Designing a Multi Echelon Supply Chain Network for Citrus Fruits Inspecting the Economic, Social and Environmental Issues

Rajan Ponnusamy* and Shahul Hamid Khan

Department of Mechanical Engineering, Indian Institute of Information Technology Design and Manufacturing, Kancheepuram, Chennai, Tamil Nadu, India
Email: me23d0005@iiitdm.ac.in (R.P.); bshahul@iiitdm.ac.in (S.H.K.)
*Corresponding author

Abstract—**The realization of sustainable logistics for any agricultural product is always challenging. The value chain and Closed Loop Supply Chain (CLSC) for agricultural products are gaining importance over the years. Oranges are one such agricultural product that has a potential value chain after being used by juice-extracting industries. Oranges in particular Mandarin orange (Citrus reticulata) is the most common orange type grown in India. This fruit alone occupies 40% of the total citrus fruits cultivated in India that demands a cost-effective supply chain network. The orange Market is widely branched into Food and Beverage industries, cosmetics, Pharma industries, food flavoring agents and essential oils. The orange peel, if wasted and not processed destroys the value of the product, though many valuable products can be derived from the peel. In this study, an attempt is made to design a new supply chain network for the orange industry after carefully studying the past literature works. A novel mixed integer linear programming model for the attempted supply chain network is developed to minimize the overall cost as an objective. An attempt is made to study the environmental issues in detail concerning the packaging and crates used and distribution problems. A mathematical model is proposed to effectively manage the packaging material and to control & reduce emissions. For optimum solution Keshtel Algorithm, the proposed network is designed to effectively serve the markets that use the value of the discarded orange peels after juice extraction.**

Keywords—**closed loop supply chain, Mixed-Integer Linear Programming (MILP), supply chain network design, sustainable agriculture, value chain**

I. Introduction

Most agricultural products that are bulk processed for their primary value are often discarded as waste after extraction and dumped into the environment as agricultural waste. Since these products are organic, they decompose quickly and don't cause environmental problems like inorganic matter. Fig. 1 shows the Global crop production by commodity group, revealing the potential of the work that can be achieved.

Recovery of the Value from such products with an efficient supply chain network will create additional profit for the processing industries and a cleaner supply of by products which are considered the raw material to those industries.

An efficient supply chain network in any business has become inevitable to stay competitive in global trade. The environmental impacts of the used products, scarce resources, by-products, and sense of responsibility has demanded the industries to design reverse logistics for their products (Jayaraman *et al.*, 1999). The reverse logistics network has enabled industries to effectively recycle the used products from customers in a multi-echelon scheme and make it reusable thereby enhancing the environment (Hajiaghaei-Keshteli & Sajadifar, 2014).

India with arable land of 155,369 hectares which is the second largest country only next to US produces nearly 70 lakh tonnes of oranges yearly. Oranges are consumed fresh, and their juice extracts are popular breakfast beverages in many parts of the world. India exports 25,000 tonnes of oranges to countries like Bangladesh, Kuwait, omen etc. Maharashtra is the leading producer of oranges contributing nearly 40% of the total production of oranges in India.

Only a portion of the total production is consumed fresh and remaining goes into processing industries for the raw juice constituting about 50% of the processed fruit, the orange peel residue becomes the by-products for different industries from which more products are derivable. Fig. 2. depicts the Gross Value output of oranges in India. The production facilities, cold storage systems, Juice processing industries and by-product (orange peel) processing industries must be properly integrated considering the location which might result in increased transportation cost if not located at optimum distances (Eskandarpour *et al.*, 2015; Garg *et al.*, 2015; Liao *et al.*, 2020).

This study considers the whole supply chain from producers to processing industries and from processing industries to by product processing industries to minimize the cost of supply chain and to boost the profit from the by-products. The extended supply chain that uses the

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orange peel addresses the problem of waste from juice extraction (Grillo *et al.*, 2019).

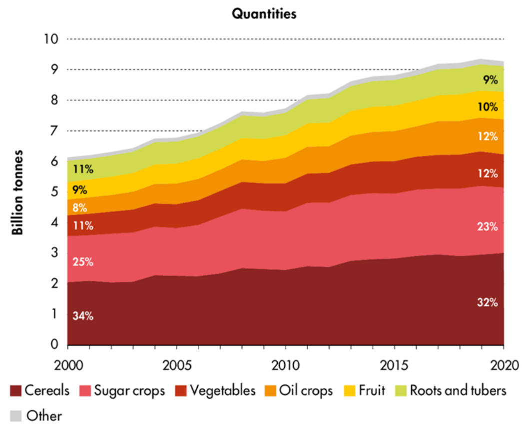

Fig. 1. Global production of crops by commodity group.

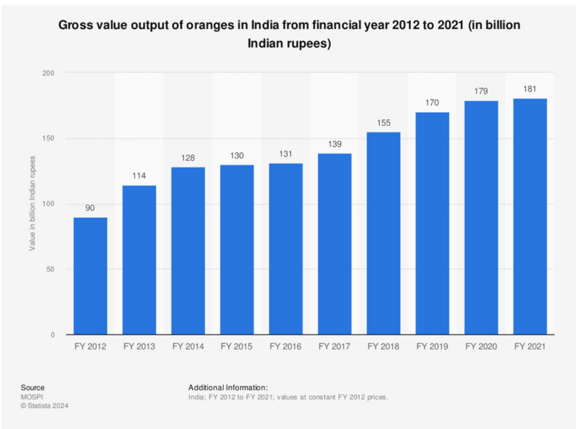

Fig. 2. Gross Value output of oranges in India.

This work is structured to design a multi echelon CLSC network for the product returned after primary processing. The total supply chain cost will be minimized until the byproducts of the orange are supplied to the secondary processing industries. The network proposes a lower fixed cost for locating a facility and a decision for routing that can efficiently and effectively handle the demand from the market for a stipulated time duration.

II. Literature Review

The preliminary search and careful examination of the published literary works revealed that very few researchers have attempted a CLSC for the citrus fruit Industry. To sustain themselves over a long period in the market and to do profitable business, industries have realized that it is not the industries that fight and win but the effective supply chain network they use. This realization has made them focus largely on reverse logistics and value chain.

A. CLSCs and RL

Garcia & Hora (2017) designed a supply chain network for waste wood reverse logistics considering the collection logistics and recycling facility locations (Hajiaghaei-Keshteli & Sajadifar, 2013). Jayant *et al.* (2014) developed a product recovery simulation model for the used acid batteries recovery using Arena (Hajiaghaei-Keshteli & Sajadifar, 2014). Zohal and Solei (2016) addressed a multi-objective logistics model that considers the green approach for the gold industry. The model used 4 echelons in forward and three in reverse logistics. The model is solved by an algorithm developed based on ant colony optimization (Jayant *et al.*, 2014).

Melo *et al.* (2009) reviewed the location-allocation study in detail and emphasized the importance of decision-making. Alongside the detailed study, it is crucial to consider the location allocation decision for any supply chain that is designed. Unfitting decisions on location allocation will increase transportation costs and have a greater ecological impact on the aspects of carbon release. A recent focus of researchers in this area has attracted extensive solutions to the problem statement (Jayaraman *et al.*, 1999). In the study (Jayaraman *et al.*, 1999), proposed a recovery model for the used product indicating the value that can be extracted from the disregarded product (Garg *et al.*, 2015). Pishvaee & Torabi (2010) designed a network that will be sustainable with a minimum number of collection facilities that could effectively supply the needs of the secondary markets and secondary processing units. He dealt the problem using metaheuristics approach for near optimal solutions. Usage of perfect CLSC's will subsequently increase the ability to recycle and to adopt an eco-friendly system during transportation (Jayant *et al.*, 2014).

B. Agricultural Supply Chain and Reuse

Any Closed Loop Supply chain network is based on the returned product type. The collected product can be reused through recovery, repair, refurbishment, remanufacturing, and recycling. The sustainability and green supply chain concept has forced companies to recover values from the used products. The industries in the developed countries strongly believe that these recovery options are good strategies to improve their business as they could profit from them. The extensive by-product of any agricultural waste is a concern to the environment and is considered a loss if not made profitable by value extraction from the by-products (Heshmati, 2017). Fattahi and Govindan (2018) proposed a biofuel supply chain design using agriculture waste-based biomass. The model's objective was to minimize the cost of the supply chain. The triangular fuzzy is the most widely used ASC optimization for uncertainty management.

C. Research Gap

The extensive research over the decade into agricultural supply chain mainly addresses forward logistics, focusing on meeting customer demand at the right time. Table I gives the details of work carried out in the Value chain for the processed agricultural products, which is demanding and found to be limited.

The following are the objectives devised to address the value chain design for the Citrus fruit:

- From the literature, we found no agricultural supply chain network for citrus fruit extraction after it was disregarded in the primary processing industry.

- A new MILP mathematical model to minimize costs and maximize profit by selling by-products to the secondary processing industries.

TABLE I. EXISTING WORK ON AGRICULTURAL PRODUCT REUSE

Author(s)	Product type	Model formulation			Problem definition	Solution Approach
		Linear	**Non-Linear**	**MILP**		
Arnaout and Maatouk (2010)	Grape			✓	To minimize the cost of the value chain	Branch and Branch Bound
Haslenda & Jamaludin (2011)	Palm oil			✓	To maximize profit by selling by products to the secondary processing industries	Exact
Cheraghalipur *et al.*, (2018)	Citrus Fruits		✓		To increase the responsiveness of the chain	Metaheuristic
Liao *et al.*, (2020)	Citrus Fruits			✓	To minimize various costs	Metaheuristic
Salema *et al.*, (2012)	Fruits	✓			To minimize transportation costs	Exact
Memari *et al.*, (2018)	Palm Fruits			✓	To minimize the total logistics costs and total carbon emissions	Exact

III. MODEL DESCRIPTION

The current trend in designing any agricultural supply chain is the need for returned products from primary processing industries. This waste (orange peel) is valuable for the secondary processing industry, as shown in Fig. 3. In this paper, a CLSC network is designed to minimize the total cost of the citrus fruit(oranges) supply chain, with a collection of orange peels to be processed further. As shown in Fig. 4, the model includes Citrus Farms (Growers), Cold storage Locations (CSL), Primary Processing Industries (PPI), General Markets (GM) in forward flow and Secondary Processing Industry (SPI) in the reverse flow or Value chain. Generally, farms produce Citrus fruits that can be distributed directly from Farms to GM. The Primary Processing Industries (PPI) purchase the Citrus fruits from the farms.

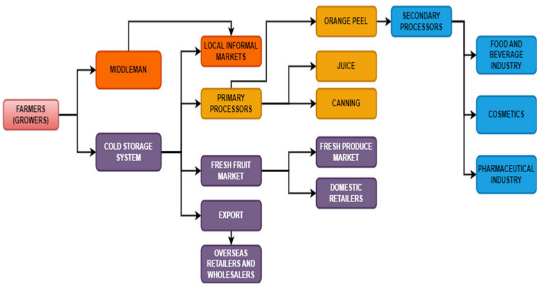

Fig. 3. Orange processing and its usage.

The Squashed oranges are canned or made available as fresh juice extract for the consumers after processing. The waste (Orange Peel) is then processed in SPI and made into valuable products to the customers.

The assumptions of the model are as follows:

- Each center (Farms, PPIs, SPIs) has a finite capacity and their potential locations are known.
- The demand rate for each type of customer is predetermined in each period.
- Shortages are not allowed.
- In all the PPIs and SPIs, there is a warehousing system. The capacity of each warehouse is limited, and the inventory cost is considered for the remaining products at the end of each period. Table II Gives information on the problem size.

A. Indices

i Index of production locations, $i \in \{1,2 \dots \dots I\}$(OF)

j Index of storage locations, $j \in \{1,2 \dots \dots J\}$(CS)

k Index of processing unit locations, $k \in \{1,2 \dots \dots K\}$ (PPI)

m Index of distribution unit locations, $m \in \{1,2 \dots \dots M\}$(SPI)

l Index of fertilizer unit locations, $l \in \{1,2 \dots \dots L\}$

o_1 Index of fertilizer markets, $o_1 \in \{1,2 \dots \dots O_1\}$

o_2 Index for some producers and gardeners as fertilizers customers, $o_2 \in \{1,2 \dots \dots O_2\}$

O Index of fertilizers customers' locations, $O \in \{O_1 + O_2\}$

g other industry location (GM)

B. Parameters

f_j Fixed cost of opening storage units

f_k Fixed cost of opening SPI units

f_m Fixed cost of opening distribution units

f_l Fixed cost of opening fertilizer units

Cx_{ij} Shipping cost per unit of products from producer i to storage unit j

Cu_{jk} Shipping cost per unit of products from storage unit j to SPI unit k

Cp_{km} Shipping cost per unit of products from SPI unit k to distribution unit m

Cv_{kg} Shipping cost per unit of products from SPI unit k to other industry g

Ce_{kl} Shipping cost per unit of products from SPI unit k to fertilizer units l

Cf_{lo} Shipping cost per unit of products from fertilizer units l to fertilizer market o

Ch_t Holding cost per unit of inventory (Oranges) from storage units j at time t

Cb_t Holding cost per unit of inventory from distribution units m at time t

Cp'_t Production cost per unit of product from producers i

Ck'_t Processing and packaging cost per unit of products unit k at time t

Cl'_t Fertilizer manufacturing cost per unit of product from fertilizer units l at time t

d_{mt} Demand of processed product by distribution unit m at time t

d_{ot} Demand of reprocessed product (fertilizers) by fertilizer markets o at time t

μc_{it} Maximum production capacity of producer i at time t

μh_{jt} Holding capacity of storage units j at time t

μb_{mt} Holding capacity of distribution units m at time t

μr_{lt} fertilizer manufacturing capacity of fertilizer units l at time t

β_t Percentage waste from PPI unit k at time t

θ_t Percentage waste SPI from the processing unit k at time t

$\emptyset$ Conversion rate of the waste product to the reprocessed product

M A Big Positive number

C. Decision Variables

X_{ijt} Quantity of product shipped from producer i to storage unit j at time t

U_{jkt} Quantity of product shipped from storage unit j to processing unit k at time t

P_{kmt} Quantity of product shipped from SPI unit k to distribution unit m at time t

E_{klt} Quantity of product shipped SPI unit k to fertilizer units l at time t

V_{kgt} Quantity of product shipped from SPI unit k to other industry g at time t

F_{lot} Quantity of product shipped fertilizer units l to fertilizer market o at time t

q_{it} Quantity of production by producer i at time t

Ih_{jt} Quantity of stored raw oranges by storage unit j at time t

Ib_{mt} Quantity of stored processed oranges by distribution unit m at time t

V_j Equal to 1 if a storage unit j is opened at location, 0 otherwise.

W_k Equal to 1 if the SPI unit k is opened at location, 0 otherwise.

Y_m Equal to 1 if the distribution unit m is opened at location, 0 otherwise.

Z_l Equal to 1 if the fertilizer unit l is opened at location, 0 otherwise.

D. Objective functions

$$\text{Min } Z = Z1 + Z2 + Z3 + Z4 \quad (1)$$

$$Z1 = \sum_{j=1}^{J} f_j * V_j + \sum_{k=1}^{K} f_k * W_k + \sum_{m=1}^{M} f_m * Y_m + \sum_{l=1}^{L} f_l * Z_l \quad (2)$$

$$Z2 = \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{t=1}^{T} Cx_{ij} \times X_{ijt} + \sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{t=1}^{T} Cu_{jk} \times U_{jkt} + \sum_{k=1}^{K}\sum_{m=1}^{M}\sum_{t=1}^{T} Cp_{km} \times P_{kmt} + \sum_{k=1}^{K}\sum_{l=1}^{L}\sum_{t=1}^{T} Ce_{kl} \times E_{klt} + \sum_{k=1}^{K}\sum_{g=1}^{G}\sum_{t=1}^{T} Cv_{kg} \times V_{kgt} + \sum_{l=1}^{L}\sum_{o=1}^{O}\sum_{t=1}^{T} Cf_{lo} \times F_{lot} \quad (3)$$

$$Z3 = \sum_{j=1}^{J}\sum_{t=1}^{T} Ch_t \times Ih_{jt} + \sum_{m=1}^{M}\sum_{t=1}^{T} Cb_t \times Ib_{mt} \quad (4)$$

$$Z4 = \sum_{i=1}^{I}\sum_{t=1}^{T} Cp' \times q_{it} + \sum_{j=1}^{J}\sum_{k=1}^{K}\sum_{t=1}^{T} Ck'_t \times U_{jkt} + \sum_{l=1}^{L}\sum_{o=1}^{O}\sum_{t=1}^{T} Cl'_t \times F_{lot} \quad (5)$$

E. Constraints

$$q_{it} \le \mu c_{it} \quad \forall i \in I, \forall t \in T \quad (6)$$

$$Ih_{jt} \le \mu h_{jt} \quad \forall j \in J, \forall t \in T \quad (7)$$

$$Ib_{mt} \le \mu b_{mt} \quad \forall m \in M, \forall t \in T \quad (8)$$

$$\sum_{o=1}^{O} F_{lot} \le \mu r_{lt} \quad \forall l \in L, \forall t \in T \quad (9)$$

$$\sum_{k=1}^{K} V_{kgt} \le \beta_t \times \sum_{j=1}^{J} U_{jkt} \; \forall k \in K, \forall t \in T \quad (10)$$

$$\sum_{l=1}^{L} E_{klt} \le \theta_t \times \sum_{j=1}^{J} U_{jkt} \; \forall l \in L, \forall t \in T \quad (11)$$

$$\sum_{m=1}^{M} P_{kmt} \le (1 - \{\beta_t + \theta_t\}) \times \sum_{j=1}^{J} U_{jkt} \quad \forall l \in L, \forall t \in T \quad (12)$$

$$\emptyset \times \sum_{k=1}^{K} E_{klt} = \sum_{o=1}^{O} F_{lot} \; \forall l \in L, \forall t \in T \quad (13)$$

$$Ih_{j(t-1)} + \sum_{i=1}^{I} X_{ijt} = Ih_t + \sum_{k=1}^{K} U_{jkt} \quad \forall j \in J, \forall t \in T \quad (14)$$

$$\sum_{m=1}^{M} P_{kmt} \le d_{mt} \; \forall m \in M, \forall t \in T \quad (15)$$

$$\sum_{l=1}^{L} F_{lot} \le d_{ot} \quad \forall o \in O, \forall t \in T \quad (16)$$

$$\sum_{i=1}^{I}\sum_{t=1}^{T} X_{ijt} \le M \times V_j \quad \forall j \in J, \forall t \in T \quad (17)$$

$$\sum_{j=1}^{J}\sum_{t=1}^{T} U_{jkt} \le M \times W_k \; \forall k \in K, \forall t \in \quad (18)$$

$$\sum_{k=1}^{K}\sum_{t=1}^{T} P_{kmt} \le M \times Y_m \; \forall m \in M, \forall t \in T \quad (19)$$

$$\sum_{k=1}^{K}\sum_{t=1}^{T} E_{klt} \le M \times Z_l \quad \forall l \in L, \forall t \in T \quad (20)$$

$$V_j, W_k, Y_m, Z_l \in \{0,1\} \quad (21)$$

$$X_{ijt}, U_{jkt}, P_{kmt}, E_{klt}, V_{kgt}, F_{lot} \ge 0 \quad (22)$$

$$Ih_{jt} \ge 0, Ib_{mt} \ge 0, q_{it} \ge 0 \quad (23)$$

The objective of this proposed supply chain for Citrus Fruits is to minimize the overall cost, including Purchase cost, storage cost in the cold storage systems, operation cost, opening cost and transportation costs between the networks.

$$Total\,\text{Cos}\,t = Min \sum \frac{\text{Cos}\,t}{(1+ir)}$$

Minimize total SSC Cost (Z) = Fixed opening costs (Z_1) + Transportation Costs (Z_2) + Holding cost (Z_3) + Production and Processing and packaging and reprocessing cost (Z_4).

The experiments were conducted on CPLEX 12.9 Solver to validate the Multi Echelon Citrus Fruit supply chain in a personal computer powered by Windows 11 OS.

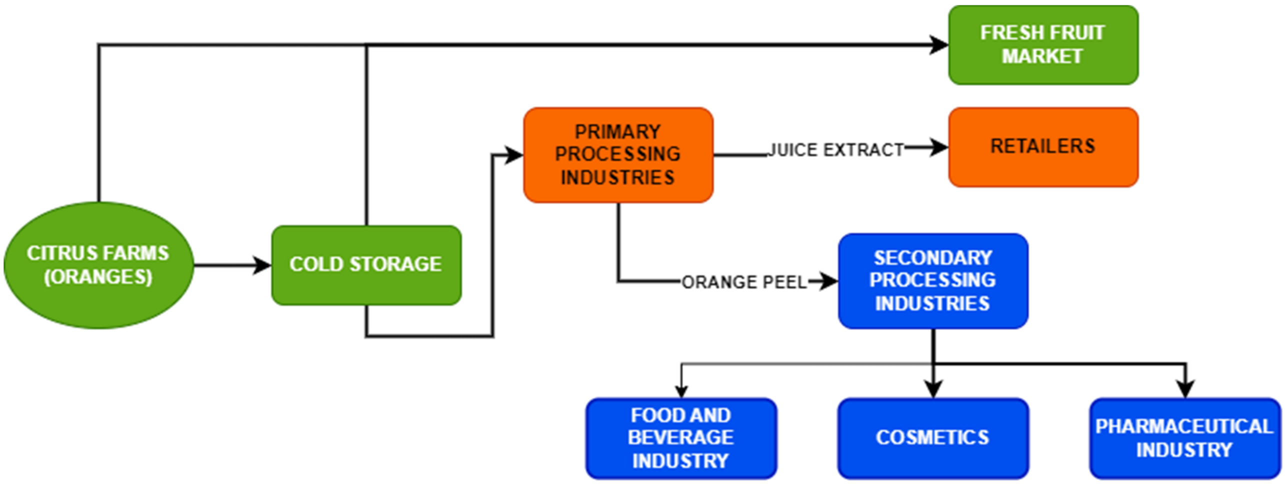

Fig. 4. Proposed Supply chain network for Citrus.

F. Keshtel Algorithm

Keshtel's algorithm was proposed by Hajiaghaei-Keshteli and Aminnayeri (2014) by observing the feeding behaviour of a duck from the anas family. As one keshtel can find the food source, it starts to circle on the water surface, which signals the neighbouring keshtel to surround it. If a better source is identified after the current food source depletes, then this process continues to find the source of food. Initially a random population is generated and called a kettle.

This Keshtel is divided into three parts N1, N2, and N3. The pseudo-code of the algorithm is presented below:

Initialize feasible Keshtels population randomly
Calculate the fitness
Sort Keshtels in three types: N1 as the best, N2, and N3 as the worst solutions
for i = I to MaxIt
for each N2,
Select a chromosome ai, from N1 population
Find the nearest neighbor to an in the populations
Determine the new solution bi, by finding distance between this best Keshtel ai and between neighbors.
Calculate the cost function of the new solution
If new solution ai, is better than the bi, then ai = bi
else
Considering half the radius generates two solutions bi1 and bi2
end if
If new solution bi1 or bi2 is better than ai, then replace it with ai,
Else
use the final generated solution as ai,
end if
end for
for each N2
selects two chromosomes randomly
move the chromosome of the population N2 according to two selected chromosomes
end for
Generates N3
chromosomes randomly
merge population N1, N2 and N3
sort the population
end for

TABLE II. PROBLEM SIZE

Classification	Instance	Problem size							
		OF	CS	PP1	GM	SPI	F&BI	CI	PI
Small	SP1	3	3	3	1	3	1	1	1
	SP2	6	6	6	3	6	2	2	2
	SP3	9	9	9	3	9	3	3	3
Medium	MP4	30	10	10	6	15	5	3	2
	MP5	40	20	20	8	20	10	5	5
	MP6	50	30	30	10	25	15	5	5
Large	LP7	100	50	50	20	30	20	5	5
	LP8	150	60	60	40	35	25	5	5
	LP9	200	70	70	60	40	25	10	5
	LP10	250	80	80	80	45	25	10	10

TABLE III. COMPARISON OF KA AND CPLEX

Problem	Total Cost		% Error
	CPLEX	KA	
1	272,536	280,520.2	2.929595
2	290,022.4	290,635.1	0.21126
3	331,002.4	332,325.2	0.399635
4	687,891.3	691,232.1	0.485658
5	681,244.8	689,217	1.17024
6	721,717.7	732,578.8	1.504896
7	1,085,000	1,086,091	0.100553
8	1,244,800	1,245,002	0.016228
9	1,498,999	1,504,232	0.3491
10	1,895,800	1,872,901	1.20788

IV. CONCLUSION

The proposed supply chain's effectiveness with the developed objective for the considered constraint was studied with both GAMS and KA. From Table III, KA has given better solutions comparatively, but the % of the variation is small.

$$Error\% = \frac{KA - CPLEX}{CPLEX} \times 100$$

The results show that the performance of GAMS is better than KA to reduce the total cost. For optimum solution Keshtel Algorithm, GA and SA are used in a hybrid fashion. The proposed network is designed to effectively serve the markets that use the value of the discarded orange peels after juice extraction.

CONFLICT OF INTEREST

The authors, Rajan Ponnusamy and Shahul Hamid Khan, affiliated with the Indian Institute of Information Technology Design and Manufacturing, Kancheepuram, Chennai, 600127, India, declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Rajan Ponnusamy conducted the research and drafted the manuscript. Shahul Hamid Khan analyzed the data and revised the manuscript. Both authors reviewed and approved the final version of the paper.

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