



## A Closed-loop Supply Chain Network Design Problem in Copper Industry

M. Akbari-Kasgari<sup>a</sup>, H. Khademi-Zare<sup>\*a</sup>, M.B. Fakhrezad<sup>a</sup>, M. Hajiaghahi-Keshteli<sup>b</sup>, M. Honarvar<sup>a</sup>

<sup>a</sup> Department of Industrial Engineering, Yazd University, Yazd, Iran

<sup>b</sup> Department of Industrial Engineering, University of Science and Technology of Mazandaran, Behshahr, Iran

### PAPER INFO

#### Paper history:

Received 05 June 2020

Received in revised form 02 September 2020

Accepted 03 September 2020

#### Keywords:

Mathematical Programming

Closed-loop Supply Chain

Copper Industry

Network Design

### ABSTRACT

Undoubtedly, metals are the basis of the sustainable development of all human societies. In the last century, the role of copper, as the third most widely used metal, after steel and aluminum, has been crucial. Copper is a recyclable metal. It has many applications such as industrial electricity, plumping, wiring, electronic equipment, transportation, and infrastructure. Today, with the growth of the industry in societies, the demand for copper has increased. This motivated us to study its supply chain network design firstly. To the best of our knowledge, there is no research reported about copper supply chain network design. This paper aims to maximize the profit of the copper closed-loop supply chain. We formulate this network design problem as a Mixed Integer Programming model. The model is considered as single-objective and multi-product. The exact solution of the model is found by using GAMS software. Sensitivity analysis results provide useful results that managers can use them in decisions.

doi: 10.5829/ije.2020.33.10a.19

## 1. INTRODUCTION

Industrial development has increased demands for basic metals such as steel, aluminium, copper, zinc, etc. [1]. Special features of copper make it a vital material for various sectors such as transportation, industrial electricity, plumping, wiring, electronic equipment, and infrastructure [2]. Today, copper demand growth is more than its supply growth. The reason for this matter is economic growth and population increase [2]. Therefore, the supply and demand management of copper and its products is an important issue that can be used as the concept of supply chain management.

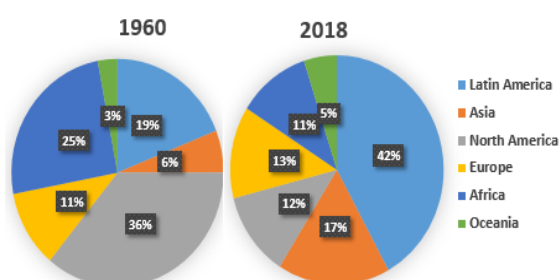
Supply chain management is an approach that coordinates suppliers, manufactures, distributors, and retailers in order to satisfy the needs of customers as much as possible. In the meantime, the goal is to satisfy the proper service level [3]. Decisions in the supply chain are divided into three phases: strategic, tactical, and operational. In recent years, network design, which is one of the strategic level decisions, has become the most important issue due to competition in the world market.

Traditional network design in the supply chain determines the structure, number, and capacity of facilities. It also specifies the mode of transportation and the type of communication [4]. Reverse Logistics (RL) is a noticeable topic in developed countries. RL is concerned with returned product flow; while the Closed-Loop Supply Chain (CLSC) considers forward and backward flows [5]. Utilizing CLSC can be a way to achieve sustainable development goals in the industrial area. Many studies on the CLSC area have been done in various cases such as citrus [5], faucet [6], gold [7], tire [8], and oil [9] industries.

In mining industries, the use of metals such as copper and its products is increased with the development of industrial infrastructure in countries. Copper can be recycled again and again without losing its original properties.

Figure 1 shows copper mine production by region, 1960 versus 2018. In this figure, the production of different regions has changed over time. For example, the share of Latin American production in this period increased from 19 to 42%. The reason for the increase is

\*Corresponding Author Institutional Email: [hkhademiz@yazd.ac.ir](mailto:hkhademiz@yazd.ac.ir) (H. Khademi-Zare)



**Figure 1.** Copper mine production by Region, 1960 versus 2018 (ICSG)

the discovery of copper mines in Chile and Peru. These two countries are the largest copper producers in the world, located in Latin America. Production in Latin America in 1960 was less than 750,000 tones, but in 2018 it reached 8.7 million tones (The World Copper Factbook 2019). It can be concluded that the discovery or non-discovery of copper mines, as well as the use of reserves, affects the production trend in an area over time.

Researchers conducted studies on various areas of copper such as processing slags of copper production [10], renewable energy in copper production [11], copper mining productivity [12], improved copper smelter, and converter productivity [13]. There is no paper on copper Supply Chain Network Design (SCND), to the best of our knowledge, although network design is a configuration which can help the supply chain to perform well [14].

In this paper, we design an SCND model for the copper supply chain. Besides, the proposed model is designed as a closed-loop to put the aforementioned real-world suppositions into practice.

The Copper supply chain includes mining, refining, fabrication, manufacturing, use, waste management, and recycling stages. Minerals are extracted from mines, copper ores are crushed, concentrates and tailings are produced during processes, and the concentrates are converted to copper with higher purity in the smelter stage. In the fabrication stage, some semi-finished products are produced [1].

The rest of the paper is organized as follows: Section 2 reviews the literature briefly. The proposed problem is precisely defined and formulated in section 3. Section 4 explains the solution method and also presents computational experiments and sensitivity analysis. Finally, conclusion and future opportunities are brought in section 5.

## 2. LITERATURE REVIEW

The lack of rich literature in the SCND of the mining industry forced us to review the SCND models in other industries. In the following, we review the literature briefly. Pishvae et al. [15] designed a multi-stage RL

network. They proposed a Mixed Integer Linear Programming (MILP) model and solved it by a metaheuristic algorithm. Then, Kannan et al. [16] developed the pishvae et al. [15] model by adding a term related to carbon to the objective function. They solved the MILP model by using an exact method and implemented it in plastic industry. Zadeh et al. [17] designed a steel supply chain network. Their model included iron ore mines, raw steel producers, steel companies, and also customers. They formulated the proposed network by using Mixed Integer Non-Linear Programming (MINLP) and MILP models by considering uncertainty and solved them by an exact method. The results showed that the MILP approach is better than MINLP for their model. Fallah-Tafti et al. [18] designed a CLSC network. They combined strategic and tactical decisions in order to make optimal decisions. The problem was formulated as a multi-objective MILP and solved by possibilistic-STEM. Ahmadi Yazdi and Honarvar [19] designed a logistic network and considered pricing policy in the dual-channel. They proposed a deterministic and a stochastic MILP model for the network. The scenario-tree method was used to solve the problem. Zohal and Soleimani [7] proposed a green forward/ reverse logistic network. In their integer linear programming model costs and emissions were minimized. They solved the model by metaheuristic and exact methods and implemented it in gold industry. Talaei et al. [20] proposed a green CLSC network. They formulated the problem as an MILP model. Costs and carbon dioxide emission rates were minimized in the model. An exact method was implemented to solve the uncertain model. Their case study was Copiers industry. Cheraghalipour et al. [5] proposed a citrus CLSC network. They formulated the problem as a Mixed Integer Programming (MIP) model and solved it by using metaheuristics algorithms. Jalali et al. [21] developed an SCND problem with disruption supposition. In their paper, a new two-stage stochastic MIP model was developed under uncertainty to minimize the costs. They solved the problem by using an exact method. Seifbarghi et al. [22] designed a CLSC network for paper industry. They formulated the problem as an MIP model. The model was solved by using fuzzy goal programming and applied in Iran. Zegordi et al. [23] designed a CLSC network. They also decided to supplier selection based on discount factor. The problem was formulated as an MIP model and costs were minimized on it. Then the model was solved by using an exact method. Leins et al. [24] investigated copper supply and value chain across Zambia, Switzerland and China. Valuerworks have shown that mining infrastructures such as insurance, transportation, finance, trade, etc. affect the decisions of the copper supply chain. Among them, the financial issue was more important. Sherafati et al. [25] proposed an SCND problem. They maximized the profit and

prioritized the less developed regions in order to social community development in the uncertain model. The problem was formulated as an MINLP model and was solved by an exact method. They implemented the model in cable industry. Mardan et al. [26] designed a green CLSC network. The problem was formulated as an MILP model. They minimized the total costs and the environmental topic of the supply chain. The model was solved by using an exact approach. They implemented the model in wire-and-cable industry. Gholipoor et al. [6] presented a faucet CLSC network design problem. The objective function of the model was maximizing the profit. Also, they paid attention to environmental issue. The proposed model was as MILP by considering uncertainty. It was solved by an exact method and was implemented in a real case study. Valderrama et al. [14] designed a supply chain network in iron ore industry. Environmental and social aspects of sustainable development were considered in their research. They formulated the problem as an MILP model. The model was solved by an exact method.

A review of literature and Table 1 reveal gaps in previous researcher’s studies, which we list here: 1- Despite the fact that mining industries are the basis of economic development in countries [27], a few studies have been done on their network design. 2- Despite the fact that copper mineral metal has high recyclability and factors such as population growth and increasing urbanization rates etc. increased its demand more than double between 1990 and 2015 [28], to the best of our knowledge, no studies have been performed on copper supply chain network design so far. 3- Network design provides the best structure for the supply chain so that it can have high economic performance in the long term [14], but to the best of our knowledge, there has not been a paper with a formal mathematical model for designing a copper supply chain network.

In this paper, we will cover deficit of research in the mining industry network design area. SCND models need to be applied in a specific industry because there is not the same solution for network design problems [14]. The copper industry is very important and it is necessary to pay attention to it because this useful metal has high recyclability and the development of human societies has increased its demand in recent years. Therefore, our contribution is to provide a network design model for the copper supply chain. In our proposed model copper scrap management is considered. This is very important and worthy for the following reasons: Copper is a non-renewable metal and has high recyclability. Also, the environmental aspect of sustainable development is considered by recycling it.

Regarding managerial insights, it should be said that our model can help managers to have proper strategic planning in the copper industry and similar industries. In addition, the recycling of scrap saves costs, energy, and

consumption of this non-renewable metal and it does not endanger the rights of future generations.

### 3. PROBLEM FORMULATION

In this section, we propose and formulate a model for the aforementioned problem. As shown in Figure 2, factories manufacture products. Then, customers receive them through distribution centers. Distribution centers deliver them to customers. When customers used products, they return them to the scrap product warehouses as scrap. Then, scrap products are transported from scrap product warehouses to production factories.

Factories melt scrap and reuse them in production cycle. Figure 2 shows the proposed copper supply chain network.

This supply chain has some features that distinguish it from other supply chains, which we describe below: 1- In this chain, scrap does not turn into iron ore, which is a raw material. Rather, it is converted into usable products

TABLE 1. Literature review of SCND

Authors	Network			Model			Solution Method		Industry	
	OL	CL	RL	MILP	MINLP	MIP	E	M		MCDM
[15]				*	*				*	
[16]				*	*			*		Plastic
[17]	*			*	*		*			Steel
[18]		*		*					*	
[19]		*		*			*			
[7]		*		*			*	*		Gold
[20]		*		*			*			Copier
[5]		*				*		*		Citrus
[21]		*				*	*			
[22]		*				*			*	Paper
[23]		*				*	*			
[25]	*				*		*			Cable
[26]		*		*			*			Wire and Cable
[6]		*		*			*			Faucet
[14]		*		*			*			Iron Ore
This paper		*				*	*			Copper

OL: Open Loop CL: Closed Loop RL: Reverse Logistic MILP: Mixed Integer Linear Programming MINLP: Mixed Integer Non-Linear Programming MIP: Mixed Integer Programming E: Exact M: Metaheuristic MCDM: Multiple Criteria Decision Making

in the factory after some processes. These conditions save a lot of energy and costs. In copper production factories, there are two production technology (pyrometallurgy and hydrometallurgy). Extracted raw materials from the mine, can be produced in two technologies, but scrap can only be produced by one technology (pyrometallurgy). This feature forces us to use two different decision variables to show the amount of production in the factory (the details are described in the model). In fact, this feature differentiates the model structure (decision variables and constraints) of the copper supply chain network design problem from other existing models. 2- The location of the mines (as suppliers) are always fixed. It means that they are not potential and it cannot be decided to build them. Therefore, equipment and facilities in the chain should be set according to their locations. 3- Copper can be recycled again and again and its value does not decrease due to recycling. Also, recycled copper can be used in the same copper supply chain.

Model assumptions:

- The location of customers and mines are fixed and other locations are potential.
- Capacity of mines, factories, and warehouses are finite.
- There is no flow between the same facilities.
- It is assumed that scrap warehouses deliver scrap to the production factory based on their weight, and the scrap of all products is considered the same.
- Raw materials extracted from the mine can be produced by two production technology: Pyrometallurgy and Hydrometallurgy, but scrap can only be produced by Pyrometallurgy.

The indices, parameters, and decision variables are shown in Table 2, 3, and 4, respectively.

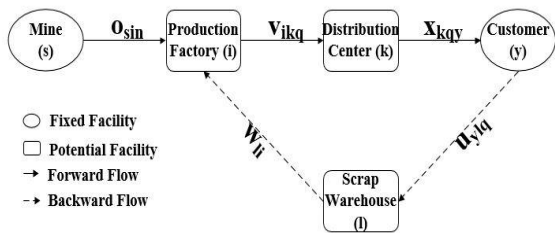


Figure 2. Proposed copper CLSC

TABLE 2. List of Indices

Indexes	Description
$s$	Fixed Suppliers (Mines) $s \in \{1, 2, \dots, S\}$
$i$	Potential production factory $i \in \{1, 2, \dots, I\}$
$k$	Potential distribution center $k \in \{1, 2, \dots, K\}$

$l$	Potential scrap warehouse $l \in \{1, 2, \dots, L\}$
$y$	Fixed customer zones $y \in \{1, 2, \dots, Y\}$
$q$	Product type $q \in \{1, 2, \dots, Q\}$
$n$	Raw Material $n \in \{1, 2, \dots, N\}$
$e$	Production technology $e \in \{1, 2, \dots, E\}$

TABLE 3. List of Parameters

Parameters	Description
$sp_q$	Unit selling price of product $q$
$fc_i$	Opening cost of production factory $i$
$fk_k$	Opening cost of distribution center $k$
$fn_l$	Opening cost of scrap warehouse $l$
$p1_{sn}$	Unit mining cost of raw material $n$ from mine $s$
$cc$	Unit transportation cost between scrap warehouse and production factory
$tc_n$	Unit transportation cost of raw material $n$ between mine and production factory
$mc_q$	Unit transportation cost of product $q$ between production factory and distribution center
$sc_q$	Unit transportation cost of product $q$ between distribution center and customer
$bc_q$	Unit transportation cost of scrap product $q$ between customer and scrap warehouse
$e1_{si}$	Distance between mine $s$ and production factory $i$
$e2_{ik}$	Distance between production factory $i$ and distribution center $k$
$e3_{ky}$	Distance between distribution center $k$ and customer $y$
$e4_{yl}$	Distance between customer $y$ and scrap warehouse $l$
$e5_{li}$	Distance between scrap warehouse $l$ and production factory $i$
$pc_{qe}$	Unit production cost of product $q$ from production technology $e$ (from raw material)
$ts_q$	Unit production cost of product $q$ from scrap
$a2_q$	Unit cost-saving in production of product $q$ due to recycling
$d1_{yq}$	Demand of customer $y$ from product $q$
$\mathcal{E}_{yq}$	Amount of scrap product $q$ returned from the customer $y$

$cs_{sn}$	Maximum capacity of mine $s$ from raw material $n$
$ci_{iq}$	Maximum production capacity of production factory $i$ from product $q$
$ck_{kq}$	Maximum capacity of distribution center $k$ from product $q$
$cn_{lq}$	Maximum capacity of scrap warehouse $l$ from product $q$
$a3_i$	Percentage of total production in production factory $i$ that related to production from scrap
$a4_i$	Conversion rate of raw material to product in production factory $i$
$a5_i$	Conversion rate of scrap to product in production factory $i$

**TABLE 4.** List of Decision Variables

Decision Variables	Description
$ift_i$	1 if production factory $i$ is opened and 0 otherwise
$fk_k$	1 if distribution center $k$ is opened and 0 otherwise
$fn_l$	1 if scrap product warehouse $l$ is opened and 0 otherwise
$o_{sin}$	Flow of raw material $n$ from mine $s$ to production factory $i$
$v1_{iqe}$	Quantity of product $q$ that produced in production factory $i$ by production technology $e$ (from raw material)
$v2_{iq}$	Quantity of product $q$ that produced in production factory $i$ from scrap
$v_{ikq}$	Quantity of product $q$ that is transported from production factory $i$ to distribution center $k$
$x_{kqy}$	Quantity of product $q$ that is transported from distribution center $k$ to customer $y$
$u_{ylq}$	Quantity of scrap product $q$ that is transported from customer $y$ to scrap warehouse $l$
$w_{li}$	Quantity of scrap that is transported from scrap warehouse $l$ to production factory $i$

Equation (1) shows the objective function. It maximizes supply chain profit. The Profit equals revenues minus costs. In our model, the products are produced either from raw material or from scrap. The sum of these products is sold in the market and the revenue of the chain is equal to the value of their sales. Costs in our model include the following: opening costs, mining, transportation, and production.

$$\begin{aligned}
 MaxZ = & \sum_k \sum_y \sum_q (sp_q - (sc_q \times e3_{ky})) \times x_{kqy} - \\
 & (\sum_s \sum_i \sum_n p1_{sn} + (tc_n \times e1_{si}) \times o_{sin} + \\
 & \sum_i \sum_q \sum_e pc_{qe} \times v1_{iqe} + \sum_i \sum_q (ts_q - a2_q) \times v2_{iq} \\
 & + \sum_i \sum_k \sum_q mc_q \times e2_{iq} \times v_{ikq} + \\
 & \sum_y \sum_l \sum_q bc_q \times e4_{yl} \times u_{ylq} + \\
 & \sum_l \sum_i cc \times e5_{li} \times w_{li} + \\
 & \sum_i fc_i \times ift_i + \sum_k fk_k \times ifk_k + \\
 & \sum_l fn_l \times ifn_l)
 \end{aligned} \tag{1}$$

Equations (2)-(3) show production balance constraints.

$$\sum_e v1_{iqe} + v2_{iq} = \sum_k v_{ikq} \quad \forall i, q \tag{2}$$

$$a3_i \times \sum_k \sum_q v_{ikq} = \sum_q v2_{iq} \quad \forall i \tag{3}$$

Equations (4)-(6) show input and output balance constraints.

$$a4_i \times \sum_s \sum_n o_{sin} = \sum_q \sum_e v1_{iqe} \quad \forall i \tag{4}$$

$$a5_i \times \sum_l w_{li} = \sum_q v2_{iq} \quad \forall i \tag{5}$$

$$\sum_i v_{ikq} = \sum_y x_{kqy} \quad \forall k, q \tag{6}$$

Equation (7) shows demand balance constraint.

$$\sum_k x_{kqy} \leq d1_{yq} \quad \forall y, q \tag{7}$$

Equations (8)-(10) show scrap flow balance constraints in backward.

$$\sum_k x_{kqy} \geq \sum_l u_{ylq} \quad \forall y, q \tag{8}$$

$$\sum_l u_{ylq} \leq \epsilon_{yq} \quad \forall y, q \tag{9}$$

$$\sum_y \sum_q u_{ylq} = \sum_l w_{li} \quad \forall l \tag{10}$$

Equations (11)-(14) show capacity constraints.

$$\sum_k \sum_q v_{ikq} \leq \sum_q ift_i \times ci_{iq} \quad \forall i \tag{11}$$

$$\sum_i \sum_n o_{sin} \leq \sum_n cs_{sn} \quad \forall s \tag{12}$$

$$\sum_i \sum_q v_{ikq} \leq \sum_q ifk_k \times ck_{kq} \quad \forall k \tag{13}$$

$$\sum_y \sum_q u_{y,q} \leq \sum_q ifn_i \times cn_{iq} \quad \forall i \quad (14)$$

Equation (15) shows the decision variables domain constraint.

$$f_i, ifk_k, ifn_i \in \begin{cases} 1 \\ 0 \end{cases}, \quad (15)$$

$$o_{sin}, v1_{iqe}, v2_{iq}, v_{ikq}, x_{kqy}, u_{y,q}, w_{li} \geq 0$$

Constraint (2) shows that products are produced by raw materials and scrap in production factories. Constraint (3) shows that production from scrap is only a part of the total production in each production factory. Constraints (4-5) show that production factory inputs, which are raw materials and scrap, are converted into products after the production process. In mathematical equations, we used conversion coefficients to show the production process. Constraint (6) shows input and output balance for each distribution center. Constraint (7) shows demand constraint for each customer. Constraints (8-10) show scrap flow balance in backward. Equations (11-14) show capacity constraints for different facilities. Equation (15) shows the decision variables domain constraint.

**4. SOLUTION APPROACH AND COMPUTATIONAL EXPERIMENTS**

We solved all test problems by using the CPLEX solver of GAMS commercial software version 24.8.2. All calculations were done on a personal computer with Intel (R) Core (TM) i7-2670QM CPU @ 2.20 GHz, 8.00 GB RAM memory.

**4. 1. Instances**

In this section, twelve test problems are examined in different sizes (small, medium, and large). There are four test problems in each size. They are shown in Table 5.

Table 5 shows that computational time and objective function value increase by increasing the size of the problem.

**4. 2. Sensitivity Analysis**

In this section, the model parameters are changed to determine their effect on the objective function. Sensitivity analysis is performed on the first example from Table 5. The results are shown in Figure 3 and Table 6.

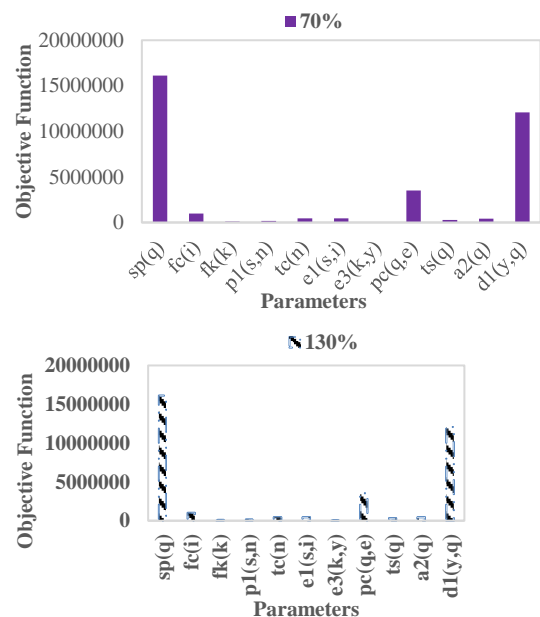
In sensitivity analysis, all parameters were changed by 70 and 130% of their original value. Among them,  $sp_q, fc_i, fk_k, p1_{sn}, tc_n, e1_{si}, e3_{ky}, pc_{qe}, ts_q, a2_q, d1_{y,q}$  parameters had the greatest impact on the objective function. According to Figure 3 and Table 6, a change in the amount of the mentioned parameters leads to changes in the objective function, but as can be seen,

$sp_q, PC_{qe}$ , and  $d1_{y,q}$  parameters have the greatest impact on the objective function compared to others.

The results of sensitivity analysis show that the demand, selling price and production cost are important factors in the proposed model and have a greater impact on the supply chain profit than other parameters. Supply chain managers can use these results to design

**TABLE 5.** Test problems

Size	Problem Number	Size of Problems (s, q, i, k, y, l, n, e)	Objective Function (Monetary Unit)	Computational Time (Second)
small	1	2,2,2,2,3,2,2,2	36634240	0.450
	2	2,2,2,2,4,2,2,2	52456140	0.567
	3	2,3,3,3,5,3,2,2	103578300	0.471
	4	2,3,3,3,6,3,2,2	119613100	0.494
medium	5	3,4,4,4,8,4,2,2	220126500	0.567
	6	3,4,4,4,9,4, 2,2	251435600	0.716
	7	3,5,5,5,10,5,2,2	364928900	0.625
	8	3,5,5,5,11,5,2,2	391258800	0.667
large	9	4,6,6,6,13,6,2,2	539564200	1.433
	10	4,6,6,6,14,6, 2,2	590285400	1.424
	11	4,7,7,7,15,7,2,2	731415700	1.698
	12	4,7,7,7,16,7, 2,2	780989400	1.765



**Figure 3.** The parameters' impact on the objective function

network, market and customer issues, as well as production processes.

**TABLE 6.** Sensitivity analysis

parameter	Sensitivity analysis	Objective function	Difference of objective value	
			70%	130%
$sp_q$	70	20524640		
	100	36634240	16109600	16109610
	130	52743850		
$fc_i$	70	37624590		
	100	36634240	990350	990340
	130	35643900		
$fk_k$	70	36733010		
	100	36634240	98770	98760
	130	36535480		
$p1_{sn}$	70	36796160		
	100	36634240	161920	161910
	130	36472330		
$tc_n$	70	37083880		
	100	36634240	449640	449630
	130	36184610		
$e1_{si}$	70	37083880		
	100	36634240	449640	449630
	130	36184610		
$e3_{ky}$	70	36652050		
	100	36634240	17810	17800
	130	36616440		
$pc_{qe}$	70	40148700		
	100	36634240	3514460	3514450
	130	33119790		
$ts_q$	70	36928570		
	100	36634240	294330	294320
	130	36339920		
$a2_q$	70	36214110		
	100	36634240	420130	420130
	130	37054370		
$d1_{yq}$	70	24553710		
	100	36634240	12080530	12080540
	130	48714780		

## 5. CONCLUSION AND FUTURE STUDIES

The Demand for copper has increased by development of technology and communication infrastructure. Copper can be extracted from mines. Its mines are not distributed throughout the world uniformly. Therefore, it is necessary to optimize copper supply chain so that everyone can use it fairly. In addition, copper can be recycled again and again. But to the best of our knowledge, there is no paper about copper SCND.

In this paper, an MIP model for a copper CLSC is proposed. Section 3 of this paper, describes the assumptions and formulation of the problem. The problem is solved by an exact approach in GAMS 24.8.2 software with CPLEX solver. Sensitivity analysis is implemented for parameters of the model in section 4. In the future, the present model can be developed by considering the uncertainty of the parameters and vehicle routing operations.

## 6. REFERENCES

- Zhang, L., Cai, Z., Yang, J., Yuan, Z. and Chen, Y., "The future of copper in China—A perspective based on analysis of copper flows and stocks", *Science of the Total Environment*, Vol. 536, (2015), 142-149, <https://doi.org/10.1016/j.scitotenv.2015.07.021>.
- Elshkaki, A., Graedel, T. E., Ciacci, L. and Reck, B. K., "Copper demand, supply, and associated energy use to 2050", *Global Environmental Change*, Vol. 39, (2016), 305-315, <https://doi.org/10.1016/j.gloenvcha.2016.06.006>.
- Simchi-Levi, D., Kaminsky, P., Simchi-Levi, E., and Shankar, R., "Designing and managing the supply chain: concepts, strategies and case studies. Tata McGraw-Hill Education", (2008).
- Fleischmann, M., Bloemhof-Ruwaard, J. M., Dekker, R., Van der Laan, E., Van Nunen, J. A. and Van Wassenhove, L. N., "Quantitative models for reverse logistics: A review", *European Journal of Operational Research*, Vol. 103, No. 1, (1997), 1-17, [https://doi.org/10.1016/S0377-2217\(97\)00230-0](https://doi.org/10.1016/S0377-2217(97)00230-0).
- Cheraghali, A., Paydar, M. M. and Hajiaghayi-Keshteli, M., "A bi-objective optimization for citrus closed-loop supply chain using Pareto-based algorithms", *Applied Soft Computing*, Vol. 69, (2018), 33-59, <https://doi.org/10.1016/j.asoc.2018.04.022>.
- Gholipour, A., Paydar, M. M. and Safaei, A. S., "A faucet closed-loop supply chain network design considering used faucet exchange plan", *Journal of Cleaner Production*, Vol. 235, (2019), 503-518, <https://doi.org/10.1016/j.jclepro.2019.06.346>.
- Zohal, M. and Soleimani, H., "Developing an ant colony approach for green closed-loop supply chain network design: a case study in gold industry", *Journal of Cleaner Production*, Vol. 133, (2016), 314-337, <https://doi.org/10.1016/j.jclepro.2016.05.091>.
- Sahebjamnia, N., Fathollahi-Fard, A. M. and Hajiaghayi-Keshteli, M., "Sustainable tire closed-loop supply chain network design: Hybrid metaheuristic algorithms for large-scale networks", *Journal of Cleaner Production*, Vol. 196, (2018), 273-296, <https://doi.org/10.1016/j.jclepro.2018.05.245>.
- Paydar, M. M., Babaveisi, V. and Safaei, A. S., "An engine oil closed-loop supply chain design considering collection risk", *Computers & Chemical Engineering*, Vol. 104, (2017), 38-55, <https://doi.org/10.1016/j.compchemeng.2017.04.005>.

10. Yusupkhodjaev, A. A., Khojiev, S. T., Valiev, X. R., Saidova, M. S. and Omonkhonov, O. X., "Application of Physical and Chemical Methods for Processing Slags of Copper Production," *International Journal of Advanced Research in Science, Engineering and Technology*, Vol. 6, No. 1, (2019), 7957.
11. Moreno-Leiva, S., Haas, J., Junne, T., Valencia, F., Godin, H., Kracht, W., Nowak, W. and Eltrop, L., "Renewable energy in copper production: A review on systems design and methodological approaches", *Journal of Cleaner Production*, Vol. 246, (2020), 118978, <https://doi.org/10.1016/j.jclepro.2019.118978>.
12. de Solminihaç, H., Gonzales, L. E. and Cerda, R., "Copper mining productivity: lessons from Chile", *Journal of Policy Modeling*, Vol. 40, No. 1, (2018), 182-193, <https://doi.org/10.1016/j.jpolmod.2017.09.001>.
13. Jak, E., Shishin, D., Hawker, W., Vaughan, J. and Hayes, P. C., "Improved copper smelter and converter productivity through the use of a novel high-grade feed", In *Extraction 2018*, 265-271, Springer, Cham, (2018), [https://doi.org/10.1007/978-3-319-95022-8\\_21](https://doi.org/10.1007/978-3-319-95022-8_21).
14. Valderrama, C. V., Santibanez-González, E., Pimentel, B., Candia-Véjar, A. and Canales-Bustos, L., "Designing an environmental supply chain network in the mining industry to reduce carbon emissions", *Journal of Cleaner Production*, Vol. 254, (2020), 119688, <https://doi.org/10.1016/j.jclepro.2019.119688>.
15. Pishvae, M. S., Kianfar, K. and Karimi, B., "Reverse logistics network design using simulated annealing", *The International Journal of Advanced Manufacturing Technology*, Vol. 47, No. (1-4), (2010), 269-281, <https://doi.org/10.1007/s00170-009-2194-5>.
16. Kannan, D., Diabat, A., Alrefaei, M., Govindan, K. and Yong, G., "A carbon footprint based reverse logistics network design model", *Resources, Conservation and Recycling*, Vol. 67, (2012), 75-79, <https://doi.org/10.1016/j.resconrec.2012.03.005>.
17. Zadeh, A. S., Sahraeian, R. and Homayouni, S. M., "A dynamic multi-commodity inventory and facility location problem in steel supply chain network design", *The International Journal of Advanced Manufacturing Technology*, Vol. 70, No. (5-8), (2014), 1267-1282, <https://doi.org/10.1007/s00170-013-5358-2>.
18. Fallah-Tafti, A. L., Sahraeian, R., Tavakkoli-Moghaddam, R. and Moeinipour, M., "An interactive possibilistic programming approach for a multi-objective closed-loop supply chain network under uncertainty", *International Journal of Systems Science*, Vol. 45, No. 3, (2014), 283-299, <https://doi.org/10.1080/00207721.2012.720296>.
19. Ahmadi Yazdi, A., "A two stage stochastic programming model of the price decision problem in the dual-channel closed-loop supply chain", *International Journal of Engineering, Transactions B: Applications*, Vol. 28, No. 5, (2015), 738-745, doi: 10.5829/idosi.ije.2015.28.05b.12.
20. Talaei, M., Moghaddam, B. F., Pishvae, M. S., Bozorgi-Amiri, A. and Gholamnejad, S., "A robust fuzzy optimization model for carbon-efficient closed-loop supply chain network design problem: a numerical illustration in electronics industry", *Journal of Cleaner Production*, Vol. 113, (2016), 662-673, <https://doi.org/10.1016/j.jclepro.2015.10.074>.
21. Jalali, G., Tavakkoli-Moghaddam, R., Ghomi-Avili, M. and Jabbarzadeh, A., "A network design model for a resilient closed-loop supply chain with lateral transshipment", *International Journal of Engineering*, Vol. 30, No. 3, (2017), 374-383, doi: 10.5829/idosi.ije.2017.30.03c.07.
22. Seifbarghi, M., Bozorgi-Amiri, A., Rahmani-Ahranjani, A. and Najafi, E., "Managing environmentally conscious in designing closed-loop supply chain for the paper industry", *International Journal of Engineering*, Vol. 30, No. 7, (2017), 1038-1047, doi: 10.5829/ije.2017.30.07a.13.
23. Zegordi, S. H., Hosseinzadeh, A., Nahavandi, N. and Sadeghi Rad, R., "An integrated closed-loop supply chain configuration model and supplier selection based on offered discount policies", *International Journal of Engineering*, Vol. 31, No. 3, (2018), 440-449, doi: 10.5829/ije.2018.31.03c.06.
24. Leins, S., Kesselring, R. and Schulz, Y., "Valueworks: effects of financialization along the copper value chain" *SNIS Working Papers*, (2019).
25. Sherafati, M., Bashiri, M., Tavakkoli-Moghaddam, R. and Pishvae, M. S., "Supply chain network design considering sustainable development paradigm: A case study in cable industry", *Journal of Cleaner Production*, Vol. 234, (2019), 366-380, <https://doi.org/10.1016/j.jclepro.2019.06.095>.
26. Mardan, E., Govindan, K., Mina, H. and Gholami-Zanjani, S. M., "An accelerated benders decomposition algorithm for a bi-objective green closed loop supply chain network design problem", *Journal of Cleaner Production*, Vol. 235, (2019), 1499-1514, <https://doi.org/10.1016/j.jclepro.2019.06.187>.
27. Umar, Z., Shahzad, S. J. H. and Kenourgios, D., "Hedging US metals & mining Industry's credit risk with industrial and precious metals", *Resources Policy*, Vol. 63, (2019), 101472, <https://doi.org/10.1016/j.resourpol.2019.101472>.
28. Kuipers, K. J., van Oers, L. F., Verboon, M. and van der Voet, E., "Assessing environmental implications associated with global copper demand and supply scenarios from 2010 to 2050", *Global Environmental Change*, Vol. 49, (2018), 106-115, <https://doi.org/10.1016/j.gloenvcha.2018.02.008>.

---

### Persian Abstract

---

#### چکیده

بی شک فلزات اساس توسعه پایدار همه جوامع بشری هستند. در قرن گذشته، نقش مس به عنوان سومین فلز پرکاربرد پس از فولاد و آلومینیوم، حیاتی بوده است. مس یک فلز قابل بازیافت است. آن کاربردهای زیادی مانند برق صنعتی، لوله‌کشی، سیم‌کشی، تجهیزات الکترونیکی، حمل‌ونقل و زیرساخت‌ها دارد. امروزه با رشد صنعت در جوامع، تقاضا برای مس افزایش یافته است. این به ما انگیزه داد تا برای اولین بار طراحی شبکه زنجیره تامین آن را مطالعه کنیم. بر مبنای بهترین دانش ما، تاکنون هیچ تحقیقی درباره طراحی شبکه زنجیره تامین مس انجام نشده است. هدف این مقاله، حداکثر کردن سود در زنجیره تامین حلقه بسته مس است. ما این مسئله طراحی شبکه را به صورت یک مدل برنامه‌ریزی عدد صحیح مختلط فرموله می‌کنیم. مدل به صورت یک هدف و چند محسولی در نظر گرفته می‌شود. جواب دقیق مدل با استفاده از نرم‌افزار گمز پیدا شده است. آنالیز حساسیت نتایج مفیدی ارائه می‌دهد که مدیران می‌توانند در تصمیم‌گیری‌ها از آنها بهره ببرند.

---