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OPTIMIZATION OF INVENTORY ROUTING PROBLEM TO MINIMIZE CARBON DIOXIDE EMISSION

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Abstract
This study proposes a modification in the considered two-stage inventory routing problem (IRP) to minimize the total amount of carbon dioxide (CO_2) emission in the network by reducing the total distance travelled by all the vehicles to meet the demand. Multiple suppliers (S) and multiple production units (PU's) are representing the two-stages of the IRP network. Each PU demand is fulfilled directly (single stage transportation) from the suppliers using homogeneous vehicles. This approach gives a long travel distance for every vehicle during each trip. The CO_2 emission mainly depends on the distance travelled by the vehicle and vehicle characteristics. The proposed modification is the induction of Centralized collection and distribution centre (CCDC) between the suppliers and the PU's. It modifies the single stage transportation approach into a two-stage approach where CO_2 emission is reduced due to less travel distance which is claimed as novelty in this study. An evolutionary algorithm of an artificial immune system (AIS) is used for studying both the network models with numerical data and their results are compared.

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Key Words: Inventory Routing, Homogeneous Vehicles, Carbon Dioxide Emission, Artificial Immune System

1. INTRODUCTION

The increasing amount of toxic gases like carbon dioxide (CO_2), carbon mono oxide and many greenhouse gases in the environment are responsible for global warming effect which is becoming a major critical threat on earth resulting in climatic changes in the world. Many governments and researchers have begun to pay close attention to green logistic concepts to reduce carbon dioxide emission caused by transportation. Though supply chain activities that include production, transportation and inventory emit CO_2, transportation module gets the main attention due to larger CO_2 emission [1]. In this direction, companies are inclined to adopt efficient vehicles such as electric and hybrid vehicles or to optimize their operational decisions. The latter one might be more economical in greater reduction of CO_2 emission than employing low-energy-consuming technologies [2].

In this research, the considered IRP network is a two stage supply chain model contains multiple suppliers (vendors) and multiple PU's (customer or buyer). The demand of the individual PU is satisfied directly by the entire suppliers using homogeneous vehicles. This model is studied as the first scenario. The inclusion of a CCDC unit (Fig. 1) between multiple suppliers and multiple PU's forms the second scenario. This modification in the network is claimed as the novelty in this study. The second scenario is the modified IRP network contains three stages, namely multiple suppliers (vendors), CCDC unit and multiple PU's (customer or buyer). The suppliers of the above two models are having a unique set of the component mix with different lot sizes for each component is as shown in Table I. At the same time, certain components in the different component mix are common. Similarly, each production unit also requires a unique set of components as demand and certain components

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are common among the different Production unit (Table II). The demand of the CCDC unit for each individual component is obtained by adding the demand of all the production units. The function of CCDC is to procure the components for its cumulative demand from the suppliers and then, distribute to each production unit exactly according to their demand requirements. Homogeneous vehicles are used for the above process. Both models are evaluated to find the optimum vehicle route to meet the demands of production units which gives the minimum amount of CO_2 emission based on the total travel distance.

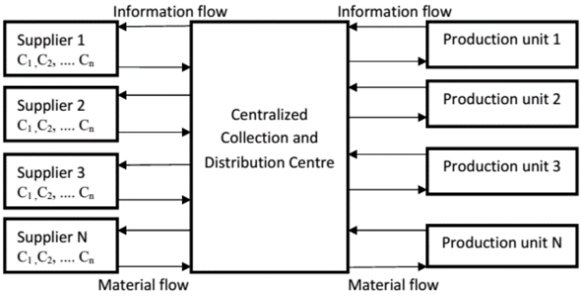

Figure 1: The proposed IRP network model with CCDC arrangement.

The IRP models were formally introduced by [3] and their recent complete academic reviews over the IRP systems were made by [4] followed by [5]. In the traditional IRP literature, researchers have considered only profits, costs and service levels through optimal inventory control strategy and vehicle schedules. Nowadays, the increase in environmental awareness related to transportation has drawn the attention of researchers and companies to consider fuel consumption or CO_2 emissions to address the environmental issues in IRP models. To obtain the optimum vehicle schedules in the IRP models, the distance travelled by the each vehicle is considered as the main criterion. At the same time, CO_2 emission is mainly based on the distance travelled by the vehicle and vehicle characteristics. So, distance is one of the key factors for the CO_2 emission in a supply chain system. Hence the transportation plays a vital role in the network for CO_2 emission. The network model considering transportation as the main source of CO_2 emissions is given by [6] and a detailed review of the research in the green logistics can be found in [1, 7].

The structure or topology of IRP models in literature [4] is classified into four types of networks, viz., One-to-One, One-to-Many, Many-to-One and Many-to-Many which decide the complexity of the problem.

In this research, the network of handling multi-product for many-to-many model is considered. The multi-product and multi-period logistics system [8] for one supplier with many customers under One-to-Many model is studied to reduce cost. Handling multi-products for many-to-many traditional IRP model, the decision support system is used for five different products to arrive the optimum transportation schedule for many plants to many destinations in a marine application [9]. A model for oil refineries to find the optimal route for the transportation of products using a fleet of ships [10] has proposed. The model of many-to-many have proposed by [11] where the product produced by one manufacturer (supplier) is not produced by any other manufacturer under a non-maritime approach to reduce the system's total cost by finding the optimum vehicle routing.

In the field of green supply chain, most of the literature deals with CO_2 emission at the level of production processes or network design decisions. Similarly, studies considering environmental concern in IRP models are also limited. Different types of environmental constraints for a proposed production model [12] have studied to decide their optimal product mix and production quantities. A carbon cap policy is used [13] for choosing the transport mode. The efficiency of supply network pooling [14] is used in reducing CO_2 emissions explained. A multi-product inventory model [15] has formulated for cold products with emission consideration. The network design decision models have studied [16-17] for environmental effects as CO_2 emission is considered along with the cost reduction.

The significance of detailed transportation process analysis [18] have found in the reduction of costs and carbon emissions for an IRP model. To improve the performance in the IRP models to control greenhouse gas emissions using transshipment option [19] have proposed. An economic order quantity (EOQ) model [20] has formulated to integrate inventory management and truckload transportation with a carbon cap constraint.

However, the network deals multi-product under many-to-many model having unique product set at each supplier and customer along with the constraints such as lot size and number of lots has not been addressed in the traditional IRP as well the models of IRP considering CO_2 emission problems so far to the best of our knowledge. So, there is a merit in the investigation of the proposed research under two different scenarios to evaluate and compare the amount of CO_2 emission in the network from the optimum total distance travelled by all the vehicles using AIS algorithm.

To estimate the total amount of CO_2 emission (E_T) in the network, researchers employ basically two approaches to measure the greenhouse gas emissions for transportation operations. Use of emission or environmental impact factors obtained through other environmental studies is considered as one approach [21, 16]. The other approach is based on the calculation of total energy consumed by the transportation operations. The first approach is used for this study to calculate the amount CO_2 emission based on the average CO_2 emission factor for Heavy Goods Vehicle (HGV) per km [22].

The AIS is already proved from its computational standpoint for the different applications, namely computer and network security [23], optimization problem [24], scheduling problems [25] and supply chain management [26].

The proposed model can be applied to the manufacturing as well as to the distribution industry such as the paper industry, automobile components, perishable items, groceries, cement and fuel. The rest of the paper is deliberated as follows: Section 2 describes the problem description, the model formulation and assumptions. Section 3 describes the AIS algorithm for Supply chain network. Section 4 describes the implementation of AIS with a numerical example. Section 5 indicates the results of the study. Section 6 concludes the study.

2. PROBLEM DESCRIPTION

This section describes the two-stage IRP network model under the two different scenarios as discussed earlier. Every supplier in the network is capable of supplying a unique set of components having a constriants such as lot sizes and number of lots as shown in Table I. Similarly, every production unit has a different component combination for the production as shown in Table II. The first scenario stands for many to many two-stage IRP model (Fig. 3) with suppliers and PU’s. Here, the demand requirement of the individual production unit is satisfied directly (single stage transportation) by the entire suppliers in the network using homogeneous vehicles. Due to the constraint of lot size at the supplier, excess components will be retained as inventory at each PU. In the direct transportation approach, each vehicle has to visit every supplier to satisfy the demand of each PU that causes the high CO_2 emission due to more transportation distance by all the vehicles. In order to reduce CO_2 emission, the above network is modified as three stage supply chain model. It stands for the second scenario that consists of three main components, namely suppliers, CCDC and PU’s, as shown in Fig. 1. Because of the addition of CCDC in the network, the considered network problem of many to many model is split into two sub problems, namely many to one and one to many model. The position of CCDC is apparently at the centre of PU’s and the suppliers' location and their distances in the network are as shown in Fig. 2. The function of CCDC is to collect components from the suppliers and distribute them from CCDC to PU's. So, the CCDC obtains the details of the total demand of the individual components from the PU's for the procurement of components from the supplier to CCDC. After the collection of components from the supplier, CCDC will distribute the exact quantity of components to production unit based on their demand requirements. Here, the excess components will be retained as inventory at the CCDC because CCDC cannot procure the exact quantity of the required components from the supplier due to lot size as a constraint. Inventory for both the models will be utilized by the next period demand. Homogenous vehicles are used for the transportation of components in the network. Due to this modification in the network, the vehicles used for transportation provide less travel distance to satisfy the demand of all the production unit. The network for both the scenarios subject to a comparative analysis in terms of the total amount of CO_2 emission based on the total travel distance of the vehicles.

2.1 Assumptions

- The demands for the PU's are known to the CCDC.
- Homogeneous vehicles are used for the collection and distribution of components.
- The availability of vehicles is enough to handle all the delivery requirements.
- A vehicle can visit more than one supplier as well as more than one PU in a single trip.
- Every supplier in the network is capable of supplying more than one type of component with different lot sizes. Similarly, for every component more than one supplier is available in the system.
- The cost of the same type components from all the suppliers is same.
- For handling of different components at the supplier's end as well as in the production unit, different container sizes are used for packing the components. Containers vary only in width; whereas the length and height of the container remain unaltered so as to accommodate components of an individual lot.
- Vehicle dimensions are taken as, length × width × height (435 × 200 × 100) cm^3. The space for complete packing of the vehicle for loading is 8,700,000 cm^3; the orientation of vehicle length (435 cm) will be shared as the width of the containers (used for components packing which may vary according to the volume of the batch size of the components); the width of the vehicle (200 cm) is fixed as the length of the container and the height of the vehicle (100 cm) is fixed as the height of the container. So the volume of the container is always represented as follows: $200 \times \underline{\quad} \times 100\ cm^3$.
- Vehicle loading at the supplier is in the order of supplier sequence according to the demand of the CCDC subject to the availability of components with the supplier.
- Vehicle loading at the CCDC is in the sequential order of the production unit.
- Setup time for producing components as batches is negligible.
- Vehicle loading and unloading duration is negligible.
- Ordering cost, loading cost and unloading cost for each component at supplier and production unit is included in the fixed cost of every vehicle.
- Setup cost and maintenance cost of the CCDC unit are also included in the fixed cost of each vehicle.
- All the vehicle used for transportation starts from the CCDC only.

2.2 Indices and parameters

i – index for suppliers ($i = 1, ..., I$),
j – index for production units ($j = 1, …, J$),
k – index for vehicles ($k = 1, ..., K$),

n – index for component ($n = 1, ..., N$),
x – index for number of lots at supplier ($x = 1, ..., q_{in}$),
S – supplier,
P – production unit,
C – component,
V_c – volume of the component in cm^3,
V_l – volume of the lot in cm^3,
W_l – weight of the lot in kg,
D_T – total travel distance in km,
E_k – amount of CO_2 emission for vehicle k,
E_T – total amount of CO_2 emission in kg,
E_{Af} – average CO_2 emission factor per km,
Q_{nj}^{P} – demand of the n^{th} component of j^{th} production unit,
Q_n – total demand of the n^{th} component at the CCDC,
q_{in} – number of lots available as inventory at the supplier i for n^{th} component,
q_{inx} – x^{th} lot at supplier i for n^{th} component,
IW_n – inventory at the CCDC for n^{th} component,
h_n – inventory carrying cost for the n^{th} component for one period,
CW – container width in cm,
VL_k^s – vehicle length utilized during loading of vehicle k used for supplier,
VL_k^p – vehicle length utilized during loading of vehicle k used for Production units,
d_k^S – distance travelled by vehicle k used for supplier,
d_k^P – distance travelled by vehicle k used for Production units,
d_k – distance travelled by vehicle k,
$y_u = 1$ – binary variable which is equal to 1 if $VL_k^s \neq 0,$ and 0 otherwise,
$y_v = 1$ – binary variable which is equal to 1 if $VL_k^p \neq 0,$ and 0 otherwise,
$d_{S[i],S[i+1]}$ – distance between i^{th} supplier and $i+1^{th}$ supplier,
$d_{S[j],S[j+1]}$ – distance between j^{th} production unit and $j+1^{th}$ production unit,
$d_{S[i],W}$ – distance between i^{th} supplier and CCDC unit,
$d_{S[j],W}$ – distance between j^{th} supplier and CCDC unit,
$d_{S[i],S[i+1]} = 0$ – when vehicle k not visiting $S[i+1]$ from $S[i]$,
$d_{S[j],S[j+1]} = 0$ – when vehicle k not visiting $S[j+1]$ from $S[j]$,
$d_{S[i+1],W} = d_{W,S[i]}$ – when vehicle k not visiting $S[i+1]$ from $S[i]$,
$d_{S[j+1],W} = d_{W,S[j]}$ – when vehicle k not visiting $S[j+1]$ from $S[j]$.

$$\text{Minimize } E_T = D_T \times E_{Af} \tag{1}$$

$$D_T = \sum_{K=1}^{K} d_k^S + \sum_{K=1}^{K} d_k^{PU} \tag{2}$$

$$\text{s. t} \qquad VL_k^s = \sum_{i=1}^{I} \sum_{n=1}^{N} \sum_{x=1}^{q_{in}} CW_{inx}^S \times y_u \qquad \forall\, k,\ \ k = 1, 2, \dots, K \tag{3}$$

$$d_k^s = \sum_{i=1}^{I} d_{w,s[i]} + d_{s[i],\ s[i+1]} + d_{s[i+1],w} \qquad \forall\, k\,,\ VL_k^s,\ \ k = 1, 2, \dots, K \tag{4}$$

$$Q_n = \sum_{j=1}^{J} Q_{nj}^P \qquad \forall\, n\,,\ \ n = 1, 2, \dots, N \tag{5}$$

$$IW_n = Q_n - \sum_{i=S[i]}^{I} \sum_{x=1}^{q_{in}} q_{nix} \quad \text{if } IW_n < 0 \text{ then } n = n + 1 \quad \forall\, n\,,\ \ n = 1, 2, \dots, N \tag{6}$$

$$VL_k^P = \sum_{j=1}^{J} \sum_{n=1}^{n} CW_{jn}^P \times y_v \qquad \forall\, k,\quad k = 1, 2, \dots, K \tag{7}$$

$$d_k^P = \sum_{j=1}^{J} d_{w,s[j]} + d_{s[j],\ s[j+1]} + d_{s[j+1],\ [w]} \qquad \forall k, VL_K^P \quad k = 1, 2, \dots, K \tag{8}$$

$$VL_k^S \leq 435 \;\;\&\;\; VL_k^P \leq 435 \quad \forall k, \quad k = 1, 2, 3, \ldots, K \tag{9}$$

The objective function of Eq. (1) is to find the minimum amount of CO_2 emission for the network, Eq. (2) gives the sum of the total distance travelled by all the vehicles at supplier and production unit, Eqs. (3) and (7) give the total vehicle space utilization for each vehicle, Eqs. (4) and (8) give the total distance travelled by each vehicle, Eq. (5) gives the total demand of the individual component, Eq. (6) gives the inventory at the CCDC for each component, Eq. (9) stands for vehicle space constraint.

3. PROPOSED AIS ALGORITHM FOR IRP NETWORK PROBLEM

The AIS algorithm for solving the IRP model is presented below. The vehicle routing schedules stands for the path in which the vehicle has to be operated to satisfy the demand of the network. The possible vehicle routing schedules are represented by integer valued sequences with the corresponding prefix s or p as follows: s1 s2 s3 s4 p1 p2 p3 p4. The total number of elements in each string is equal to the sum of the number of suppliers and PU's. Therefore, the total number of combination strings is composed of the permutations of supplier multiplied by permutations of PU. Those strings are accepted as antibodies of the AIS. The algorithm provides solution by the evolution of these antibodies. The proposed algorithm is presented below:

```
Create a population of A antibodies (A is the parameter of antibody population size):
For each generation do:
        Decode the antibodies (sequences) in the antibody population
        Determine the total travel distance (affinity) of antibodies
        Calculate the selection probabilities (rate of cloning)
        Cloning (generate copies of the antibodies)
Steps in the mutation process:
For each generated clone do:
        Inverse mutation (generate a new string)
        Decode the new string
        Calculate the total travel distance of the new string
if the total travel distance (new string) < total travel distance (clone) then
clone= new string
else,
clone = clone:
do pair wise interchange mutation (generate a new string):
decode the new string:
Calculate the total travel distance of the new string:
If the total travel distance (new string)  < total travel distance (clone) then
         clone = new string:
else
         clone = clone:
         antibody= clone:
Eliminate worst % B number of antibodies in the population:
         (B is the parameter of the elimination ratio of antibodies)
(Create new antibodies at the same number (% B of population)
 Change the newly created ones with the eliminated ones:
While stopping criteria = false.
          Repeat
else
stop:
```

4. IMPLEMENTATION OF AIS ALGORITHM TO IRP MODEL

4.1 Software development

The artificial immune system algorithm is implemented in C language on a personal computer Pentium (R) Dual-core T4200@2.00 GHz with 2 GB RAM. The maximum number of iterations has been set to 25 × N, where N is the population size.

4.2 Numerical example

The modified IRP network having CCDC model (scenario 2) is considered for the numerical illustration with the following data. Number of suppliers = 4; number of production units = 4; population size (N) = 5; the vehicle model of TATA 909 EX is considered for transportation model whose load carrying capacity is 6350 kg and its dimensions are taken as length × width × height (435 × 200 × 100) cm^3. The suppliers and production unit details are shown in Table I and II. The schematic representation of the two models along with their distances to be evaluated using AIS are shown in Figs. 2 and 3. The evaluation of both models is carried out to find the minimum total amount of CO_2 emission (E_T) by all the vehicles and compared to the objective function. Defra [23] has reported the average emission factor for different type of vehicle at different loads. Here, the HGV model with average emission factor per km of 584.4 g is considered in the calculation of the amount of CO_2 emission.

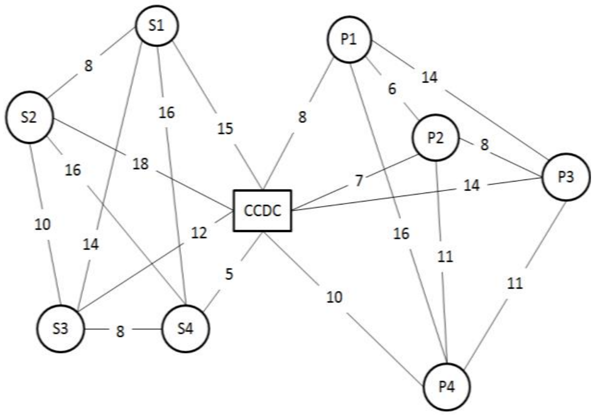

Figure 2: Proposed network with CCDC and its distance between suppliers and PU's in km.

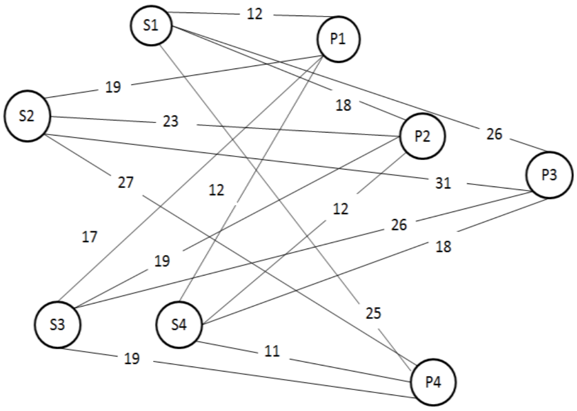

Figure 3: Two stage IRP network and its distance between supplier units and PU's in km.

Vehicles are loaded with components using a container. Consider the supplier S_2 who can supply the component 1 with a lot size as 400 components requires 600000 cm^3 spaces for packing. The width required to accommodate 600000 cm^3 is calculated as 30 cm (600000 / (200 × 100) = 30). So the container size is 200 × **30** ×100 cm^3. The width of the container occupies 30 cm out of 435 cm of the vehicle length. Once the summation of the loaded container width exceeds 435 cm, the vehicle will be sent for delivery and a new vehicle will arrive for loading. The width required for various containers are given in the last column of Table I and II.

Table I shows the details of the component mix for each supplier unit with its individual component lot size, the available number of lots, volume per lot and container width for each lot.

Table I: Details of component for each supplier unit.

S	***C***	**Lot size**	q_{in}	h_n **INR**	V_c (cm^3)	V_l (cm^3)	W_l (kg)	***CW*** (cm^3)
S_1	1	300	2	1.50	1500	450000	282	25
	2	500	1	1.50	1500	750000	471	40
	3	200	3	1.60	1531.25	306250	193	18
	5	1000	2	0.75	750	750000	471	40
	6	1500	2	0.75	625	937500	589	50
	7	300	3	2.25	1875	562500	353	30
	12	3000	2	0.25	123.16	369480	231	20
S_2	1	400	2	1.50	1500	600000	377	30
	3	400	2	1.60	1531.25	612500	384	35
	4	500	2	2.00	1562.5	781250	490	40
	5	1500	2	0.75	750	1125000	706	60
	6	1500	4	0.75	625	937500	589	50
	8	350	2	3.00	3000	1050000	659	55
	9	400	3	1.25	1250	500000	314	25
	11	300	4	3.00	3000	900000	565	50
S_3	2	300	3	1.50	1500	450000	282	25
	4	400	2	2.00	1562.5	625000	392	35
	5	1000	3	0.75	750	750000	471	40
	6	1000	3	0.75	625	625000	392	35
	8	400	2	3.00	3000	1200000	753	60
	9	200	5	1.25	1250	250000	157	15
	10	500	3	1.00	1125	562500	353	30
S_4	5	1500	3	0.75	750	1125000	706	60
	6	2000	4	0.75	625	1250000	785	65
	7	400	3	2.25	1875	750000	471	40
	10	400	5	1.00	1125	450000	282	25
	11	200	4	3.00	3000	600000	377	30
	12	4500	2	0.25	123.16	554220	346	30

Table II shows the details of the component mix for each production unit with its individual component demand size, volume and container width.

Table II: Demand details of the components of each production unit.

P	***C***	***Q***	h_n **INR**	V_c (cm^3)	V_l (cm^3)	W_l (kg)	***CW*** (cm^3)
P_1	1	500	1.50	1500	750000	471	40
	2	500	1.50	1500	750000	471	40
	3	500	1.60	1531.25	765625	481	40
	4	500	2.00	1562.5	781250	490	40
	5	2500	0.75	750	1875000	1177	95
	6	2500	0.75	625	1562500	981	80
	12	1500	0.25	123.16	183985	116	10
P_2	1	400	1.50	1500	600000	377	30
	3	400	1.60	1531.25	612500	384	35
	4	400	2.00	1562.5	625000	392	35
	5	2000	0.75	750	1500000	942	75
	6	2000	0.75	625	1250000	785	63
	7	400	2.25	1875	750000	471	38
	9	400	1.25	1250	500000	314	25
	10	400	1.00	1125	450000	282	25
	12	1600	0.25	123.16	197056	123	12

P_3	2	600	1.50	1500	900000	565	45
	5	3000	0.75	750	2250000	1413	115
	6	3000	0.75	625	1875000	1177	95
	8	600	3.00	3000	1800000	1130	90
	9	600	1.25	1250	750000	471	40
	10	600	1.00	1125	675000	424	35
	11	600	3.00	3000	1800000	1130	90
	12	2400	0.25	123.16	294375	185	15
P_4	4	500	2.00	1562.5	781250	490	40
	5	2500	0.75	750	1875000	1177	95
	6	2500	0.75	625	1562500	981	80
	7	500	2.25	1875	937500	589	50
	8	500	3.00	3000	1500000	942	75
	10	500	1.00	1125	562500	353	30
	11	500	3.00	3000	1500000	942	80
	12	2000	0.25	123.16	245313	154	15

Table III shows the randomly generated initial population set of sequences for the modified network (scenario 2) with its E_T and D_T values. The sequence with a less E_T value among the set will have more clones. Affinity factor is calculated as $1/E_T$.

Number of clones = Round off [(affinity factor / total affinity factor) × population size].

Table III: Initial population set of sequences with their E_T, D_T values and number of clones.

Seq. no.	**Generated sequence**								**E_T** (kg)	**D_T** (km)	**Affinity factor**	**Number of clones**	**Ceiled clone value**
	s				p								
1	2	1	3	4	4	1	2	3	181.75	311	0.005502	0.9347	1
2	2	4	3	1	3	2	1	4	171.23	293	0.005840	0.9921	1
3	4	1	2	3	2	4	1	3	158.37	271	0.006314	1.0727	2
4	1	2	4	3	2	3	4	1	175.90	301	0.005685	0.9658	1
5	1	2	3	4	3	2	4	1	164.22	281	0.006089	1.0345	2
Total affinity factor											0.029430		

The sequences shown in the Table IV are sorted out in the ascending order on the basis of the E_T and then repeated sequences are removed, followed by the removal of extra sequences above the population size at the bottom level. Finally, 30 % of sequences (having higher total travel distance) from the bottom of the latest population set are replaced by newly generated random sequences as receptor editing process in order to give a new search space in the population set.

Table IV: Selected sequence after cloning and mutation process based on the E_T value.

Sequence no.	**No. of clones**	**Cloned sequence**								**E_T** (kg)			**Selected sequence after mutation for lowest E_T**								**D_T** (km)	**E_T** (kg)
		s				p				**Actual**	**Mutation process**		s				p					
											Inverse	**Pair wise**										
1	1	2	1	3	4	4	1	2	3	181.74	176.48	145.51	4	3	1	2	3	2	1	4	249	145.52
2	1	2	4	3	1	3	2	1	4	171.22	167.13	185.25	4	2	3	1	4	1	2	3	286	167.14
3	2	4	1	2	3	2	4	1	3	158.37	191.68	176.48	4	1	2	3	2	4	1	3	271	158.37
		4	1	2	3	2	4	1	3	158.37	158.37	185.25	4	1	2	3	2	4	1	3	271	158.37
4	1	1	2	4	3	2	3	4	1	175.90	166.55	154.28	3	4	2	1	1	4	3	2	264	154.28
5	2	1	2	3	4	3	2	4	1	164.21	155.45	146,68	4	3	2	1	1	4	3	2	251	146.68
		1	2	3	4	3	2	4	1	164.21	154.86	154.86	4	3	2	1	1	4	2	3	265	154.87

The above process gets terminated, if the top two antibodies of the previous iteration are same as that of current iteration antibodies obtained after the receptor editing process and the final result is obtained from the latest receptor editing process table. So the first antibody will give the minimum amount of CO_2 emission with the total travel distance.

Table V shows the details of the optimum sequence with lowest E_T and D_T value along with each vehicle length utilization of the proposed network having CCDC (two-stage transportation) after the 9th iteration of the simulation process.

Table V: Results of the antibody s-4 s-3 s-2 s-1 p-1 p-2 p-3 p-4 with their lowest E_T and D_T values.

K	**Suppliers – CCDC**			**CCDC – Production units**			
	VL **200 × --- × 100** (cm^3)	d_k^S (km)	E_k (kg)	***K***	***VL*** **200 × --- × 100** (cm^3)	d_k^P (km)	E_k (kg)
1	375	10	5.84	1	410	21	12.27
2	435	10	5.84	2	433	29	16.95
3	425	25	14.61	3	405	35	20.45
4	405	40	23.38	4	425	20	11.69
5	248	41	23.96				
Total		126	73.63		Total	105	61.36
D_T = 126 + 105 = 231 km				E_T = 73.63 + 61.36 = 134.99 kg			

Similarly, the two stage network also solved for the same input parameters using the same simulation procedure. Table VI shows the result of the network model without CCDC unit (direct transportation) is obtained after the 11th iteration. The sequence shown in the table gives the lowest E_T and D_T values along with the vehicle length utilization for each vehicle.

Table VI: Results of the antibody p-1 p-4 p-2 p-3 s-2 s-1 s-3 s-4 with their lowest E_T and D_T values.

K	***VL*** **200 × --- × 100** (cm^3)	E_k (kg)	d_k (km)
01	430	23.38	40
02	410	40.32	69
03	431	50.25	86
04	415	58.44	100
05	430	38.57	66
Total		E_T = 210.96	D_T = 361

5. RESULTS AND DISCUSSION

The two-stage and its modified three-stage IRP networks are validated with different combinations of suppliers and PU's and their results are as shown in Table VII and VIII. In every combination, the scenario 1 follows direct (single stage) transportation approach and the scenario 2 uses the two-stage transportation approach. i.e., the method of satisfying the demand of the production units follows different approaches for the scenario 1 and scenario 2. The input facts for solving the network scenarios are same for the given combination. Both scenarios are solved with the help of an AIS algorithm to find the optimum sequence which gives the minimum values for both E_T and D_T.

The detailed discussion of the results of the network can be classified into two categories. First category stands for the network combination of equal number of supplier and PU's and second category stands for the network combination of different number of suppliers and PU's. In both categories, the result of the network clearly shows the advantages of CCDC in the IRP network being derived in terms of considerable reduction of CO_2 emission due to a drastic cut in the total travel distance.

The results shown in Table VII compare the two scenarios of the network for different combinations which are standing for the first category where the number of suppliers and PU's are equal in the network. For each network combination, the value of E_T and D_T for scenario 2 is much lesser than the scenario 1 and its comparison and reduction of value in percentage with scenario 1 is shown in Table VII. The result of this category for each combination illustrates that, the scenario 2 shows an average reduction of 36.07 % in the total CO_2 emission (E_T) as well as the total travel distance (D_T) in comparison with the scenario 1. This category gives an exemplary advantage of having a CCDC unit in the IRP network both in terms of E_T and D_T values.

Table VII: Result of the IRP model having equal number of PU's and suppliers in the network.

Network combination	**Type of network scenario**	**Optimum sequence**	E_T (kg)	**Reduction on E_T** ((1 – 2) / 1) × 100 (%)	D_T (km)	**Reduction on D_T** ((1 – 2) / 1) × 100 (%)
p-3 / s-3	1	p3 p2 p1 / s3 s2 s1	133.82	34.91	229	34.91
	2	s1 s2 s3 / p3 p1 p2	87.08		149	
p-4 / s-4	1	p1 p4 p2 p3 / s2 s1 s3 s4	210.96	36.01	361	36.01
	2	s4 s3 s2 s1 / p1 p2 p3 p4	134.99		231	
p-5 / s-5	1	p1 p2 p3 p4 p5/ s2 s1 s4 s3 s5	241.35	37.28	413	37.28
	2	s2 s1 s4 s3 s5 / p1 p2 p4 p3 p5	151.35		259	

The second category of analysis as shown in Table VIII is obtained with a variation in the number of production and supply units. If three production units are fulfilled by the four suppliers (P-3 / S-4) and vice versa forms the two network combination. For each network combination, the value of E_T and D_T for scenario 2 is much lesser than the scenario 1 and its comparison and reduction of value in percentage with scenario 1 is shown in Table VIII.

Based on the result, this category gives an average reduction of 13.11 % for scenario 2 of E_T and D_T values over the scenario 1. At the same time, the results of this category are much lesser (an average of 13.11 %) in comparison with the previous category (an average of 36.07 %) due to the reduction in the routing distance between the unequal number of supplier and PU's. Even though the second category as given in Table VIII alone is taken for consideration, there is an acknowledgeable and an appreciable role played by CCDC in the network models. The significant finding in the comparative study between these categories ascertains that the inclusion of CCDC in these network models gives environmental benefits through the reduction of the total CO_2 emission (E_T) in the network.

Table VIII: Result of the IRP model having different number of PU's and supplier in the network.

Network combination	**Type of network scenario**	**Optimum sequence**	E_T (kg)	**Reduction on E_T** ((1 – 2) / 1) × 100 (%)	D_T (km)	**Reduction on D_T** ((1 – 2) / 1) × 100 (%)
p-3 / s-4	1	p1 p3 p2 / s1 s3 s2 s4	147.27	14.68	252	14.68
	2	s1 s4 s3 s2 / p3 p1 p2	125.65		215	
p-4 / s-3	1	p4 p3 p1 p2 / s1 s2 s3	182.33	11.53	312	11.53
	2	s1 s2 s3 / p1 p2 p3 p4	161.29		276	

6. CONCLUSION

In the view of minimizing the total amount of CO_2 emission in the considered two-stage IRP network, a modification of introducing a CCDC unit between the two stages of the network is proposed. This converts the network as the three-stage network. These two types of network approach have been solved for the various network combinations using an AIS algorithm to arrive the values of the optimum amount of the total CO_2 emission in the network. From the results of these two approaches, the amount of reduction of the total CO_2 emission in the modified network is calculated in comparison with the two-stage network. Based on the above comparison, the conclusions are drawn as follows:

(1) The included CCDC unit in the two-stage network reduces CO_2 emission due to the reduced total travel distance travelled by all the vehicles to fulfil the demand of the network. This reduced travel distance in the network is because of the modified two-stage transportation approach instead of single- stage transportation approach.

(2) It is validated with different network combinations under two different categories. In both categories, the significance of the CCDC uint is proved through its calculated values, which is greatly less value than the values of the two-stage network.

From the above argument, It is proved that the inclusion of CCDC unit in the two-stage network under the given scenario is the more effective approach to reduce the total amount CO_2 emission in the network through the reduced total travel distance covered by all the vehicles.

This proposed model is highly useful in manufacturing industries, retailer business and other VMI problems. The above problem has considered for a single period. So there is scope for studying the effect of this approach for more than one period with same demand or variable demand pattern to increase the environmental benefits by reducing CO_2 emission in the IRP network.

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