussed that this source of protein consumption is decreasing due to the increasing rate of retailers' prices for final consumers. Figure 1 illustrates trends in red meat production and consumption in Iran (ur Rahman and ur Rahman, 2020). As shown, red meat consumption has decreased, while red meat production has increased over time. In Iran, the rising prices of raw materials and economic sanctions have led to a dramatic increase in the price of red meat, a 2-3 fold increase in the price per kg of red meat in 2019 compared to 2016. As a result, the consumption rate of red meat (as the most important source of protein in Iran) has decreased significantly. In this regard, this research set to design and optimise the red meat supply chain to reduce costs as a strategy to reduce the final price of the product.

### Insert Figure 1 Here

In a theoretical context, the supply chain of any product consists of three parts, i.e. upstream, midstream, and downstream. Improving the performance of each of these parts improves the performance of the entire chain, consequently reducing the total costs and final product prices. Upstream operations involve the procurement of raw materials for the product of interest. Midstream and downstream operations involve the production and distribution of the product. Supply chain management (SCM) aims to coordinate all parts of the supply chain to improve processes, minimise costs, and increase productivity (Mahdiraji *et al.*, 2019, 2020). To keep the price of red meat to a minimum, its supply chain must be examined and optimised. Figure 2 illustrates the studied red meat supply chain in Iran. In addition to the elements shown in this figure, the supply chain may include several opened cold storage facilities (distribution centres) for a more efficient red meat distribution system. Buying livestock and slaughtering them is not economical for some companies (Frisk *et al.*, 2018); thus, these companies buy carcasses, pack them, and ultimately sell them to the final consumer. Moreover, the purpose of this study is to design a red meat supply chain in two-stages, four-echelon, and multi-period models, in which the operational decisions of location, production, inventory, and routing are considered simultaneous, and products are transported using a fleet of heterogeneous vehicles. Furthermore, the red meat supply chain starts from the carcass supply level and after performing the relevant operations, the packed meat is transferred to the retailers at the last level. To the best of our knowledge, this combination and problem have not been investigated previously based on the available literature.

### Insert Figure 2 Here

There are various parameters in SCM; for instance, single-period or multi-period, single-product or multi-product, homogeneous or heterogeneous vehicle fleet, and single or multi-echelon supply chain network can all be taken into account (Mosca *et al.*, 2019). Furthermore, for each echelon, networks can be shaped as one-to-one, one-to-many, many-to-one, or many-to-many (Coelho *et al.*, 2014). Different characteristics can also be added to the model, including time window (Wang *et al.*, 2016), risk management (Heidari *et al.*, 2018), transshipment (Rahbari *et al.*, 2018), and perishability (Mirzaei and Seifi, 2015).

Furthermore, issues such as the location of facilities, routing of vehicles, and inventory can be examined for each supply chain (Biuki *et al.*, 2020). According to the mentioned points, the type of product has a great impact on the design and analysis of the supply chain network (Yavari and Geraeili, 2019). Over time, researchers have turned to supply chain design for a particular product, while in the past a supply chain was designed for a specific product category. Rice is an example of a product whose supply chain network has been studied (Cheraghalipour *et al.*, 2019). Recent articles have shown that all echelons of the supply chain should be considered for better decision-making; nonetheless, as the number of echelons of the chain increases, it makes the model more complex (Tirkolae *et al.*, 2020). As a result, modelling approaches have moved toward staging based on product type, vehicle type, or different strategic decisions (Heidari *et al.*, 2019). Due to differences in some characteristics of the agricultural supply chain, such as the type of product transported during the supply chain or the type of vehicles used to transport products, it is necessary to model the problem in several stages to achieve appropriate results. Since the product transported in the red meat supply chain consists of two different types, a two-stage model has been scheduled. In the first stage, the carcass is prepared and distributed among the packing facilities, and then the red meat production operation is performed. In the second stage, the packed meat will be distributed among retailers, which cold storage facilities will be also used if needed.

In the present research, the supply chain spans from carcass purchase to the delivery of packed meat to retailers. The proposed model is a multi-period, single-product model for the red meat supply chain with a heterogeneous vehicle fleet. Moreover, the designed network consists of four echelons, including carcass suppliers, packing facilities, cold storage facilities, and retailers. The proposed model is presented in two stages; the first stage includes carcass suppliers and packing facilities, and the second stage includes packing facilities, cold storage facilities, and retailers. After solving the model in both stages, the number of products transferred at each level, the number of products held in storage nodes, the quantity of red meat produced, the cold storage facilities that are opened, and the required vehicles are specified. Additionally, a sensitivity analysis is performed on the holding capacity of retailers and supply capacity at carcass suppliers, and changes in the solutions are examined. **The originality of this paper can be summarised as follows:**

- Designing a two-stage, four-echelon red meat supply chain from carcass suppliers to retailers by simultaneously considering location-routing and inventory-production operating decisions;
- Providing two mixed-integer linear programming models for red meat supply chain (a single-echelon and a three-echelon problem for the first and second stage respectively) in which a heterogeneous vehicle fleet is considered;
- Solving a real instance using information from a meat supplier in Iran and comparing the outcomes of solving the model with real information;
- Analysing the effect of retailers' holding capacity and supply capacity at carcass suppliers on the outcomes obtained from solving the proposed model with different scenarios;

The remainder of this paper is structured as follows. Section 2 provides a review of the literature on the design of various supply chain networks, including food supply chains. The proposed models for the red meat supply chain network are presented in Section 3. In Section 4, these models are applied to a real case scenario in Iran. In Section 5, sensitivity analysis and discussion are conducted. Finally, Section 6 provides the conclusion and future research directions derived from the research.

## 2. Literature Review

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3 Recently, network design for agricultural and livestock products has received  
4 increasing attention from researchers. This has led to an increase in the efficiency of these  
5 supply chains and a reduction in the cost of these products (Rahbari *et al.*, 2020). This section  
6 provides a review of the literature. Studies on network design for agricultural and livestock  
7 products can be divided into qualitative and quantitative categories. Qualitative studies have  
8 mainly focused on issues such as improving supply chain quality, product tracking methods  
9 and systems, factors influencing the price of products, lead time (due to perishability of the  
10 products), etc. (Moons *et al.*, 2019). On the other hand, quantitative studies have focused on  
11 the design of the supply chain network for the product of interest and the variables related to  
12 supply chain management, including reducing supply chain costs, increasing supply chain  
13 profits, reducing lead time, and reducing product shortages (Govindan *et al.*, 2017). In the  
14 following sub-sections, relevant studies are categorised and reviewed in detail.  
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## 17 **2.1. Supply Chain Network Design and Management**

18  
19 Although SCM has received considerable attention since the early 1980s, it is not  
20 particularly well understood and there is still the opportunity for improvements and future  
21 research (Li and Liu, 2019). Geoffrion and Graves (1974) were amongst the first  
22 investigators in the study of supply chain design. They employed Benders' decomposition  
23 approach to determine the optimal number and location of distribution centres (DCS) to be  
24 established. Pirkul and Jayaraman (1996) proposed a multi-product MIP model for a three-  
25 echelon, capacitated plant, and a warehouse location problem that aimed to minimise  
26 operating warehouses and the annual fixed costs of establishing as well as total transportation  
27 and distribution costs. Lagrangian relaxation was applied to the model as an effective  
28 approach for solving large-scale problems. Miranda and Garrido (2004) developed a  
29 simultaneous model that incorporates economic order quantity and safety stock decisions into  
30 a facility location problem with three echelons, including a plant, warehouses, and retailers.  
31 This was a real case of frozen food distribution, and they solved the problem through  
32 Lagrangian relaxation. Miranda and Garrido (2009) developed a mathematical programming  
33 model based on Lagrangian relaxation to determine optimal ordering size, client assignment,  
34 and warehouse locations for a location-distribution-inventory problem. Demand was  
35 stochastic and normally distributed. Furthermore, the objective function minimised  
36 transportation costs, ordering and inventory costs, safety stock costs, and fixed and variable  
37 warehouse costs. Yao *et al.* (2010) proposed a mixed-integer programming model for a  
38 location-allocation-inventory problem. In their proposed model, customers can be served  
39 directly by a warehouse or a plant. Moreover, there was a constraint on the production  
40 capacity of plants; however, no capacity constraint was considered for warehouses. Pishvae  
41 and Rabbani (2011) studied the network design for a supply chain consisting of plants, DCs,  
42 and customers. The model incorporates decisions about the optimal number and location of  
43 plants and DCs as well as the quantity of product flow between facilities. They considered  
44 both direct and indirect shipments to customers. The objective was to minimise opening  
45 costs, transportation costs, and costs associated with unused products in plants and DCs.  
46 Mousavi and Tavakkoli-Moghaddam (2013) developed a two-stage mixed-integer  
47 programming model for a location-routing problem. As a novel approach, they considered  
48 cross-docking centre location and vehicle routing scheduling simultaneously. Their proposed  
49 algorithm was based on hybrid simulated annealing and tabu search. Supply chain  
50 management and related decisions have been investigated to reduce costs by various  
51 researchers (Tsao *et al.*, 2012). However, some articles have focused on CO<sub>2</sub> emissions to  
52 model their problems (Al Shamsi *et al.*, 2014). Mirzaei and Seifi (2015) developed a  
53 mathematical model for an inventory-routing problem that considers lost sales for perishable  
54 goods. They used an algorithm based on simulated annealing and tabu search to solve the  
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3 problem on a large scale. The objective function minimised the total cost of transportation,  
4 lost sales, and holding inventories. In the related articles on supply chain management, the  
5 scholars considered the location-inventory-routing problems, and most of them concentrated  
6 on the design of supply chain networks and algorithms (Tavakkoli-Moghaddam and Raziiei,  
7 2016).

8  
9 More recent studies on supply chain network design have been investigated. For  
10 instance, Zhao and Ke (2017) developed a bi-objective location-inventory-routing problem  
11 for hazardous material management. This study incorporates risk into the model, and the  
12 objective function minimises total cost and risk. Hiassat et al. (2017) studied a location-  
13 inventory-routing problem for perishable products. They considered a homogeneous fleet of  
14 vehicles and used a genetic algorithm to solve the model on a large scale. The problem was  
15 formulated as a many-to-many network, and the objective function considered warehouse  
16 fixed location cost, routing cost, and inventory holding cost. Rafie-Majd et al. (2018)  
17 addressed a multi-objective location-inventory-routing problem for a three-echelon supply  
18 chain of perishable products. Demand was stochastic, and the model was a multi-period,  
19 multi-product, and heterogeneous fleet composition with an integer non-linear programming  
20 structure that was solved by Lagrangian relaxation. Rahbari et al. (2018) developed a multi-  
21 period, multi-product, and green inventory-routing problem that sought to minimise both  
22 costs and CO<sub>2</sub> emissions. A key innovation in their research was to consider transshipment  
23 costs. Their proposed model was a mixed-integer linear program solved on a small scale.  
24 Supply chain network design and location-inventory-routing problems have been considered  
25 to reduce costs by several researchers (Koç, 2019). In this regard, some articles focused on an  
26 exact method to solve their problems (Zheng *et al.*, 2019). The application of the two-echelon  
27 vehicle routing problem in last-mile delivery with drone delivery has been also investigated  
28 recently (Kitjacharoenchai *et al.*, 2020; Martins *et al.*, 2021).

## 32 2.2. Supply Chain Network Design for Agricultural Products

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35 In the related articles on agricultural products, scholars have investigated supply chain  
36 network design, with most of them concentrating on the nature of agricultural products  
37 (Boudahri *et al.*, 2011; Mahmoudi *et al.*, 2019). Govindan et al. (2014) studied a two-echelon  
38 LRP for a perishable food supply chain with time windows. Their proposed model was multi-  
39 period and considered a heterogeneous vehicle fleet. Finally, a meta-heuristic algorithm was  
40 employed to solve the model. Javanmard et al. (2014) solved a multi-product distribution  
41 problem with cross-docking. A time window constraint was considered for each delivery and  
42 pickup. Their objective function minimised inventory holding costs and transportation costs.  
43 González-Araya et al. (2015) proposed an optimisation model for apple harvest planning.  
44 Their objective function sought to minimise costs related to workforce, goods, and fruit loss  
45 due to poor quality. Linnemann et al. (2015) used the multi-criteria decision-making  
46 (MCDM) approach to design a supply chain of protein foods. The results of solving the  
47 model indicated that their design resulted in optimal values for different variables. Wang et  
48 al. (2016) proposed a multi-objective vehicle routing problem with time windows for a food  
49 supply chain. The first objective function minimised fixed costs, transportation costs, penalty  
50 costs, and damaged costs. The second objective function of their proposed model maximised  
51 the average freshness of products. Finally, the model was solved using a two-stage heuristic  
52 algorithm based on the Pareto variable neighbourhood search and genetic algorithm.  
53 Agricultural products and supply chain network design have been considered to reduce costs  
54 by various researchers (Orjuela-Castro *et al.*, 2017; Mahdiraji *et al.*, 2019). In this regard,  
55 some articles have focused on a particular agricultural product to model their problems  
56 (Gholamian and Taghanzadeh, 2017). The application of supply chain network design models  
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in distributing wheat considering sustainability indicators has also been recently investigated (Motavalli-Taher *et al.*, 2020; Nayeri *et al.*, 2020). The sustainable network design of the supply chains due to the importance of economic, social, and environmental pillars in agricultural products has been recently considered via multi-objective optimisation models (Fakhrzad *et al.*, 2021).

### 2.3. Red Meat Supply Chain Network Design

To develop the holding and logistic condition of the red meat supply chain and minimise costs, the well-designed integrated network for supply chain components is amongst the most important researches. Schütz *et al.* (2009) designed a supply chain network for red meat with probabilistic conditions. Their proposed model was formulated in two stages. The first stage involved strategic location decisions while the second stage involved operating decisions. The model was solved through a real case in Norway. Soysal *et al.* (2014) designed and solved a beef supply chain with environmental considerations. Their proposed model was a multi-objective linear programming model aimed to minimise inventory and transportation costs while minimising CO<sub>2</sub> emissions from transportation operations. Mohammed and Wang (2017a) used a multi-objective probabilistic programming approach to design a meat supply chain network. Their objective functions minimised total transportation cost, the number of vehicles, and delivery time. Mohammed and Wang (2017b) developed a fuzzy multi-objective model for a green meat supply chain. Their proposed model aimed to minimise the environmental impact of the supply chain and was solved using MCDM. Neves-Moreira *et al.* (2019) developed a multi-product production-routing problem with delivery time windows and heterogeneous vehicles. Their objective function minimised routing cost as well as inventory holding cost for the supplier and retailers. Their model was tested on a European meat store chain. Sustainable and resilient supply networks in the meat industry in Iran have been recently designed and optimised via a multi-objective model (Gholami Zanjani *et al.*, 2021). Beyond these mentioned developments, the main studies are presented in Table 1.

#### Insert Table 1 Here

According to the studies conducted in the field of the agricultural supply chain, especially the red meat supply chain, it is possible to identify gaps in this field. For instance, from a supply chain design and management perspective, Jafarian *et al.* (2019) proposed a multi-period, multi-product inventory-routing problem with a heterogeneous vehicle fleet, by considering the likelihood of vehicle failure via a meta-heuristic algorithm. Moreover, Anderluh *et al.* (2019) proposed a model for a two-echelon vehicle routing problem by considering time uncertainty thru a two-stage GRASP with path relinking. However, in this research, in addition to investigating vehicle routing and inventory problems, operational decisions in production, inventory and location are also addressed. Furthermore, from a supply chain design and agricultural perspective, Saragih *et al.* (2019) proposed a location-inventory-routing problem for a three-echelon food supply chain consisting of a single supplier, multiple depots, and multiple retailers. They considered a probabilistic and normally distributed retailer demand to minimise fixed warehouse installation costs, transportation costs, and inventory holding costs via a mixed-integer nonlinear program and was solved using a heuristic algorithm. In their study, the single-period time horizon was considered; however, in this research, the multi-period time horizon is considered. Moreover, Cheraghalipour *et al.* (2019) designed and solved a bi-stage model for a rice supply chain consisting of producers, DCs, rice factories, and customers. The objective functions for both levels sought to minimise the supply chain costs, including fixed DC, production, inventory

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3 holding, and transportation costs. In their research, the operational decision related to the  
4 vehicle routing problem was not considered; however, in our proposed approach, it has been  
5 investigated as a key issue. Eventually, from the red meat supply chain perspective, Rahbari  
6 et al. (2020) proposed a multi-period location-inventory-routing problem model with  
7 heterogeneous vehicles using the General Algebraic Modeling Language (GAMS). In their  
8 research, a single-stage model containing the livestock suppliers to retailers was presented;  
9 however, in the current research, a two-stage model containing the carcass suppliers to  
10 retailers is proposed. Moreover, Mohebalizadehgashti et al. (2020) proposed a multi-  
11 objective green supply chain for meat via a multi-period, multi-product, and multi-level  
12 model for a homogeneous vehicle fleet. However, in this article, a heterogeneous vehicle fleet  
13 is considered.  
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17 By and large, the supply of raw materials of this supply chain is one of the issues that  
18 should be considered in the design of a red meat supply chain. In other words, livestock  
19 supply is not always at the first level of the red meat supply chain; hence, organisations may  
20 decide to prepare the carcass first according to various issues and then perform the  
21 meatpacking and distribution operations. As a result, this is one of the most important  
22 questions and issues that this research addresses. According to previous studies, consideration  
23 of the supply chain of agricultural products in several stages makes the problem closer to the  
24 real world, and more accurate results are obtained. Also, this will be even more important  
25 when the product shipped is different along the supply chain. In the red meat supply chain,  
26 the transported product is different in the network. In this regard, this research addresses this  
27 issue. Moreover, in the present research, supply chain design is assumed in a two-stage, four-  
28 echelon model by simultaneously considering location-routing and inventory-production  
29 operating decisions. Furthermore, the fleet of vehicles used in this study is considered  
30 heterogeneous. Compared to previous researches, this combination and problem have not  
31 been investigated. Furthermore, solving real instances using information from a meat supplier  
32 in Iran and comparing the outcomes of solving the model with real information could  
33 demonstrate the applicability of the proposed model. Finally, to achieve better results, a series  
34 of sensitivity analyses are performed on different parameters of the problem, and the  
35 reliability of the problem was tested in different scenarios.  
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### 39 40 **3. Modeling**

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42 In this section, the problem is stated and presented, and the case red meat network is  
43 described. Moreover, the assumptions and the two-stage model are formulated in this section.  
44 The schematic algorithm of the method used is represented in Figure 3.  
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#### 46 **Insert Figure 3 Here**

47  
48 Figure 4 illustrates the schematic diagram of the presented model for a red meat supply  
49 chain network. As shown in this diagram, the considered supply chain consists of two stages.  
50 In the first stage with a single echelon, the carcass is transported from the supplier to the  
51 packing facilities. In the second stage with three echelons, products are transported either  
52 directly from packing facilities to retailers or from packing facilities to cold storage facilities  
53 and then to retailers.  
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#### 56 **Insert Figure 4 Here**

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58 The proposed model is a multi-period and single-product mixed-integer linear  
59 programming model with a heterogeneous vehicle fleet. The objective of the first stage of the  
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model is to determine the quantity of packed meat produced and held in each period, the amount of carcass transported to packing facilities, and the best vehicles and routes for transportation. The objective of the second stage is to determine the quantity of packed meat transported in each route, the amount of meat held at each node, whether cold storage facilities are opened in the supply chain, and the best vehicles and routes for transportation.

Notations used in this research are described as follows.

#### Sets.

$c = \{1,2,\dots,C\}$	Set of carcass suppliers
$p = \{1,2,\dots,P\}$	Set of packing facilities
$s = \{1,2,\dots,S\}$	Set of cold storage facilities
$m = \{1,2,\dots,M\}$	Set of retailers
$\omega = c \cup p \cup s \cup m$	Set of all nodes
$vc = \{1,2,\dots,VC\}$	Set of vehicle types at 1 <sup>st</sup> echelon
$vp = \{1,2,\dots,VP\}$	Set of vehicle types at 2 <sup>nd</sup> echelon
$vs = \{1,2,\dots,VS\}$	Set of vehicle types at 3 <sup>rd</sup> echelon
$vm = \{1,2,\dots,VM\}$	Set of vehicle types at 4 <sup>th</sup> echelon
$t = \{1,2,\dots,T\}$	Set of periods

#### Parameters.

$de_{kt}$	The demand for node $k$ for red meat in period $t$ ( $k \in m$ )
$ho_{jt}$	Inventory holding cost for node $j$ in period $t$ ( $j \in p \cup s \cup m$ )
$vpc_{it}$	Variable production cost at packing facility type $i$ for produce red meat in period $t$ ( $i \in p$ )
$fpc_i$	Fixed production cost at packing facility type $i$ for produce red meat ( $i \in p$ )
$sc_i$	Supply cost at carcass supplier type $i$ for supply carcass in period $t$ ( $i \in c$ )
$afc_j$	Annual fixed cost for opening cold storage facility type $j$ ( $j \in s$ )
$disa_{ij}$	The distance among nodes $i$ and $j$ ( $i, j \in p \cup s$ )
$disb_{jk}$	The distance among nodes $j$ and $k$ ( $j, k \in s \cup m$ )
$disc_{ik}$	The distance among nodes $i$ and $k$ ( $i, k \in p \cup m$ )
$disd_{ij}$	The distance among nodes $i$ and $j$ ( $i, j \in c \cup p$ )
$caps_j$	Holding capacity of cold storage facility type $j$ for holding red meat ( $j \in s$ )
$capf_i$	Holding capacity of packing facility type $i$ for holding red meat ( $i \in p$ )
$capr_k$	Holding capacity of retailer type $k$ for holding red meat ( $k \in m$ )
$thf_{it}$	Maximum production capacity at packing facility type $i$ in period $t$ ( $i \in p$ )
$thc_{it}$	Maximum supply capacity at carcass supplier type $i$ in period $t$ ( $i \in c$ )
$cva_{vp}$	The storage capacity of vehicle type $vp$
$cvb_{vs}$	The storage capacity of vehicle type $vs$
$cvc_{vc}$	The storage capacity of vehicle type $vc$
$cvd_{vm}$	The storage capacity of vehicle type $vm$
$vta_{vp}$	Variable transport cost for vehicle type $vp$ per unit distance
$vtb_{vs}$	Variable transport cost for vehicle type $vs$ per unit distance
$vtc_{vc}$	Variable transport cost for vehicle type $vc$ per unit distance
$vtd_{vm}$	Variable transport cost for vehicle type $vm$ per unit distance
$fta_{vp}$	Fixed transport cost for vehicle type $vp$ per trip
$ftb_{vs}$	Fixed transport cost for vehicle type $vs$ per trip
$ftc_{vc}$	Fixed transport cost for vehicle type $vc$ per trip
$ftd_{vm}$	Fixed transport cost for vehicle type $vm$ per trip

$nva_{vpt}$	The number of vehicle type $vp$ existing in period $t$
$nvb_{vst}$	The number of vehicle type $vs$ existing in period $t$
$nvc_{vct}$	The number of vehicle type $vc$ existing in period $t$
$nvd_{vmt}$	The number of vehicle type $vm$ existing in period $t$
$tn$	The number of all available nodes
$\beta$	A coefficient converting the meat to carcass unit
$I_{i0}$	Initial inventory level of red meat in node $i$ ( $i \in p \cup m$ )

### Decision Variables.

$ZS_j$	1, if cold storage facility type $j$ opened, 0, else ( $j \in s$ )
$UA_{vpt}$	1, if vehicle type $vp$ is used in period $t$ , 0, else
$UB_{vst}$	1, if vehicle type $vs$ is used in period $t$ , 0, else
$UC_{vct}$	1, if vehicle type $vc$ is used in period $t$ , 0, else
$UD_{vmt}$	1, if vehicle type $vm$ is used in period $t$ , 0, else
$OP_{it}$	1, if packing facility type $i$ produces in period $t$ , 0, else ( $i \in p$ )
$XA_{ijvpt}$	1, if arc $(i,j)$ is visited by vehicle type $vp$ in period $t$ , 0, else ( $i,j \in p \cup s$ )
$XB_{ikvct}$	1, if arc $(i,k)$ is visited by vehicle type $vc$ in period $t$ , 0, else ( $i,k \in c \cup p$ )
$YA_{jkvst}$	1, if arc $(j,k)$ is visited by vehicle type $vs$ in period $t$ , 0, else ( $j,k \in s \cup m$ )
$YB_{ikvmt}$	1, if arc $(i,k)$ is visited by vehicle type $vm$ in period $t$ , 0, else ( $i,k \in p \cup m$ )
$XP_{it}$	The quantity of red meat that facility type $i$ produced in period $t$ ( $i \in p$ )
$QA_{ijvpt}$	The quantity of red meat transferred among node $i$ and $j$ by the vehicle type $vp$ in period $t$ ( $i,j \in p \cup s$ )
$QB_{ikvct}$	The quantity of red meat transferred among node $i$ and $k$ by the vehicle type $vc$ in period $t$ ( $i,k \in c \cup p$ )
$GA_{jkvst}$	The quantity of red meat transferred among node $j$ and $k$ by the vehicle type $vs$ in period $t$ ( $j,k \in s \cup m$ )
$GB_{ikvmt}$	The quantity of red meat transferred among node $i$ and $k$ by the vehicle type $vm$ in period $t$ ( $i,k \in p \cup m$ )
$I_{jt}$	The inventory level at node $j$ for red meat in period $t$ ( $j \in p \cup s \cup m$ )
$EA_{jt}$	An auxiliary variable used for sub-tour elimination for cold storage facility type $j$ in period $t$ ( $j \in s$ )
$EB_{kt}$	An auxiliary variable used for sub-tour elimination for retailer type $k$ at 3 <sup>rd</sup> echelon in period $t$ ( $k \in m$ )
$EC_{it}$	An auxiliary variable used for sub-tour elimination for packing facility type $i$ in period $t$ ( $i \in p$ )
$ED_{kt}$	An auxiliary variable used for sub-tour elimination for retailer type $k$ at 4 <sup>th</sup> echelon in period $t$ ( $k \in m$ )

### 3.1. Model Stage 1

There are multiple carcass suppliers and multiple packing facilities, and retailers' demand is deterministic and variable in different periods. Carcass suppliers have a limited supply capacity in each period (Leksakul and Apiromchaiyakul, 2019). Besides, meat production by packing facilities deals with two types of costs, i.e. variable cost of red meat production and fixed cost of meat production processes. Furthermore, packing facilities have limited production throughput (Teigiserova *et al.*, 2019). Note that, packing facilities can store meat, and each warehouse has a specific capacity for holding products and incurs inventory holding costs. In this model, each echelon uses a different fleet, and the number of vehicles is limited. Moreover, vehicles have different and limited capacities. Vehicles start their trip from carcass suppliers and return after delivering carcasses. Besides, variable transportation costs per trip and fixed vehicle costs are considered. The objective function (1) minimises the total supply chain costs, including the cost of carcass purchase from suppliers,

variable and fixed production cost at packing facilities, inventory holding cost at packing facilities, variable transportation cost, and fixed vehicle cost.

$$\min z = \begin{cases} \sum_{i=1}^C \sum_{j=1}^P \sum_{vc=1}^{VC} \sum_{t=1}^T QB_{ijvct} sc_{it} + \sum_{i=1}^P \sum_{t=1}^T vpc_{it} XP_{it} + \sum_{i=1}^P \sum_{t=1}^T fpc_i OP_{it} + \\ \sum_{j=1}^P \sum_{t=1}^T ho_{jt} I_{jt} + \sum_{i=1}^{C+P} \sum_{k=1|i \neq k}^{C+P} \sum_{vc=1}^{VC} \sum_{t=1}^T vtc_{vc} disd_{ik} XB_{ikvct} + \sum_{vc=1}^{VC} \sum_{t=1}^T ftc_{vc} UC_{vct} \end{cases} \quad (1)$$

The constraints of the first stage are represented below. Constraint (2) is the inventory balance constraint for packing facilities.

$$I_{it} = I_{i(t-1)} + XP_{it} - \left( \sum_{j=1}^S \sum_{vp=1}^{VP} QA_{ijvpt} + \sum_{k=1}^M \sum_{vm=1}^{VM} GB_{ikvmt} \right) \quad \forall i \in p, t \quad (2)$$

Constraint (3) sets the amount of carcass needed based on the meat conversion factor.

$$\beta XP_{it} + \sum_{k=1|k \neq i}^P \sum_{vc=1}^{VC} QB_{ikvct} = \sum_{j=1|j \neq i}^{C+P} \sum_{vc=1}^{VC} QB_{jivct} \quad \forall i \in p, t \quad (3)$$

The capacity constraints are formulated in Eqs. (4) to (7). Constraint (4) ensures that meat production by packing facilities does not exceed their maximum throughput. Constraint (5) ensures that products held in the warehouses of packing facilities do not exceed the maximum allowable capacity. Constraint (6) denotes that the amount of carcass shipped by the supplier does not exceed the associated supply capacity. Constraint (7) indicates that, at each echelon, the total volume of products loaded on the vehicle does not exceed its maximum capacity.

$$XP_{it} \leq thf_{it} OP_{it} \quad \forall i \in p, t \quad (4)$$

$$I_{it} \leq capf_i \quad \forall i \in p, t \quad (5)$$

$$\sum_{j=1}^P \sum_{vc=1}^{VC} QB_{ijvct} \leq thc_{it} \quad \forall i \in c, t \quad (6)$$

$$QB_{ikvct} \leq cvc_{vc} XB_{ikvct} \quad \forall i \& k \in c \cup p, vc, t, i \neq k \quad (7)$$

The next set of constraints are related to transportation. Constraint (8) clarifies that if a vehicle is used for transportation, it must start its trip from the source node. Constraint (9) ensures that the number of vehicles used at each echelon does not exceed availability limits. Constraint (10) is related to node assignment at each echelon, convincing that a vehicle entering a node should leave the same node. Constraint (11) precludes the formation of sub-tours among nodes.

$$\sum_{j=1}^C \sum_{k=1}^P XB_{jkvct} = UC_{vct} \quad \forall vc, t \quad (8)$$

$$\sum_{i=1}^C \sum_{k=1}^P XB_{ikvct} \leq nvc_{vct} \quad \forall vc, t \quad (9)$$

$$\sum_{j=1|j \neq k}^{C+P} XB_{jkvct} = \sum_{j=1|j \neq k}^{C+P} XB_{kjavct} \quad \forall k \in c \cup p, vc, t \quad (10)$$

$$EC_{it} - EC_{jt} \geq 1 - tn(1 - \sum_{vc=1}^{VC} XB_{jivct}) \quad \forall i, j \in p, t, i \neq j \quad (11)$$

Constraint (12) certifies that the quantity of products transported by a vehicle is greater at the start of the trip than along the route.

$$\sum_{i=1}^C \sum_{k=1}^P QB_{ikvct} \geq \sum_{k=1}^P \sum_{j=1|k \neq j}^P QB_{kjavct} \quad \forall vc, t \quad (12)$$

The last set of constraints is related to the decision variables. Constraint (13) is related to decision variables for the first stage of the model.

$$\begin{aligned} OP_{it}, XB_{ikvct}, UC_{vst} &\in \{0, 1\} \\ QB_{jkvct}, I_{jt}, EC_{it}, XP_{it} &\geq 0 \end{aligned} \quad \forall i \& j \& k \in c \cup p, vc, t \quad (13)$$

### 3.2. Model Stage 2

Model stage 2 consists of multiple packing facilities, multiple cold storage facilities, and multiple retailers. The demand is deterministic and alternates in different periods. Packing facilities deliver meat to retailers either directly or indirectly through cold storage facilities. Besides, cold storage facilities and retailers can store meat, and warehouses at each node have a specific capacity for holding products and incur inventory holding costs. Note that, in this model, each echelon uses a different fleet, and the number of vehicles is limited. Also, vehicles have different and limited capacities. Vehicles start their trip from packing facilities and return to the initial node after delivering products. In this routing, variable transportation costs per trip and fixed vehicle costs are considered. The second stage objective function (14) is to minimise the total supply chain costs, including inventory holding costs at nodes, cold storage facility opening cost (if needed), and variable transportation cost, as well as fixed vehicle cost at each echelon.

$$\min z = \begin{cases} \sum_{j=1}^{S+M} \sum_{t=1}^T ho_{jt} I_{jt} + \sum_{j=1}^S afc_j ZS_j + \sum_{i=1}^{P+S} \sum_{j=1|i \neq j}^{P+S} \sum_{vp=1}^{VP} \sum_{t=1}^T vta_{vp} disa_{ij} XA_{ijvpt} + \\ \sum_{vp=1}^{VP} \sum_{t=1}^T fta_{vp} UA_{vpt} + \sum_{j=1}^{S+M} \sum_{k=1|j \neq k}^{S+M} \sum_{vs=1}^{VS} \sum_{t=1}^T vtb_{vs} disb_{jk} YA_{jkvst} + \sum_{vs=1}^{VS} \sum_{t=1}^T ftb_{vs} UB_{vst} + \\ \sum_{i=1}^{P+M} \sum_{k=1|i \neq k}^{P+M} \sum_{vm=1}^{VM} \sum_{t=1}^T vtd_{vm} disc_{ik} YB_{ikvmt} + \sum_{vm=1}^{VM} \sum_{t=1}^T ftd_{vm} UD_{vmt} \end{cases} \quad (14)$$

The first set of constraints in the second stage is related to inventory balance. Constraints (15) and (16) are related to inventory balance at cold storage facilities and retailers, respectively.

$$I_{jt} = I_{j(t-1)} + \sum_{i=1|i \neq j}^{P+S} \sum_{vp=1}^{VP} QA_{ijvpt} - \sum_{i=1|i \neq j}^S \sum_{v=1}^{VP} QA_{jivpt} - \sum_{k=1}^M \sum_{vs=1}^{VS} GA_{jkvst} \quad \forall j \in s, t \quad (15)$$

$$I_{kt} = I_{k(t-1)} + \sum_{j=1|j \neq k}^{S+M} \sum_{vs=1}^{VS} GA_{jkvst} - \sum_{j=1|j \neq k}^M \sum_{vs=1}^{VS} GA_{kjavst} + \sum_{i=1|i \neq k}^{P+M} \sum_{vm=1}^{VM} GB_{ikvmt} - \sum_{i=1|i \neq k}^M \sum_{vm=1}^{VM} GB_{kivmt} - de_{kt} \quad \forall k \in m, t \quad (16)$$

The second set of the second stage constraints are related to the capacity. Constraint (17) determines that if a cold storage facility is opened, the amount of meat in the warehouse

of the cold storage facility does not exceed the maximum allowable capacity. Constraint (18) indicates that the quantity of products held in retailer warehouses does not exceed their holding capacity. Constraints (19) to (21) ensure that, at any echelon, the total volume of products loaded on a vehicle does not exceed its capacity.

$$I_{jt} \leq caps_j ZS_j \quad \forall j \in s, t \quad (17)$$

$$I_{kt} \leq capr_k \quad \forall k \in m, t \quad (18)$$

$$QA_{ijvpt} \leq cva_{vp} XA_{ijvpt} \quad \forall i \& j \in p \cup s, vp, t, i \neq j \quad (19)$$

$$GA_{jkvst} \leq cvb_{vs} YA_{jkvst} \quad \forall j \& k \in s \cup m, vs, t, j \neq k \quad (20)$$

$$GB_{ikvmt} \leq cvd_{vm} YB_{ikvmt} \quad \forall i \& k \in p \cup m, vm, t, i \neq k \quad (21)$$

The vehicle-related constraints are added next. Constraints (22) to (24) ensure that if a vehicle is used, it should start its trip from the source node. Constraints (25) to (27) ensure that the number of vehicles used at each echelon does not exceed availability limits.

$$\sum_{i=1}^P \sum_{j=1}^S XA_{ijvpt} = UA_{vpt} \quad \forall vp, t \quad (22)$$

$$\sum_{j=1}^S \sum_{k=1}^M YA_{jkvst} = UB_{vst} \quad \forall vs, t \quad (23)$$

$$\sum_{i=1}^P \sum_{k=1}^M YB_{ikvmt} = UD_{vmt} \quad \forall vm, t \quad (24)$$

$$\sum_{i=1}^P \sum_{j=1}^S XA_{ijvpt} \leq nva_{vpt} \quad \forall vp, t \quad (25)$$

$$\sum_{j=1}^S \sum_{k=1}^M YA_{jkvst} \leq nvb_{vst} \quad \forall vs, t \quad (26)$$

$$\sum_{i=1}^P \sum_{k=1}^M YB_{ikvmt} \leq nvd_{vmt} \quad \forall vm, t \quad (27)$$

Constraints (28) to (30) are related to node assignment at each echelon, ensuring that a vehicle entering a node should leave the same node.

$$\sum_{i=1|j \neq i}^{P+S} XA_{ijvpt} = \sum_{i=1|j \neq i}^{P+S} XA_{jivpt} \quad \forall j \in p \cup s, vp, t \quad (28)$$

$$\sum_{j=1|j \neq k}^{S+M} YA_{jkvst} = \sum_{j=1|j \neq k}^{S+M} YA_{kjavst} \quad \forall k \in s \cup m, vs, t \quad (29)$$

$$\sum_{i=1|i \neq k}^{P+M} YB_{ikvmt} = \sum_{i=1|i \neq k}^{P+M} YB_{kivmt} \quad \forall k \in p \cup m, vm, t \quad (30)$$

Constraints (31) to (33) preclude the formation of sub-tours among nodes.

$$EA_{it} - EA_{jt} \geq 1 - tn \left( 1 - \sum_{vp=1}^{VP} XA_{jivpt} \right) \quad \forall i, j \in s, t, i \neq j \quad (31)$$

$$EB_{it} - EB_{jt} \geq 1 - tn \left( 1 - \sum_{vs=1}^{VS} YA_{jivst} \right) \quad \forall i, j \in m, t, i \neq j \quad (32)$$

$$ED_{it} - ED_{jt} \geq 1 - tn(1 - \sum_{vm=1}^{VM} YB_{jivmt}) \quad \forall i, j \in m, t, i \neq j \quad (33)$$

Constraints (34) to (36) ensure that the quantity of products transported by a vehicle at each echelon is greater at the start of the trip than along the route.

$$\sum_{i=1}^P \sum_{j=1}^S QA_{ijvpt} \geq \sum_{j=1}^S \sum_{k=1|j \neq k}^S QA_{jkvpt} \quad \forall vp, t \quad (34)$$

$$\sum_{j=1}^S \sum_{k=1}^M GA_{jkvst} \geq \sum_{k=1}^M \sum_{i=1|k \neq i}^M GA_{kivst} \quad \forall vs, t \quad (35)$$

$$\sum_{i=1}^P \sum_{k=1}^M GB_{ikvmt} \geq \sum_{k=1}^M \sum_{j=1|k \neq j}^M GB_{kjmvt} \quad \forall vm, t \quad (36)$$

The next two constraints are due to the balance of products entered and sent from cold storage facilities. Constraint (37) ensures that the quantity of products transported from cold storage facilities does not exceed its capacity. Constraint (38) convinces that the quantity of products transported from packing facilities to cold storage facilities is equal to the quantity transported from cold storage facilities to retailers. Constraint (39) ensures that the quantity of products produced by packing facilities plus the products held in the warehouses of packing facilities is more than or equal to the number of products transported from packing facilities to cold storage facilities, plus the number of products transported from packing facilities to retailers.

$$\sum_{k=1}^M \sum_{vs=1}^{VS} GA_{jkvst} \leq caps_j ZS_j \quad \forall j \in s, t \quad (37)$$

$$\sum_{i=1}^P \sum_{j=1}^S \sum_{vp=1}^{VP} \sum_{t=1}^T QA_{ijvpt} = \sum_{j=1}^S \sum_{k=1}^M \sum_{vs=1}^{VS} \sum_{t=1}^T GA_{jkvst} \quad (38)$$

$$XP_{it} + I_{i(t-1)} \geq \sum_{j=1}^S \sum_{vp=1}^{VP} QA_{ijvpt} + \sum_{k=1}^M \sum_{vm=1}^{VM} GB_{ikvmt} \quad \forall i \in p, t \quad (39)$$

The last set of constraints, i.e. constraint (40) is related to decision variables for the second stage of the model.

$$\begin{aligned} XA_{ijvpt}, YA_{jkvst}, YB_{ikvmt}, UA_{vpt}, UB_{vst}, UD_{vmt}, ZS_j &\in \{0,1\} & \forall vp, vs, vm, t, \\ QA_{ijvpt}, GA_{jkvst}, GB_{ikvmt}, I_{jt}, EA_{it}, EB_{it}, ED_{it} &\geq 0 & i \& j \& k \in p \cup s \cup m \end{aligned} \quad (40)$$

#### 4. Case Study and Results

In this section, the two-stage model for the designed red meat supply chain is applied to a numerical instance. After solving the model, the outcomes are evaluated, and the best strategy for the company is determined. This instance includes 63 nodes, 42 retailers, 12 cold storage facilities, four packing facilities, and five carcass suppliers. Retailers are the major stores across Iran with significant demand for red meat. The 12 cold storage facilities were randomly selected. In addition to the main meatpacking facility of the company, the rest of the packing facilities were randomly selected from different parts of the country. The five carcass suppliers were also randomly selected based on their reputation. Seven periods were considered, and the length of each period is one month. Two types of vehicles were considered at every echelon, 20-ton ( $v_1$ ), and 10-ton ( $v_2$ ) vehicles. However, only for the routes among cold storage facilities and retailers (within Tehran), four types of vehicles were considered, 20-ton ( $v_1$ ), 10-ton ( $v_2$ ), 5-ton ( $v_3$ ), and 2-ton ( $v_4$ ) vehicles. A key point

1  
2  
3 regarding red meat transportation in Iran is that according to veterinary organisation  
4 limitations, it is not feasible to transfer red meat by a vehicle between two provinces or two  
5 different retailers. Table 2 presents the retailers' demand and holding capacity information in  
6 each period. The data are in tons. Moreover, the costs of carcass supply are calculated using  
7 information from the *State Livestock Affairs Company* and are \$21,515, \$20,909, \$19,697,  
8 \$19,091, and \$18,788, respectively. There are no constraints on carcass supply by suppliers.  
9

10  
11 **Insert Table 2 Here**  
12

13 The required tonnage of the carcass is determined by multiplying the production  
14 quantity of the packing facility by the meat conversion factor. This factor ( $\beta$ ) is considered to  
15 be 1.25 based on the opinion of the company's experts. For example, 10 tons of packed meat  
16 requires 12.5 tons of carcasses. Note that, the variable transportation cost per ton for each  
17 vehicles type is \$0.063, \$0.068, \$0.072, and \$0.077; the fixed transportation cost for each  
18 vehicles type is \$518, \$382, \$305, and \$195; eventually, the storage capacity of vehicles in  
19 each echelon is 20, 10, 5, and 2 (Tons), respectively. The fixed and variable transportation  
20 costs are obtained based on the rates set by *Iran Road Maintenance and Transportation*  
21 *Organisation*. The number of available vehicles is considered unlimited since vehicle rental  
22 companies can provide the company with an unlimited number of vehicles. Information about  
23 meatpacking costs is provided in Table 3. This information is based on the analyses made by  
24 the company's experts and middle-level managers.  
25

26  
27 **Insert Table 3 Here**  
28

29 The initial inventory level is considered zero at all nodes. Inventory holding costs and  
30 loading/unloading costs of cold storage facilities in 2018 were \$18 and \$4, respectively;  
31 according to the *Consumer and Producer Protection Organisation of Iran*. The holding  
32 capacity of cold storage facilities is considered to be 20,000 tons. The distance among nodes  
33 is calculated in kilometers (Tables 4 to 7).  
34

35 **Insert Table 4 Here**  
36

37 **Insert Table 5 Here**  
38

39 **Insert Table 6 Here**  
40

41 **Insert Table 7 Here**  
42

43 The proposed models are solved using GAMS software (version 24.1.2) on a personal  
44 computer (Intel(R) Core (TM) i3-4000@2.40GHz 2.40GHz). Solving both stages of the  
45 model indicates that the required carcass is only purchased from the fifth supplier ( $c_5$ ).  
46 Moreover, meat packing facilities 1 and 2 ( $p_1, p_2$ ) affiliated with the company are used for red  
47 meat production. The outcomes indicate that there is no need for opening cold storage  
48 facilities, and that red meat is directly shipped from packing facilities to retailers.  
49 Additionally, the warehouses of retailers and packing facilities are used for holding  
50 inventory. Meatpacking facilities operate only during the first six periods. Table 8 illustrates  
51 the quantity of meat transported between different echelons. The outcomes indicate that no  
52 product is transported in the seventh period since the demanded meat has been supplied to  
53 retailers during the prior periods, and there is no need to produce meat in packing facilities  
54 during the seventh period.  
55

56 **Insert Table 8 Here**  
57

58 The vehicle employed at each echelon has the following characteristics/parameters:  
59  
60

- For the carcass suppliers to packing facilities node, vehicle  $v_1$  should be used 60, 24, 20, 18, 4, and 2 times, respectively, for periods one to six;
- For the packing facilities to retailers node, vehicle  $v_1$  should be used 50, 18, 13, 12, 3, and 2 times, respectively, for periods one to six;
- For the packing facilities to retailers node, vehicle  $v_2$  should be used 4, 6, 7, and 5 times, respectively, for periods one to four.

The outcomes indicate that the first vehicle type (20 tons) is used more frequently than the second vehicle type (10 tons). The quantity of inventory held by meatpacking facilities and retailers is provided in Table 9. The data indicates that only the quantity of meat required by these facilities is stored in their warehouses.

### Insert Table 9 Here

The total cost for this instance is \$50,385,721 obtained by GAMS in 2,664 seconds. The total transportation cost for all echelons, including variable and fixed costs, is \$358,918. Meat production and inventory holding cost, which includes the fixed and variable cost of meat production in packing facilities in the first stage is \$2,328,924. Finally, the cost of carcass purchase in the first stage is \$47,697,879. Based on the calculated retailer demand that is 2,031 tons, the cost per kg of meat is \$24.8. Reports gathered from the experts at the studied company indicate that the cost per kg of meat for the proposed instance was \$25.3, while the cost obtained by solving the proposed model was \$24.8, indicating an improvement of about \$0.5.

## **5. Discussion and Implication**

For this section, sensitivity analysis has been considered to assess any changes in the system, and it recommends more practical insights for the managers.

### **5.1. Sensitivity Analysis: Retailers' Holding Capacity**

According to the case study, the retailers' holding capacity is considered to be limited and equal to their maximum demand during the studied periods. Based on reports from previous years, it may not be possible to fully utilise this capacity in certain periods. Here, the effect on the solution of the model is examined. The worst-case scenario is considered, and the response of the model is observed. The assumption is that retailers have zero capacity for holding products, and every product received is delivered to the customers. Solving both stages of the model indicates that, similar to the original scenario, the required carcass is only purchased from the fifth supplier ( $c_5$ ). Moreover, meat packing facilities 1 and 2 ( $p_1, p_2$ ) affiliated with the company are used for red meat production. Even in this scenario, there is no need for opening cold storage facilities, and red meat is directly transported from packing facilities to retailers. An important observation in this scenario is that only the warehouses of packing facilities are used to hold inventory, and these facilities operate in all seven periods. Table 10 illustrates the quantity amount of meat transported among echelons in scenario 2.

### Insert Table 10 Here

As the results indicate, products are shipped in every period, whereas in the prior scenario (scenario 1), no product is produced/transported in the seventh period. In other words, transportation has increased in this scenario compared to the previous one. Vehicle usage at each echelon for this scenario is as follows:



- For the carcass suppliers to packing facilities' node, vehicle  $v_1$  should be used 43, 35, 24, 16, 6, 3, and 1 times, respectively, for periods one to seven.
- For the packing facilities to retailers' node, vehicle  $v_1$  should be used 35, 20, 12, 8, 3, and 2 times, respectively, for periods one to six.
- For the packing facilities to retailers' node, vehicle  $v_2$  should be used 13, 25, 17, 14, 5, 2, and 2 times, respectively, for periods one to seven.

Compared to scenario number 1, the second vehicle type (10 tons) is used more frequently in the route among packing facilities and retailers. The quantity of inventory held in packing facilities is 5 tons for period two in the first node, and 2,11,11, and 7 tons for the second node, respectively, in period one to four. These data indicate higher levels of inventory holding in the warehouses of packing facilities compared to scenario number 1.

In the second scenario, the total cost is \$50,402,240 obtained by GAMS in 21 seconds. Solution time has decreased significantly compared to the prior scenario, which is due to no inventory holding strategy followed by retailers. Transportation cost at different echelons is \$372,106, which includes both variable and fixed costs. Meat production and inventory holding cost, which includes the fixed and variable cost of meat production in packing facilities in the first stage, is \$2,332,255. Finally, the cost of carcass purchase in the first stage is \$47,697,879. Comparing these outcomes with the original scenario indicates an increase in total costs by \$16,519. This increase is due to the higher levels of inventory held in the warehouses of packing facilities as well as the increase in transportation cost.

## 5.2. Sensitivity Analysis: Supply Capacity at Carcass Suppliers

In this section, a sensitivity analysis is performed on the supply capacity of carcass suppliers which has been considered infinite in the real case study. However, according to previous reports, some suppliers may face a limited carcass supply in some periods; thus, it is necessary to investigate the impact of this issue on the results of the case study. In this part, the least possible case stated in the reports, which is equal to 300 tons per month, is considered as the maximum supply capacity at carcass suppliers. After solving the problem in two stages, it is observed that all the values obtained in the second stage are the same as the first scenario. Nonetheless, the values obtained in the first stage have been affected. The main point of this scenario is the purchase of the required carcass from suppliers 2 to 5 ( $c_2, c_3, c_4, c_5$ ). Table 11 illustrates the amounts of meat transferred between nodes in the third scenario.

### Insert Table 11 Here

The transportation of products in the second stage is similar to that of the first scenario. However, in the first stage, it is observed that the cost of transportation has increased due to the increase in the number of carcass suppliers. After comparing the results with Scenario 1, it is obvious that the same number and types of vehicles have been used. Only in the sixth period in the first stage, a 10-ton vehicle has been employed. Moreover, the amount of inventory held in the packing facility warehouse has decreased compared to Scenario 1, and only in the second period, an amount of 4 tons is stored in the first packing facility warehouse.

In the third scenario, the total cost is \$51,493,366, which was obtained by GAMS in 2,823 seconds. Solution time increased compared to Scenario 1, which was due to the reduction of the capacity of carcass suppliers and supply from different suppliers. The transportation cost at different echelons is \$385,460, which includes both variable and fixed costs. Meat production and inventory holding cost, which includes the fixed and variable cost

of meat production in packing facilities in the first stage, is \$2,328,815. Eventually, the cost of carcass purchase in the first stage is \$48,779,091. Comparing these outcomes with the original scenario indicates an increase in total costs by \$1,107,645. This increase is due to the supply of carcasses at higher prices from different suppliers. This increase is also due to the increase in the cost of transporting products. Figure 5 illustrates a comparison between the outcomes of solving the three scenarios for more clarification.

### Insert Figure 5 Here

### 5.3. Managerial Insights

*Theoretically*, the problem presented in this research is a multi-period mixed-integer linear programming considering a heterogeneous vehicle fleet and vehicle routing problem. One of the main contributions considered in this problem is the two-stage model consisting of a single-echelon in the first and a three-echelon in the second stage of the model. The first stage includes several carcass suppliers and several packing facilities where after purchasing the carcass, production operations related to red meatpacking are performed. The second stage includes several packing facilities, several cold storage facilities, and several retailers where after determining the required cold storage facilities, the product is transferred to retailers.

In *practical* terms, the results presented in section 4 specify the optimal network structure of a meat production and distribution network. Considering the importance of this product in the nutrition of the population in the emerging economy of Iran and the social and economic impacts of poor performance for these networks, the results can be used as a basis for structuring, producing, and optimally distributing similar products. The various parameters of the problem play a crucial role in operational decisions. Increasing and decreasing the parameters can change the supply chain members decisions so that they have a direct impact on determining the final price of a product. Furthermore, decisions made by the red meat supply chain members have both direct and indirect impacts on other issues, such as environmental problems that must be addressed by all members of the supply chain and government agencies. The following illustrates the *managerial implications* derived from this research, which can help to design the supply chain networks of red meat for similar real circumstances.

- In some red meat supply chain networks, livestock is not purchased directly, i.e. carcasses are purchased, converted to red meat, and delivered to customers. Hence, to achieve the best economic outcomes, different scenarios in the supply chain network should be investigated and examined. Moreover, given the outcomes from solving the proposed model, it is clear that some real-world problems such as vehicle routing problems are not addressed accurately.
- The capacity set by retailers for holding products plays a significant role in strategic decision-making within the supply chain and could lead to significant changes in the cost per kg of product. Thus, in case an integrated supply chain is considered and information continuously flows between its different echelons, the price of red meat can be minimised significantly.
- Another important issue to consider in the red meat supply chain is the carcass supply capacity provided by suppliers. This amount varies at different times of the year, and producers must plan carefully to supply the red meat consumed by customers to avoid carcass shortages. This is important in an emergency when the demand for red meat increases. It is also possible to rent the cold storage facilities to reduce transportation costs and maintain the quality of the final product to store the red meat needed for a subsequent time and distribute it to retailers at specified times.

- The adverse impact of meat consumption decline (per capita) on the health of the general public highlights the significance of the reduction in the price of red meat. In other words, cost reduction not only increases the profitability of meat producers but also benefits society. Coordination and integration within the entire red meat supply chain are necessary for achieving this goal and controlling the prices in the market.

## 6. Conclusion

In this study, a two-stage, four-echelon location-inventory-routing problem for the red meat supply chain was presented. Important assumptions of this research include considering the vehicle fleet as heterogeneous, time horizon as multi-period, and considering the carcass suppliers in the first level and retailers in the last level. Compared to previous researches, this combination and problem were not investigated. To validate the two-stage model, the presented models were implemented in a real case scenario. The real instance was solved using GAMS, and the outcomes indicated that the proposed model resulted in a reduction in the cost per kg of red meat by about 2%, compared to the current market price. Other outcomes obtained by solving the model include (1) the definition of the optimal quantity of meat production in packing facilities in each period, (2) a determination as to whether to produce meat at any given period, (3) whether to open cold storage facilities as part of the supply chain, (4) the definition of the quantity of product transported at each level of the supply chain, (5) the definition of the quantity of product held at each node, (6) the best vehicles, and (7) the best transportation routes. Moreover, a sensitivity analysis was performed on the inventory holding capacity of the retailers. This scenario assumed that retailers have no holding capacity in their warehouses. Solving the model with this assumption indicated an increase in total costs due to higher levels of inventory held in the warehouses of packing facilities as well as the increase in the transportation cost. Eventually, another sensitivity analysis was performed on the supply capacity at carcass suppliers. In this scenario, it was assumed that each supplier can supply carcasses up to the minimum amount that was available in previous reports. After solving the model with these conditions, it was found that costs had increased. This increase is due to the supply of carcasses at higher prices from different suppliers.

According to relevant literature and the proposed model, the red meat supply chain was integrated from the livestock supply level to the customer level, given that there are three different types of products in this chain (livestock, carcasses, and red meat). As some meat-producing companies may purchase packed red meat directly from other countries as imported goods and only focus on the distribution and supplier selection issues, the supply chain of packed red meat distribution may be examined in future researches. To generalise the proposed model for supply chains of other agricultural products and livestock products, the constraints of the supply chain of each product must be carefully examined and considered in the network design. Moreover, depending on the problem, conditions such as fuzzy or stochastic demand can be incorporated into the model instead of deterministic parameters. Features such as a transshipment and time window can also be added to the modelling to better distribute the red meat. Experimental design can also be used to integrate and consider other parameters for sensitivity analysis. The main advantage of experimental design is to consider the interaction of the parameters and their effects on the initial results. Other characteristics can also be included in the model if needed. For instance, the sustainability pillars especially social and environmental aspects should be considered in future models.

## References

- 1  
2  
3 Adesogan, A.T. Havelaar, A.H. McKune, S.L. Eilittä, M. and Dahl, G.E. (2020), "Animal source foods:  
4 Sustainability problem or malnutrition and sustainability solution? Perspective matters", *Global Food*  
5 *Security*, Vol 25, pp.100-125.
- 6 Anderluh, A. Larsen, R. Hemmelmayr, V.C. and Nolz, P.C. (2019), "Impact of travel time uncertainties on the  
7 solution cost of a two-echelon vehicle routing problem with synchronization", *Flexible Services and*  
8 *Manufacturing Journal*, pp.1-23.
- 9 Al Shamsi, A. Al Raisi, A. and Aftab, M. (2014), "Pollution-inventory routing problem with perishable goods".  
10 In *Logistics operations, supply chain management and sustainability* (pp. 585-596), Springer, Cham.
- 11 Biuki, M. Kazemi, A. and Alinezhad, A. (2020), "An integrated location-routing-inventory model for  
12 sustainable design of a perishable products supply chain network", *Journal of Cleaner Production*,  
13 p.120842.
- 14 Bergeron, N. Chiu, S. Williams, P.T. M King, S. and Krauss, R.M. (2019), "Effects of red meat, white meat, and  
15 nonmeat protein sources on atherogenic lipoprotein measures in the context of low compared with high  
16 saturated fat intake: a randomized controlled trial", *The American journal of clinical nutrition*, 110(1),  
17 pp.24-33.
- 18 Boudahri F, Bennekrouf M, Sari Z (2011), "Optimization and design of the transportation network of agri-foods  
19 supply chain: application chicken meat". *Int J Adv Eng Sci Tech*, 11(1): 213-220.
- 20 Coelho, L.C. Cordeau, J.F. and Laporte, G. (2014), "Thirty years of inventory routing", *Transportation Science*,  
21 48(1), pp.1-19.
- 22 Cheraghalipour, A. Paydar, M.M. and Hajiaghahi-Keshteli, M. (2019), "Designing and solving a bi-level model  
23 for rice supply chain using the evolutionary algorithms", *Computers and Electronics in Agriculture*, 162,  
24 pp.651-668.
- 25 do C. Martins, L., Hirsch, P., and Juan, A. A. (2021), "Agile optimization of a two-echelon vehicle routing  
26 problem with pickup and delivery", *International Transactions in Operational Research*, 28(1), pp.201-  
27 221.
- 28 Fakhrzad, M. B., and Goodarzian, F. (2021), "A new multi-objective mathematical model for a Citrus supply  
29 chain network design: Metaheuristic algorithms" *Journal of Optimization in Industrial Engineering*,  
30 14(2), pp.127-144.
- 31 Frisk, M. Jonsson, A. Sellman, S. Flisberg, P. Rönnqvist, M. and Wennergren, U. (2018), "Route optimization  
32 as an instrument to improve animal welfare and economics in pre-slaughter logistics", *PloS one*, 13(3),  
33 p.e0193223.
- 34 Geoffrion AM, Graves GW (1974), "Multi commodity distribution system design by Bender's decomposition"  
35 *Manage Sci*, 20(5), pp/822-844.
- 36 Gholamian, M.R. and Taghazadeh, A.H. (2017), "Integrated network design of wheat supply chain: A real case  
37 of Iran", *Computers and Electronics in Agriculture*, 140, pp.139-147.
- 38 Gholami-Zanjani, S. M., Jabalameli, M. S., and Pishvae, M. S. (2021), "A resilient-green model for multi-  
39 echelon meat supply chain planning" *Computers and Industrial Engineering*, 152, 107018.
- 40 González-Araya, M. C. Soto-Silva, W. E. and Espejo, L. G. A. (2015), "Harvest planning in apple orchards  
41 using an optimization model", In *Handbook of operations research in agriculture and the agri-food*  
42 *industry* (pp. 79-105), Springer, New York, NY.
- 43 Govindan K, Jafarian A, Khodaverdi R, Devika K (2014), "Two-echelon multiple-vehicle location-routing  
44 problem with time windows for optimization of sustainable supply chain network of perishable food" *Int J*  
45 *Prod Econ*, 152, pp.9-28.
- 46 Govindan, K. Fattahi, M. and Keyvanshokoo, E. (2017), "Supply chain network design under uncertainty: A  
47 comprehensive review and future research directions", *European Journal of Operational Research*,  
48 263(1), pp.108-141.
- 49 Hajiagha, S. H. R., Mahdiraji, H. A., Taviana, M., & Hashemi, S. S. (2018), "A novel common set of weights  
50 method for multi-period efficiency measurement using mean-variance criteria", *Measurement*, 129, pp.  
51 569-581.
- 52 Heidari, M., Jafari, M. J., & Rahbari, M. (2018, February). Modeling a Multi-Objective Location-Routing  
53 Problem for Hazardous Materials with CO2 Emissions Consideration. In *14th International Industrial*  
54 *Engineering Conference (IIEC 2018)*.
- 55 Heidari, M., Rahbari, M., & Mohseni, A. R. (2019, January). Modeling a Multi-Objective Vehicle Routing  
56 Problem for Monetary Operation in the Banking System. In *2019 15th Iran International Industrial*  
57 *Engineering Conference (IIIEC) (pp. 18-22)*. IEEE.
- 58 Hiassat, A. Diabat, A. and Rahwan, I. (2017), "A genetic algorithm approach for location-inventory-routing  
59 problem with perishable products", *Journal of manufacturing systems*, 42, pp.93-103.
- 60 Jafarian, A. Asgari, N. Mohri, S.S. Fatemi-Sadr, E. and Farahani, R.Z. (2019), "The inventory-routing problem  
subject to vehicle failure", *Transportation Research Part E: Logistics and Transportation Review*, 126,  
pp.254-294.

- 1  
2  
3 Javanmard, S. Vahdani, B. and Tavakkoli-Moghaddam, R. (2014), "Solving a multi-product distribution  
4 planning problem in cross docking networks: An imperialist competitive algorithm", *The International*  
5 *Journal of Advanced Manufacturing Technology*, 70(9-12), pp.1709-1720.
- 6 Kitjacharoenchai, P., Min, B. C., and Lee, S. (2020), "Two echelon vehicle routing problem with drones in last  
7 mile delivery" *International Journal of Production Economics*, 225, 107598.
- 8 Koç, Ç. (2019), "Analysis of vehicle emissions in location-routing problem", *Flexible Services and*  
9 *Manufacturing Journal*, 31(1), pp.1-33.
- 10 Leksakul, K. and Apiromchaiyakul, C. (2019), "Fuzzifying approach to special cutting in poultry meat  
11 production planning", *Journal of Industrial and Production Engineering*, 36(7), pp.419-432.
- 12 Li, Q. and Liu, A. (2019), "Big data driven supply chain management", *Procedia CIRP*, 81, pp.1089-1094.
- 13 Linnemann AR, Hendrix EM, Apaiah R, van Boekel TA (2015), "Food chain design using multi criteria  
14 decision making, an approach to complex design issues" *NJAS-Wagen J Life Sci*, 72-73, pp.13-21.
- 15 Mahdiraji, H.A. Turskis, Z. Jafarnejad, A. and Rezayar, A. (2019), "Non-cooperative two-echelon supply chains  
16 with a focus on social responsibility", *Technological and Economic Development of Economy*, 25(6),  
17 pp.1162-1187.
- 18 Mahdiraji, H. A., Kazimieras Zavadskas, E., Kazeminia, A., & Abbasi Kamardi, A. (2019), "Marketing  
19 strategies evaluation based on big data analysis: a CLUSTERING-MCDM approach", *Economic*  
20 *research-Ekonomiska istraživanja*, 32(1), pp. 2882-2892.
- 21 Mahdiraji, H.A. Hafeez, K. Jafarnejad, A. and Rezayar, A. (2020), "An analysis of the impact of negative CSR  
22 'forced labour' parameter on the profitability of supply chain contracts", *Journal of Cleaner Production*,  
23 p.122274.
- 24 Mahmoudi, M., Mahdiraji, H. A., Jafarnejad, A., & Safari, H. (2019). Dynamic prioritization of equipment and  
25 critical failure modes. *Kybernetes*.
- 26 Miranda, P.A. and Garrido, R.A. (2004), "Incorporating inventory control decisions into a strategic distribution  
27 network design model with stochastic demand", *Transportation Research Part E: Logistics and*  
28 *Transportation Review*, 40(3), pp.183-207.
- 29 Miranda PA, Garrido RA (2009), "Inventory service-level optimization with in distribution network design  
30 problem", *international journal of production economics*, 122(1), pp. 276–285.
- 31 Mirzaei, S. and Seifi, A. (2015), "Considering lost sale in inventory routing problems for perishable goods",  
32 *Computers and Industrial Engineering*, 87, pp.213-227.
- 33 Mohammed, A. and Wang, Q. (2017a), "Developing a meat supply chain network design using a multi-objective  
34 possibilistic programming approach", *British Food Journal*, 119(3), PP.690-706.
- 35 Mohammed, A. and Wang, Q. (2017b), "The fuzzy multi-objective distribution planner for a green meat supply  
36 chain", *International Journal of Production Economics*, 184, pp.47-58.
- 37 Mohebalzadehgashti, F. Zolfagharinia, H. and Amin, S.H. (2020), "Designing a green meat supply chain  
38 network: A multi-objective approach", *International Journal of Production Economics*, 219, pp.312-327.
- 39 Moons, K. Waeyenbergh, G. and Pintelon, L. (2019), "Measuring the logistics performance of internal hospital  
40 supply chains—a literature study", *Omega*, 82, pp.205-217.
- 41 Mosca, A. Vidyarthi, N. and Satir, A. (2019), "Integrated transportation–inventory models: A review",  
42 *Operations Research Perspectives*, 6, p.100101.
- 43 Motevalli-Taher, F., Paydar, M. M., and Emami, S. (2020), "Wheat sustainable supply chain network design  
44 with forecasted demand by simulation", *Computers and Electronics in Agriculture*, 178, 105763.
- 45 Mousavi SM, Tavakkoli-Moghaddam R (2013), "A Hybrid Simulated Annealing Algorithm for Location and  
46 Routing Scheduling Problems With Cross-Docking in the Supply Chain", *Journal of Manufacturing*  
47 *systems*, 32(2), pp. 335-347.
- 48 Nayeri, S., Paydar, M. M., Asadi-Gangraj, E., and Emami, S. (2020), "Multi-objective fuzzy robust optimization  
49 approach to sustainable closed-loop supply chain network design", *Computers and Industrial*  
50 *Engineering*, 148, 106716.
- 51 Neves-Moreira, F. Almada-Lobo, B. Cordeau, J.F. Guimarães, L. and Jans, R. (2019), "Solving a large multi-  
52 product production-routing problem with delivery time windows", *Omega*, 86, pp.154-172.
- 53 Orjuela-Castro, J.A. Sanabria-Coronado, L.A. and Peralta-Lozano, A.M. (2017), "Coupling facility location  
54 models in the supply chain of perishable fruits", *Research in transportation business and management*, 24,  
55 pp.73-80.
- 56 Pirkul H, Jayaraman V., (1996), "Production, Transportation and Distribution Planning in a Multi-Commodity  
57 Tri-Echelon System", *Transportation Science*, 30(4), pp. 291-302.
- 58 Pishvae MS, Rabbani M (2011), "A graph theoretic-based heuristic algorithm for responsive supply chain  
59 network design with direct and indirect shipment", *Advanced engineering software*, 42(3), pp. 57–63.
- 60 Rahbari, M. Naderi, B. and Mohammadi, M. (2018), "Modelling and Solving the Inventory Routing Problem  
with CO 2 Emissions Consideration and Transshipment Option", *Environmental Processes*, 5(3), pp.649-  
665.

- 1  
2  
3 Rahbari, M. Hajiagha, S.H.R. Dehaghi, M.R. Moallem, M. and Dorcheh, F.R. (2020), "Modeling and solving a  
4 five-echelon location–inventory–routing problem for red meat supply chain", *Kybernetes*, In press.
- 5 Rafie-Majd, Z. Pasandideh, S.H.R. and Naderi, B. (2018), "Modelling and solving the integrated inventory-  
6 location-routing problem in a multi-period and multi-perishable product supply chain with uncertainty:  
7 Lagrangian relaxation algorithm", *Computers and chemical engineering*, 109, pp.9-22.
- 8 Saragih, N.I. Bahagia, N. and Syabri, I. (2019), "A heuristic method for location-inventory-routing problem in a  
9 three-echelon supply chain system", *Computers and Industrial Engineering*, 127, pp.875-886.
- 10 Schütz P, Tomasgard A, Ahmed S (2009), "Supply chain design under uncertainty using sample average  
11 approximation and dual decomposition", *European Journal of Operational Research*, 199(2), pp. 409-  
12 419.
- 13 Soysal, M. Bloemhof-Ruwaard, J.M. and Van Der Vorst, J.G. (2014), "Modelling food logistics networks with  
14 emission considerations: The case of an international beef supply chain", *International Journal of  
15 Production Economics*, 152, pp.57-70.
- 16 Tavakkoli-Moghaddam, R. and Raziei, Z. (2016), "A new bi-objective location-routing-inventory problem with  
17 fuzzy demands", *IFAC-PapersOnLine*, 49(12), pp.1116-1121.
- 18 Teigiserova, D.A. Hamelin, L. and Thomsen, M. (2019), "Review of high-value food waste and food residues  
19 biorefineries with focus on unavoidable wastes from processing", *Resources, Conservation and Recycling*,  
20 149, pp.413-426.
- 21 Tirkolaee, E.B. Mardani, A. Dashtian, Z. Soltani, M. and Weber, G.W. (2020), "A novel hybrid method using  
22 fuzzy decision making and multi-objective programming for sustainable-reliable supplier selection in two-  
23 echelon supply chain design", *Journal of Cleaner Production*, 250, p.119517.
- 24 Tsao YC, Mangotra D, Lu JC, Dong M (2012), "A continuous approximation approach for the integrated  
25 facility-inventory allocation problem", *European Journal of Operational Research*, 222(2), pp. 216-228.
- 26 ur Rahman, M.S. and ur Rehman, M.S. (2020), "CPEC and Pakistan-India Economic Integration: Prospects and  
27 Challenges", *Journal of Global Peace and Security Studies (JGPSS)*, 1(1), pp.70-89.
- 28 van Huis, A. and Oonincx, D.G. (2017), "The environmental sustainability of insects as food and feed. A  
29 review", *Agronomy for Sustainable Development*, 37(5), pp.43-60.
- 30 Wang, X. Wang, M. Ruan, J. and Zhan, H. (2016), "The multi-objective optimization for perishable food  
31 distribution route considering temporal-spatial distance", *Procedia Computer Science*, 96, pp.1211-1220.
- 32 Yao, Z. Lee, L.H. Jaruphongsa, W. Tan, V. and Hui, C.F. (2010), "Multi-source facility location–allocation and  
33 inventory problem", *European Journal of Operational Research*, 207(2), pp.750-762.
- 34 Yavari, M. and Geraeli, M. (2019), "Heuristic method for robust optimization model for green closed-loop  
35 supply chain network design of perishable goods", *Journal of Cleaner Production*, 226, pp.282-305.
- 36 Zhao, J. and Ke, G.Y. (2017), "Incorporating inventory risks in location-routing models for explosive waste  
37 management", *International Journal of Production Economics*, 193, pp.123-136.
- 38 Zheng, X. Yin, M. and Zhang, Y. (2019), "Integrated optimization of location, inventory and routing in supply  
39 chain network design", *Transportation Research Part B: Methodological*, 121, pp.1-20.
- 40  
41  
42  
43  
44  
45  
46  
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Table 1. Overview of previous researches

Scholar	Year	Modeling Stages		Objectives			Industry (Supply Chain)	Main Attribute/ Solving Approach
		Single	Multi	I	II	III		
Soysal et al.	2014	*		Inventory and transportation costs (TC)	CO <sub>2</sub> emissions	Transportation operations	Beef	PIAP/εconstraint method
Al Shamsi et al.	2014	*		TC	Inventory cost	CO <sub>2</sub> emissions	Perishable goods	IRP/GAMS
Javanmard et al.	2014	*		Inventory holding cost	TC		Food	SCM/ A heuristic procedure and imperialist competitive algorithm
GonzálezAraya et al.	2015	*		Costs related to workforce	Fruit loss	Costs related to goods	Apple	SCM/CPLEX
Mirzaei and Seifi	2015	*		TC	Costs of lost sales	Costs of holding inventories	Perishable goods	IRP/Simulated annealing and tabu search
TavakkoliMoghaddam and Raziei	2016	*		Total supply chain costs (TSCC)	Shortage of products		Any products	LIRP/GAMS
Wang et al.	2016	*		TSCC	The average freshness of products		Food	VRP/Two phase heuristic algorithm
Mohammed and Wang	2017a	*		TSCC	Number of vehicles	Delivery time	Meat	LRP/LINGO
Mohammed and Wang	2017b	*		TSCC	Environmental impact	Distribution time and delivery rate	Meat	FLRP/LINGO
OrjuelaCastro et al.	2017	*		Facility location			Perishable fruits	LAP/GAMS
Gholamian and Taghanzadeh	2017	*		TSCC			Wheat	PLIP/GAMS
Zhao and Ke	2017	*		TSCC	Risk		Hazardous products	LIRP/CPLEX
Hiassat et al.	2017	*		Warehouse fixed location cost	Routing cost	Inventory holding cost	Perishable products	LIRP/Genetic algorithm
RafieMajd et al.	2018	*		TSCC			Perishable products	LIRP/Lagrangian relaxation
Rahbari et al.	2018	*		TSCC	CO <sub>2</sub> emissions		Any products	IRP/ Simulated annealing

Scholar	Year	Modeling Stages		Objectives			Industry (Supply Chain)	Main Attribute/ Solving Approach
		Single	Multi	I	II	III		
Zheng et al.	2019	*		TSCC			Passenger car	LIRP/Generalized benders decomposition
Koç	2019	*		Total costs of depots	Costs of drivers	Costs of fuel	Any products	LRP/Adaptive large neighborhood search
Jafarian et al.	2019	*		Routing cost	Inventory holding cost		Any products	IRP/Metaheuristic algorithm
Anderluh et al.	2019		*	Routing cost			Perishable products	VRP/Twostage GRASP
Saragih et al.	2019	*		Fixed warehouse installation costs	TC	Inventory holding cost	Food	LIRP/ Simulated annealing
NevesMoreira et al.	2019	*		Routing cost	Inventory holding cost		Meat	PRP/Metaheuristic algorithm
Cheraghalipour et al.	2019		*	TSCC			Rice	PLIP/Genetic algorithms and particle swarm optimization
Rahbari et al.	2020	*		TSCC			Red meat	PLIRP/GAMS
Mohebalizadehgashti et al.	2020	*		TSCC	CO <sub>2</sub> emissions	Factory utilization	Meat	LAP/augmented $\epsilon$ constraint method
Current Research	2021		*	Fixed and variable transportation costs	Inventory holding and production costs	Costs of opening cold storage facilities	Red meat	ProductionLocationInventoryRouting Problem/GAMS



**Table 2.** The demand for retailers and holding capacity

Retailer	Holding Capacity	Period							Retailer	Holding Capacity	Period						
		t <sub>1</sub>	t <sub>2</sub>	t <sub>3</sub>	t <sub>4</sub>	t <sub>5</sub>	t <sub>6</sub>	t <sub>7</sub>			t <sub>1</sub>	t <sub>2</sub>	t <sub>3</sub>	t <sub>4</sub>	t <sub>5</sub>	t <sub>6</sub>	t <sub>7</sub>
<b>m<sub>1</sub></b>	15	15	15	15	15	15	15	5	<b>m<sub>22</sub></b>	15	15	10					
<b>m<sub>2</sub></b>	10	10	10	10	10	10			<b>m<sub>23</sub></b>	20	20	20	20	20			
<b>m<sub>3</sub></b>	22	22	21	20	20	20	20		<b>m<sub>24</sub></b>	20	20	20	17	10			
<b>m<sub>4</sub></b>	15	15	10	10	10				<b>m<sub>25</sub></b>	10	10	10	7				
<b>m<sub>5</sub></b>	13	13	13	10	10				<b>m<sub>26</sub></b>	20	20	10					
<b>m<sub>6</sub></b>	15	15	10	10	10	10			<b>m<sub>27</sub></b>	36	36	30	30	30			
<b>m<sub>7</sub></b>	15	15	15	15	15	15	10		<b>m<sub>28</sub></b>	13	12	13					
<b>m<sub>8</sub></b>	10	10	10	10	10	10			<b>m<sub>29</sub></b>	10	10	10					
<b>m<sub>9</sub></b>	10	10	10	10	10	10			<b>m<sub>30</sub></b>	22	22	20	20				
<b>m<sub>10</sub></b>	15	15	10						<b>m<sub>31</sub></b>	11	11	10	10				
<b>m<sub>11</sub></b>	10	10	5						<b>m<sub>32</sub></b>	20	20	20	20	12			
<b>m<sub>12</sub></b>	15	15	15	10	10	10	10	10	<b>m<sub>33</sub></b>	10	10	5					
<b>m<sub>13</sub></b>	50	50	35	32	28				<b>m<sub>34</sub></b>	15	15	10					
<b>m<sub>14</sub></b>	10	10	10						<b>m<sub>35</sub></b>	20	20	20	20	10			
<b>m<sub>15</sub></b>	10	10	10	10	6				<b>m<sub>36</sub></b>	20	20	15	10				
<b>m<sub>16</sub></b>	15	15	10	10					<b>m<sub>37</sub></b>	25	25	20	10				
<b>m<sub>17</sub></b>	10	10	10	10	10				<b>m<sub>38</sub></b>	10	10	10					
<b>m<sub>18</sub></b>	20	20	11						<b>m<sub>39</sub></b>	15	15						
<b>m<sub>19</sub></b>	10	10	10	10					<b>m<sub>40</sub></b>	20	20	10	10				
<b>m<sub>20</sub></b>	15	15	10	10	10				<b>m<sub>41</sub></b>	20	20	12					
<b>m<sub>21</sub></b>	10	10	10						<b>m<sub>42</sub></b>	15	15	13					

**Table 3.** Meatpacking facility specifications of the problem

<b>Packing Facility</b>	<b>Inventory Holding Cost (\$)</b>	<b>Warehouse Capacity</b>	<b>Maximum Production Capacity</b>	<b>Fixed Production Cost (\$)</b>	<b>Variable Production Cost (\$)</b>
p <sub>1</sub>	9	4000	900	475	611
p <sub>2</sub>	9	100	300	455	727
p <sub>3</sub>	14	100	600	909	909
p <sub>4</sub>	14	500	900	818	818

Kybernetes

**Table 4.** Trip distances among packing facilities and cold storage facilities (KM)

Node	p <sub>1</sub>	p <sub>2</sub>	p <sub>3</sub>	p <sub>4</sub>	s <sub>1</sub>	s <sub>2</sub>	s <sub>3</sub>	s <sub>4</sub>	s <sub>5</sub>	s <sub>6</sub>	s <sub>7</sub>	s <sub>8</sub>	s <sub>9</sub>	s <sub>10</sub>	s <sub>11</sub>	s <sub>12</sub>
p <sub>1</sub>	0	632	2322	1796	1811	1797	1790	1422	1589	631	1987	1953	1844	1240	690	1488
p <sub>2</sub>	651	0	2008	1482	1496	1481	1476	1226	979	2	1509	1640	1609	1073	754	1172
p <sub>3</sub>	2306	1991	0	612	560	571	612	1188	1488	1991	790	485	923	1387	1781	898
p <sub>4</sub>	1790	1475	617	0	49	45	22	746	879	1477	193	164	794	956	1265	458
s <sub>1</sub>	1804	1489	582	45	0	20	62	724	939	1489	230	130	785	922	1279	433
s <sub>2</sub>	1792	1477	569	42	20	0	50	712	927	1477	232	145	773	910	1267	421
s <sub>3</sub>	1789	1474	630	20	60	53	0	754	876	1474	206	178	791	944	1264	455
s <sub>4</sub>	1399	1217	1200	747	762	747	740	0	1365	1217	938	799	451	200	760	349
s <sub>5</sub>	1616	976	1498	886	927	939	884	1315	0	976	769	1045	1609	1394	1409	1138
s <sub>6</sub>	651	2	2008	1482	1498	1483	1476	1227	981	0	1511	1640	1610	1077	754	1174
s <sub>7</sub>	1978	1504	784	189	226	228	202	934	794	1504	0	332	980	1142	1452	644
s <sub>8</sub>	1939	1624	474	153	122	149	172	788	1030	1596	331	0	849	986	1385	497
s <sub>9</sub>	1765	1620	931	792	786	771	785	449	1600	1620	983	812	0	566	1158	565
s <sub>10</sub>	1215	1070	1394	941	957	942	935	201	1396	1069	1132	993	567	0	576	523
s <sub>11</sub>	676	747	1799	1247	1289	1274	1267	748	1421	747	1465	1431	1154	566	0	965
s <sub>12</sub>	1480	1165	906	454	435	420	447	347	1120	1165	645	506	557	536	955	0

**Table 5.** Trip distances among carcass suppliers and packing facilities (KM)

<b>Node</b>	<b>c<sub>1</sub></b>	<b>c<sub>2</sub></b>	<b>c<sub>3</sub></b>	<b>c<sub>4</sub></b>	<b>c<sub>5</sub></b>	<b>p<sub>1</sub></b>	<b>p<sub>2</sub></b>	<b>p<sub>3</sub></b>	<b>p<sub>4</sub></b>
<b>c<sub>1</sub></b>	0					1806	1584	606	15
<b>c<sub>2</sub></b>		0				1506	1192	880	438
<b>c<sub>3</sub></b>			0			1569	952	1500	890
<b>c<sub>4</sub></b>				0		5	635	2311	1794
<b>c<sub>5</sub></b>					0	628	4	1993	1482
<b>p<sub>1</sub></b>	1800	1502	1565	4	628	0	632	2322	1796
<b>p<sub>2</sub></b>	1492	1187	938	635	3	651	0	2008	1482
<b>p<sub>3</sub></b>	603	889	1489	2326	2007	2306	1991	0	612
<b>p<sub>4</sub></b>	12	437	878	1800	1476	1790	1475	617	0

Kybernetes

**Table 6.** Trip distances among cold storage facilities and retailers (KM)

<b>Node</b>	<b>S<sub>1</sub></b>	<b>S<sub>2</sub></b>	<b>S<sub>3</sub></b>	<b>S<sub>4</sub></b>	<b>S<sub>5</sub></b>	<b>S<sub>6</sub></b>	<b>S<sub>7</sub></b>	<b>S<sub>8</sub></b>	<b>S<sub>9</sub></b>	<b>S<sub>10</sub></b>	<b>S<sub>11</sub></b>	<b>S<sub>12</sub></b>
<b>m<sub>1</sub></b>	44	47	32	758	880	1487	190	156	803	957	1274	467
<b>m<sub>2</sub></b>	59	57	31	762	874	1492	190	177	809	962	1280	473
<b>m<sub>3</sub></b>	37	42	36	758	893	1487	199	147	801	957	1288	452
<b>m<sub>4</sub></b>	53	58	37	766	881	1492	188	160	818	966	1284	473
<b>m<sub>5</sub></b>	33	40	34	755	891	1485	205	146	799	955	1273	466
<b>m<sub>6</sub></b>	47	45	19	750	876	1479	191	164	796	949	1267	460
<b>m<sub>7</sub></b>	59	55	32	762	877	1491	186	168	809	961	1280	472
<b>m<sub>8</sub></b>	44	50	35	760	892	1489	194	153	806	959	1277	470
<b>m<sub>9</sub></b>	63	63	43	773	888	1502	183	163	819	972	1290	483
<b>m<sub>10</sub></b>	42	46	40	755	887	1485	192	152	802	950	1273	466
<b>m<sub>11</sub></b>	93	91	44	727	852	1456	230	210	775	926	1244	437
<b>m<sub>12</sub></b>	24	41	75	762	932	1526	233	111	807	996	1314	455
<b>m<sub>13</sub></b>	934	939	890	1292	30	952	813	1051	1615	1371	1395	1141
<b>m<sub>14</sub></b>	768	773	725	1239	241	1111	517	886	1450	1364	1486	1007
<b>m<sub>15</sub></b>	1146	1131	1124	1008	522	458	1052	1287	1387	1086	1047	862
<b>m<sub>16</sub></b>	318	320	295	1026	679	1432	80	424	1073	1225	1388	737
<b>m<sub>17</sub></b>	162	147	140	575	955	1364	338	257	658	774	1153	285
<b>m<sub>18</sub></b>	125	142	176	781	1033	1584	335	8	842	979	1372	490
<b>m<sub>19</sub></b>	312	329	363	920	1220	1724	522	190	823	1119	1512	630
<b>m<sub>20</sub></b>	304	321	354	950	1211	1753	288	182	924	1148	1541	659
<b>m<sub>21</sub></b>	451	455	428	1089	547	1307	213	557	1242	1214	1397	803
<b>m<sub>22</sub></b>	259	264	215	892	662	1371	231	376	940	1091	1230	602
<b>m<sub>23</sub></b>	744	761	794	1352	1652	2155	953	622	1005	1550	1943	1061
<b>m<sub>24</sub></b>	599	589	649	1207	1507	2010	808	477	1120	1405	1798	916
<b>m<sub>25</sub></b>	649	634	665	878	1543	1814	854	596	434	995	1534	658
<b>m<sub>26</sub></b>	567	558	618	1175	1475	1978	558	445	1089	1374	1767	885
<b>m<sub>27</sub></b>	430	416	435	321	1139	1184	641	502	531	501	925	37
<b>m<sub>28</sub></b>	1049	1034	1027	295	1666	1360	1224	1086	475	305	744	635
<b>m<sub>29</sub></b>	519	504	531	268	1335	1280	728	590	487	457	968	131
<b>m<sub>30</sub></b>	799	783	798	430	1612	1602	995	824	22	548	1106	547
<b>m<sub>31</sub></b>	1486	1472	1465	1216	969	9	1500	1628	1599	1064	722	1163
<b>m<sub>32</sub></b>	940	925	918	182	1379	1076	1116	976	547	22	580	507
<b>m<sub>33</sub></b>	764	748	742	6	1317	1217	939	801	446	195	753	350
<b>m<sub>34</sub></b>	471	455	486	1009	1364	1812	675	417	598	1216	1600	718
<b>m<sub>35</sub></b>	478	463	494	786	892	1779	683	425	473	959	1277	587
<b>m<sub>36</sub></b>	998	982	976	727	938	519	1173	1139	1110	574	496	673
<b>m<sub>37</sub></b>	468	453	467	611	1281	1565	664	493	316	860	1285	409
<b>m<sub>38</sub></b>	267	252	267	561	1081	1490	464	338	525	785	1279	302
<b>m<sub>39</sub></b>	564	581	614	1172	1471	1975	773	442	938	1370	1763	881
<b>m<sub>40</sub></b>	1286	1270	1264	768	1417	726	1461	1427	1168	585	2	961
<b>m<sub>41</sub></b>	301	286	317	731	1195	1643	506	248	568	1038	1431	549
<b>m<sub>42</sub></b>	625	610	603	386	931	870	801	767	768	464	658	301

**Table 7.** Trip distances among packing facilities and retailers (KM)

<b>Node</b>	<b>p<sub>1</sub></b>	<b>p<sub>2</sub></b>	<b>p<sub>3</sub></b>	<b>p<sub>4</sub></b>	<b>Node</b>	<b>p<sub>1</sub></b>	<b>p<sub>2</sub></b>	<b>p<sub>3</sub></b>	<b>p<sub>4</sub></b>
<b>m<sub>1</sub></b>	1802	1487	608	13	<b>m<sub>22</sub></b>	1757	1371	829	217
<b>m<sub>2</sub></b>	1806	1492	629	18	<b>m<sub>23</sub></b>	2470	2155	188	775
<b>m<sub>3</sub></b>	1802	1489	600	30	<b>m<sub>24</sub></b>	2325	2010	121	630
<b>m<sub>4</sub></b>	1810	1496	613	22	<b>m<sub>25</sub></b>	2129	1814	621	663
<b>m<sub>5</sub></b>	1799	1485	598	15	<b>m<sub>26</sub></b>	2293	1978	328	599
<b>m<sub>6</sub></b>	1794	1479	616	6	<b>m<sub>27</sub></b>	1499	1184	894	441
<b>m<sub>7</sub></b>	1806	1491	620	18	<b>m<sub>28</sub></b>	1403	1360	1397	1033
<b>m<sub>8</sub></b>	1804	1489	606	16	<b>m<sub>29</sub></b>	1595	1280	990	537
<b>m<sub>9</sub></b>	1817	1502	616	29	<b>m<sub>30</sub></b>	1747	1602	943	804
<b>m<sub>10</sub></b>	1799	1485	604	12	<b>m<sub>31</sub></b>	651	9	1997	1471
<b>m<sub>11</sub></b>	1771	1456	663	55	<b>m<sub>32</sub></b>	1221	1076	1377	930
<b>m<sub>12</sub></b>	1841	1526	563	56	<b>m<sub>33</sub></b>	1394	1217	1201	748
<b>m<sub>13</sub></b>	1592	952	1504	892	<b>m<sub>34</sub></b>	2127	1812	326	484
<b>m<sub>14</sub></b>	1751	1111	1338	727	<b>m<sub>35</sub></b>	1804	1489	461	492
<b>m<sub>15</sub></b>	1098	458	1656	1130	<b>m<sub>36</sub></b>	834	519	1508	982
<b>m<sub>16</sub></b>	1915	1432	874	279	<b>m<sub>37</sub></b>	1880	1565	628	473
<b>m<sub>17</sub></b>	1679	1352	658	147	<b>m<sub>38</sub></b>	1805	1490	612	273
<b>m<sub>18</sub></b>	1899	1584	462	157	<b>m<sub>39</sub></b>	2290	1975	18	595
<b>m<sub>19</sub></b>	2038	1724	276	344	<b>m<sub>40</sub></b>	655	724	1795	1270
<b>m<sub>20</sub></b>	2068	1753	472	335	<b>m<sub>41</sub></b>	1958	1643	444	315
<b>m<sub>21</sub></b>	1923	1307	1011	416	<b>m<sub>42</sub></b>	1185	870	1135	609

**Table 8.** Transferred red meat among nodes

Node	Vehicle	Period							Node	Vehicle	Period								
		t <sub>1</sub>	t <sub>2</sub>	t <sub>3</sub>	t <sub>4</sub>	t <sub>5</sub>	t <sub>6</sub>	t <sub>7</sub>			t <sub>1</sub>	t <sub>2</sub>	t <sub>3</sub>	t <sub>4</sub>	t <sub>5</sub>	t <sub>6</sub>	t <sub>7</sub>		
c <sub>5</sub>	p <sub>1</sub>	v <sub>1</sub>	817.5	98.75	20					p <sub>2</sub>	m <sub>5</sub>	v <sub>1</sub>	20						
c <sub>5</sub>	p <sub>2</sub>	v <sub>1</sub>	375	375	375	357.5	80	40		p <sub>2</sub>	m <sub>6</sub>	v <sub>1</sub>							20
p <sub>1</sub>	m <sub>1</sub>	v <sub>1</sub>	15							p <sub>2</sub>	m <sub>7</sub>	v <sub>2</sub>			10				
p <sub>1</sub>	m <sub>2</sub>	v <sub>1</sub>	20							p <sub>2</sub>	m <sub>7</sub>	v <sub>1</sub>						20	20
p <sub>1</sub>	m <sub>3</sub>	v <sub>1</sub>	40							p <sub>2</sub>	m <sub>8</sub>	v <sub>2</sub>			10				
p <sub>1</sub>	m <sub>4</sub>	v <sub>1</sub>	15							p <sub>2</sub>	m <sub>8</sub>	v <sub>1</sub>	20						20
p <sub>1</sub>	m <sub>5</sub>	v <sub>1</sub>	16							p <sub>2</sub>	m <sub>9</sub>	v <sub>2</sub>			10				
p <sub>1</sub>	m <sub>6</sub>	v <sub>1</sub>	15	20						p <sub>2</sub>	m <sub>9</sub>	v <sub>1</sub>							20
p <sub>1</sub>	m <sub>7</sub>	v <sub>1</sub>	15	20						p <sub>2</sub>	m <sub>10</sub>	v <sub>2</sub>		5					
p <sub>1</sub>	m <sub>9</sub>	v <sub>1</sub>	20							p <sub>2</sub>	m <sub>11</sub>	v <sub>1</sub>	15						
p <sub>1</sub>	m <sub>10</sub>	v <sub>1</sub>	20							p <sub>2</sub>	m <sub>12</sub>	v <sub>1</sub>		20					20
p <sub>1</sub>	m <sub>12</sub>	v <sub>1</sub>	20							p <sub>2</sub>	m <sub>13</sub>	v <sub>2</sub>		5					
p <sub>1</sub>	m <sub>17</sub>	v <sub>1</sub>	20							p <sub>2</sub>	m <sub>13</sub>	v <sub>1</sub>	60	20	40	20			
p <sub>1</sub>	m <sub>18</sub>	v <sub>1</sub>	31							p <sub>2</sub>	m <sub>14</sub>	v <sub>1</sub>	20						
p <sub>1</sub>	m <sub>19</sub>	v <sub>1</sub>	20							p <sub>2</sub>	m <sub>15</sub>	v <sub>1</sub>	20		16				
p <sub>1</sub>	m <sub>20</sub>	v <sub>1</sub>	20							p <sub>2</sub>	m <sub>16</sub>	v <sub>1</sub>	15	20					
p <sub>1</sub>	m <sub>25</sub>	v <sub>1</sub>	20							p <sub>2</sub>	m <sub>17</sub>	v <sub>1</sub>							20
p <sub>1</sub>	m <sub>27</sub>	v <sub>1</sub>	36							p <sub>2</sub>	m <sub>19</sub>	v <sub>2</sub>							10
p <sub>1</sub>	m <sub>28</sub>	v <sub>2</sub>	5							p <sub>2</sub>	m <sub>20</sub>	v <sub>2</sub>		5					
p <sub>1</sub>	m <sub>28</sub>	v <sub>1</sub>	20							p <sub>2</sub>	m <sub>20</sub>	v <sub>1</sub>							20
p <sub>1</sub>	m <sub>29</sub>	v <sub>1</sub>	20							p <sub>2</sub>	m <sub>21</sub>	v <sub>1</sub>	20						
p <sub>1</sub>	m <sub>30</sub>	v <sub>2</sub>	2							p <sub>2</sub>	m <sub>22</sub>	v <sub>2</sub>		5					
p <sub>1</sub>	m <sub>30</sub>	v <sub>1</sub>	40							p <sub>2</sub>	m <sub>22</sub>	v <sub>1</sub>	20						
p <sub>1</sub>	m <sub>32</sub>	v <sub>1</sub>	20	20	20					p <sub>2</sub>	m <sub>23</sub>	v <sub>1</sub>	20	20	20	20			
p <sub>1</sub>	m <sub>33</sub>	v <sub>1</sub>	15							p <sub>2</sub>	m <sub>24</sub>	v <sub>2</sub>							10
p <sub>1</sub>	m <sub>34</sub>	v <sub>1</sub>	20							p <sub>2</sub>	m <sub>24</sub>	v <sub>1</sub>	20	20	17				
p <sub>1</sub>	m <sub>36</sub>	v <sub>1</sub>	20	15						p <sub>2</sub>	m <sub>25</sub>	v <sub>2</sub>							7
p <sub>1</sub>	m <sub>37</sub>	v <sub>1</sub>	35							p <sub>2</sub>	m <sub>26</sub>	v <sub>2</sub>		10					
p <sub>1</sub>	m <sub>38</sub>	v <sub>1</sub>	20							p <sub>2</sub>	m <sub>26</sub>	v <sub>1</sub>	20						
p <sub>1</sub>	m <sub>39</sub>	v <sub>1</sub>	15							p <sub>2</sub>	m <sub>27</sub>	v <sub>2</sub>							10
p <sub>1</sub>	m <sub>40</sub>	v <sub>1</sub>	40							p <sub>2</sub>	m <sub>27</sub>	v <sub>1</sub>		40	20	20			
p <sub>1</sub>	m <sub>41</sub>	v <sub>1</sub>	20							p <sub>2</sub>	m <sub>30</sub>	v <sub>1</sub>							20
p <sub>1</sub>	m <sub>42</sub>	v <sub>1</sub>	19							p <sub>2</sub>	m <sub>31</sub>	v <sub>1</sub>	16	15					
p <sub>2</sub>	m <sub>1</sub>	v <sub>1</sub>		20	20	20		20		p <sub>2</sub>	m <sub>32</sub>	v <sub>1</sub>							12
p <sub>2</sub>	m <sub>2</sub>	v <sub>2</sub>			10					p <sub>2</sub>	m <sub>34</sub>	v <sub>2</sub>	5						
p <sub>2</sub>	m <sub>2</sub>	v <sub>1</sub>				20				p <sub>2</sub>	m <sub>35</sub>	v <sub>2</sub>							10
p <sub>2</sub>	m <sub>3</sub>	v <sub>2</sub>		3						p <sub>2</sub>	m <sub>35</sub>	v <sub>1</sub>	20	20	20				
p <sub>2</sub>	m <sub>3</sub>	v <sub>1</sub>			20	20	40			p <sub>2</sub>	m <sub>36</sub>	v <sub>2</sub>							10
p <sub>2</sub>	m <sub>4</sub>	v <sub>2</sub>				10				p <sub>2</sub>	m <sub>37</sub>	v <sub>1</sub>		20					
p <sub>2</sub>	m <sub>4</sub>	v <sub>1</sub>		20						p <sub>2</sub>	m <sub>41</sub>	v <sub>1</sub>			12				
p <sub>2</sub>	m <sub>5</sub>	v <sub>2</sub>				10				p <sub>2</sub>	m <sub>42</sub>	v <sub>2</sub>	9						

**Table 9.** The inventory level in nodes

Node	Period							Node	Period						
	t <sub>1</sub>	t <sub>2</sub>	t <sub>3</sub>	t <sub>4</sub>	t <sub>5</sub>	t <sub>6</sub>	t <sub>7</sub>		t <sub>1</sub>	t <sub>2</sub>	t <sub>3</sub>	t <sub>4</sub>	t <sub>5</sub>	t <sub>6</sub>	t <sub>7</sub>
<b>p<sub>1</sub></b>		4						<b>m<sub>21</sub></b>	10						
<b>p<sub>2</sub></b>				4	8			<b>m<sub>22</sub></b>	5						
<b>m<sub>1</sub></b>		5	10	15		5		<b>m<sub>23</sub></b>							
<b>m<sub>2</sub></b>	10			10				<b>m<sub>24</sub></b>							
<b>m<sub>3</sub></b>	18				20			<b>m<sub>25</sub></b>	10						
<b>m<sub>4</sub></b>		10						<b>m<sub>26</sub></b>							
<b>m<sub>5</sub></b>	3	10						<b>m<sub>27</sub></b>		10					
<b>m<sub>6</sub></b>		10		10				<b>m<sub>28</sub></b>	13						
<b>m<sub>7</sub></b>		5		5	10			<b>m<sub>29</sub></b>	10						
<b>m<sub>8</sub></b>	10			10				<b>m<sub>30</sub></b>	20						
<b>m<sub>9</sub></b>	10			10				<b>m<sub>31</sub></b>	5	10					
<b>m<sub>10</sub></b>	5							<b>m<sub>32</sub></b>							
<b>m<sub>11</sub></b>	5							<b>m<sub>33</sub></b>	5						
<b>m<sub>12</sub></b>	5	10		10		10		<b>m<sub>34</sub></b>	10						
<b>m<sub>13</sub></b>	10		8					<b>m<sub>35</sub></b>							
<b>m<sub>14</sub></b>	10							<b>m<sub>36</sub></b>							
<b>m<sub>15</sub></b>	10		6					<b>m<sub>37</sub></b>	10	10					
<b>m<sub>16</sub></b>		10						<b>m<sub>38</sub></b>	10						
<b>m<sub>17</sub></b>	10		10					<b>m<sub>39</sub></b>							
<b>m<sub>18</sub></b>	11							<b>m<sub>40</sub></b>	20	10					
<b>m<sub>19</sub></b>	10							<b>m<sub>41</sub></b>							
<b>m<sub>20</sub></b>	5		10					<b>m<sub>42</sub></b>	13						



**Table 10.** Transferred red meat among nodes (Scenario 2)

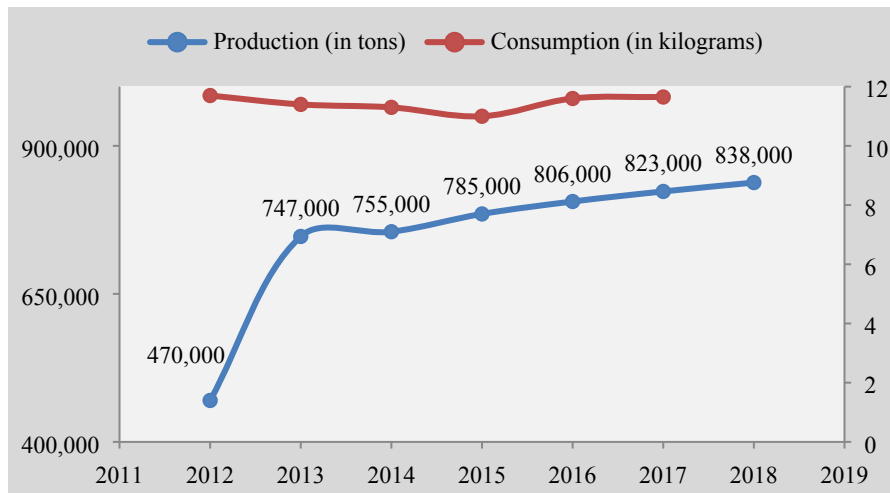
Node	Vehicle	Period						
		t <sub>1</sub>	t <sub>2</sub>	t <sub>3</sub>	t <sub>4</sub>	t <sub>5</sub>	t <sub>6</sub>	t <sub>7</sub>
c <sub>5</sub> p <sub>1</sub>	v <sub>1</sub>	476.25	318.75	100				
c <sub>5</sub> p <sub>2</sub>	v <sub>1</sub>	375	375	375	320	120	60	18.75
p <sub>1</sub> m <sub>3</sub>	v <sub>1</sub>	22	21	20				
p <sub>1</sub> m <sub>5</sub>	v <sub>1</sub>		13					
p <sub>1</sub> m <sub>6</sub>	v <sub>1</sub>	15						
p <sub>1</sub> m <sub>7</sub>	v <sub>1</sub>	15	15	15				
p <sub>1</sub> m <sub>10</sub>	v <sub>1</sub>	15						
p <sub>1</sub> m <sub>12</sub>	v <sub>1</sub>	15	15					
p <sub>1</sub> m <sub>18</sub>	v <sub>1</sub>	20						
p <sub>1</sub> m <sub>20</sub>	v <sub>1</sub>	15						
p <sub>1</sub> m <sub>23</sub>	v <sub>1</sub>	20						
p <sub>1</sub> m <sub>24</sub>	v <sub>1</sub>	20	20					
p <sub>1</sub> m <sub>27</sub>	v <sub>1</sub>	36	30					
p <sub>1</sub> m <sub>28</sub>	v <sub>1</sub>	12	13					
p <sub>1</sub> m <sub>30</sub>	v <sub>1</sub>	22	20	20				
p <sub>1</sub> m <sub>32</sub>	v <sub>1</sub>	20	20	20				
p <sub>1</sub> m <sub>33</sub>	v <sub>2</sub>	10	5					
p <sub>1</sub> m <sub>34</sub>	v <sub>1</sub>	15						
p <sub>1</sub> m <sub>35</sub>	v <sub>1</sub>	20	20					
p <sub>1</sub> m <sub>36</sub>	v <sub>1</sub>	20	15					
p <sub>1</sub> m <sub>37</sub>	v <sub>1</sub>	14	20					
p <sub>1</sub> m <sub>40</sub>	v <sub>2</sub>		10	10				
p <sub>1</sub> m <sub>40</sub>	v <sub>1</sub>	20						
p <sub>1</sub> m <sub>41</sub>	v <sub>1</sub>	20						
p <sub>1</sub> m <sub>42</sub>	v <sub>1</sub>	15	13					
p <sub>2</sub> m <sub>1</sub>	v <sub>1</sub>	15	15	15	15	15	15	
p <sub>2</sub> m <sub>1</sub>	v <sub>2</sub>							5
p <sub>2</sub> m <sub>2</sub>	v <sub>2</sub>	10	10	10	10	10		
p <sub>2</sub> m <sub>3</sub>	v <sub>1</sub>				20	20	20	
p <sub>2</sub> m <sub>4</sub>	v <sub>2</sub>		10	10	10			
p <sub>2</sub> m <sub>4</sub>	v <sub>1</sub>	15						
p <sub>2</sub> m <sub>5</sub>	v <sub>2</sub>			10	10			
p <sub>2</sub> m <sub>5</sub>	v <sub>1</sub>	13						
p <sub>2</sub> m <sub>6</sub>	v <sub>2</sub>		10	10	10	10		
p <sub>2</sub> m <sub>7</sub>	v <sub>2</sub>						10	
p <sub>2</sub> m <sub>7</sub>	v <sub>1</sub>				15	15		
p <sub>2</sub> m <sub>8</sub>	v <sub>2</sub>	10	10	10	10	10		
p <sub>2</sub> m <sub>9</sub>	v <sub>2</sub>	10	10	10	10	10		
p <sub>2</sub> m <sub>10</sub>	v <sub>2</sub>		10					
p <sub>2</sub> m <sub>11</sub>	v <sub>2</sub>	10	5		20			
p <sub>2</sub> m <sub>12</sub>	v <sub>2</sub>							10
p <sub>2</sub> m <sub>12</sub>	v <sub>2</sub>			10	10	10	10	
p <sub>2</sub> m <sub>13</sub>	v <sub>1</sub>	50	35	32	28			
p <sub>2</sub> m <sub>14</sub>	v <sub>2</sub>	10	10					
p <sub>2</sub> m <sub>15</sub>	v <sub>2</sub>	10	10	10	6			
p <sub>2</sub> m <sub>16</sub>	v <sub>2</sub>		10	10				
p <sub>2</sub> m <sub>16</sub>	v <sub>1</sub>	15						
p <sub>2</sub> m <sub>17</sub>	v <sub>2</sub>	10	10	10	10			
p <sub>2</sub> m <sub>18</sub>	v <sub>2</sub>		11					
p <sub>2</sub> m <sub>19</sub>	v <sub>2</sub>	10	10	10				
p <sub>2</sub> m <sub>20</sub>	v <sub>2</sub>		10	10	10			
p <sub>2</sub> m <sub>21</sub>	v <sub>2</sub>	10	10					
p <sub>2</sub> m <sub>22</sub>	v <sub>2</sub>		10					
p <sub>2</sub> m <sub>22</sub>	v <sub>1</sub>	15						
p <sub>2</sub> m <sub>23</sub>	v <sub>1</sub>		20	20	20			

Node	Vehicle	Period						
		$t_1$	$t_2$	$t_3$	$t_4$	$t_5$	$t_6$	$t_7$
$p_2$	$m_{24}$	$v_2$				10		
$p_2$	$m_{24}$	$v_1$			17			
$p_2$	$m_{25}$	$v_2$	10	10	7			
$p_2$	$m_{26}$	$v_2$		10				
$p_2$	$m_{26}$	$v_1$	20					
$p_2$	$m_{27}$	$v_1$			30	30		
$p_2$	$m_{29}$	$v_2$	10	10				
$p_2$	$m_{31}$	$v_2$		10	10			
$p_2$	$m_{31}$	$v_1$	11					
$p_2$	$m_{32}$	$v_2$				12		
$p_2$	$m_{34}$	$v_2$		10				
$p_2$	$m_{35}$	$v_2$				10		
$p_2$	$m_{35}$	$v_1$			20			
$p_2$	$m_{36}$	$v_2$			10			
$p_2$	$m_{37}$	$v_2$			10			
$p_2$	$m_{37}$	$v_1$	11					
$p_2$	$m_{38}$	$v_2$	10	10				
$p_2$	$m_{39}$	$v_1$	15					
$p_2$	$m_{41}$	$v_1$		12				

**Table 11.** Transferred red meat among nodes (Scenario 3)

Node	Vehicle	Period						
		t <sub>1</sub>	t <sub>2</sub>	t <sub>3</sub>	t <sub>4</sub>	t <sub>5</sub>	t <sub>6</sub>	t <sub>7</sub>
c <sub>2</sub>	p <sub>1</sub> v <sub>1</sub>	277.5						
c <sub>2</sub>	p <sub>2</sub> v <sub>1</sub>	15						
c <sub>3</sub>	p <sub>1</sub> v <sub>1</sub>	240						
c <sub>3</sub>	p <sub>2</sub> v <sub>1</sub>	60						
c <sub>4</sub>	p <sub>1</sub> v <sub>1</sub>	300	98.75	20				
c <sub>4</sub>	p <sub>2</sub> v <sub>1</sub>		75	75	52.5			
c <sub>5</sub>	p <sub>1</sub> v <sub>2</sub>							10
c <sub>5</sub>	p <sub>2</sub> v <sub>1</sub>	300	300	300	300	75	40	

Kybernetes



**Figure 1.** Meat production and consumption in Iran

Kybernetes

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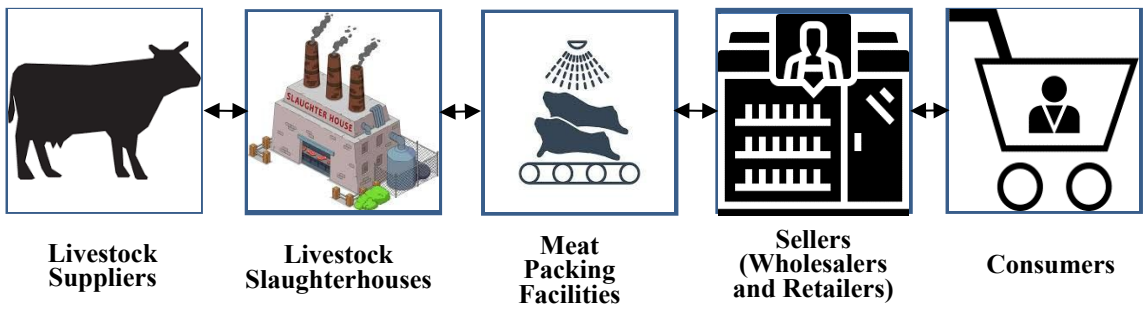
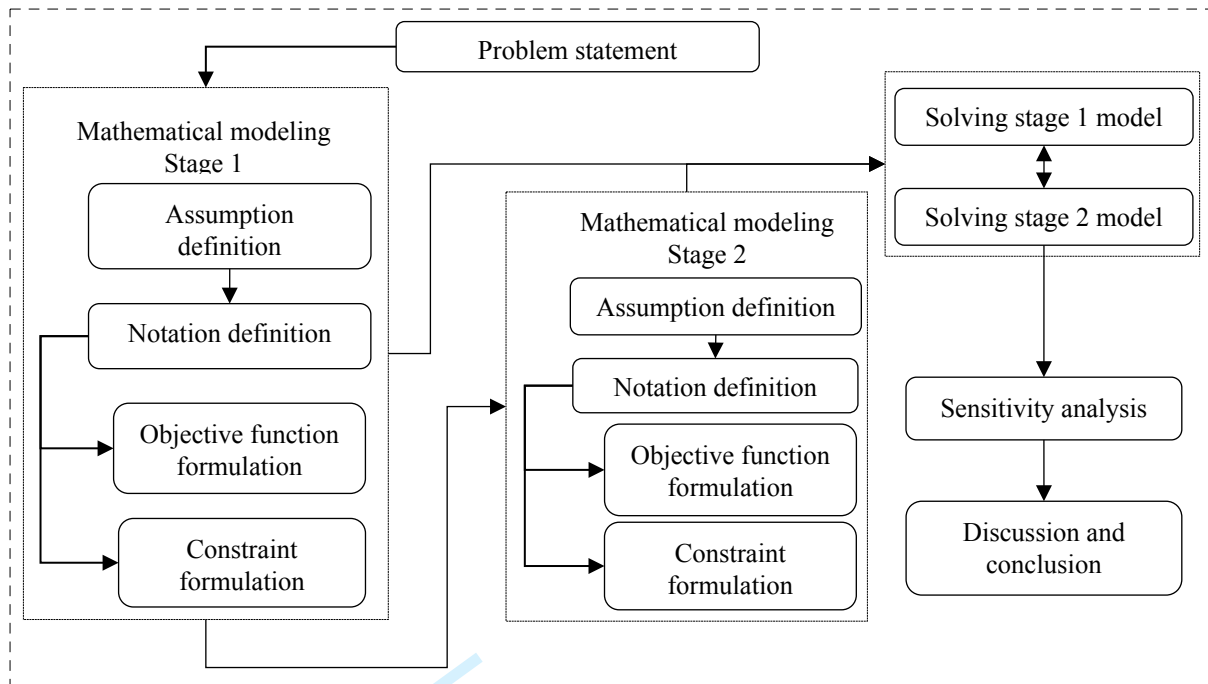


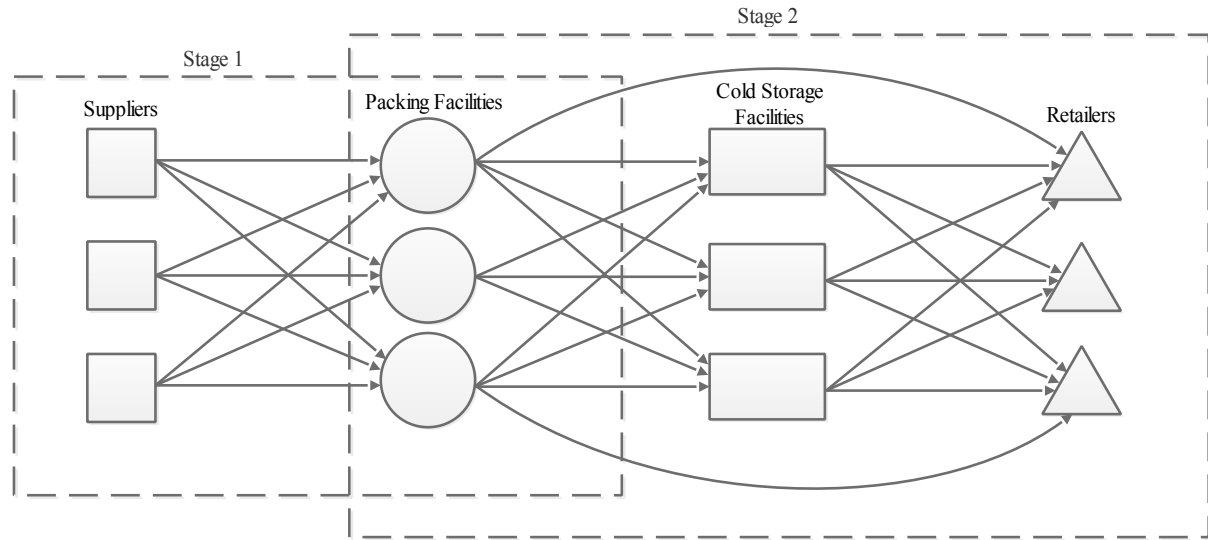
Figure 2. Red meat supply chain

Kybernetes



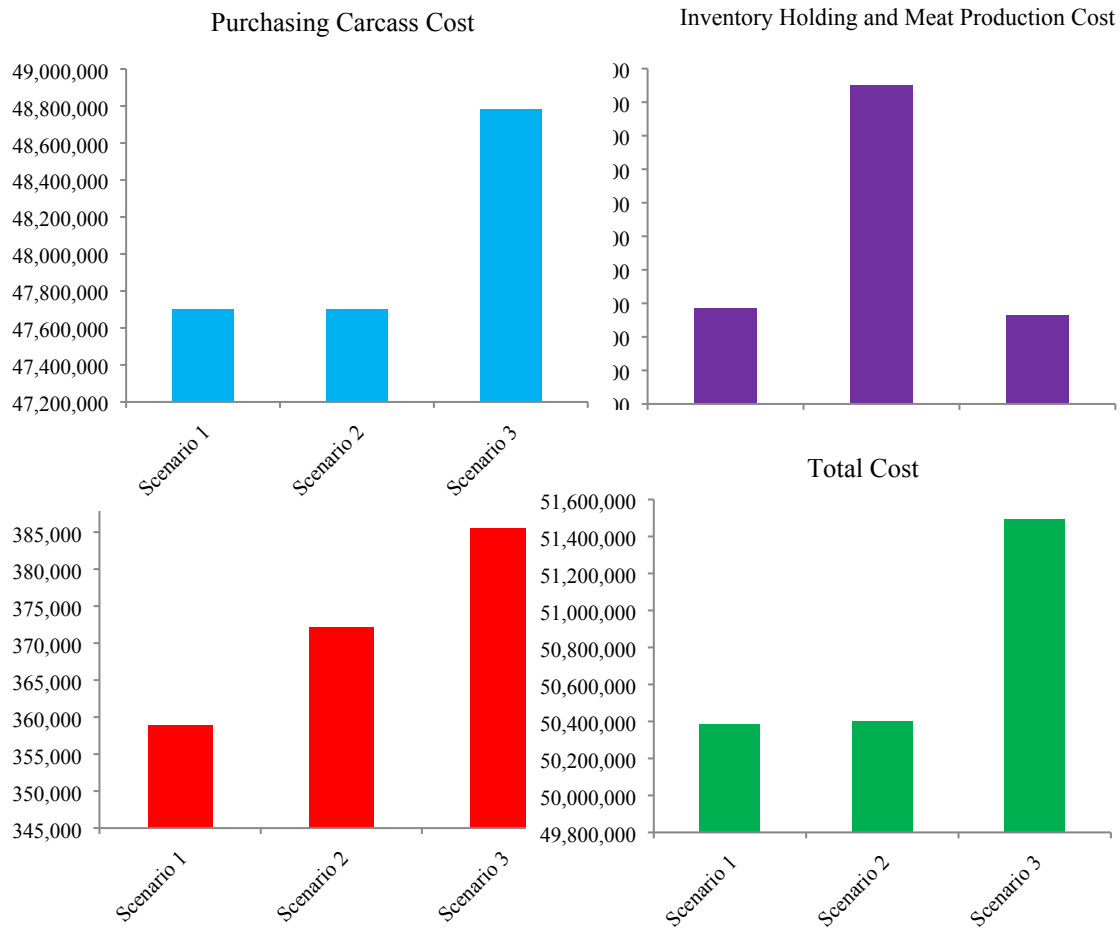
**Figure 3.** The algorithmic scheme of the study

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**Figure 4.** Red meat supply chain network of this research

Kybernetes



**Figure 5.** Comparison of the outcomes of the three scenarios