Solving the e-commerce logistics problem using anti-predatory NIA

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Abstract: E-commerce is expanding their roots in every business. Fast, efficient, reliable, timely delivery of goods and optimal transportation cost are the major challenges in e-commerce. To overcome these challenges, e-commerce companies are using a well-planned arrangement of warehouses and distribution centres (logistics network). This logistics network also reduces the operational cost and capital investment of an e-commerce company. This study proposes a novel solution to deal with e-commerce logistics problem (ECLP) using anti-predatory NIA (APNIA). The proposed approach is useful for identifying cities where warehouses and distribution centres can be established; and allocating the distribution centres to warehouse in order to reduce total cost of goods transportation. The proposed approach is also useful for predicting the number of warehouses to be established for optimal logistics network. The experimental evaluation reveals that the proposed method achieves 2.30% lower gap value and 20% more consistent optimal results as compared to the genetic algorithm.

Keywords: APNIA; anti-predatory NIA; distribution centre; e-commerce; establishment cost; genetic algorithm; goods; HLP; hub location problem; logistics; meta-heuristic; spoke; transportation cost; warehouse.

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1 Introduction

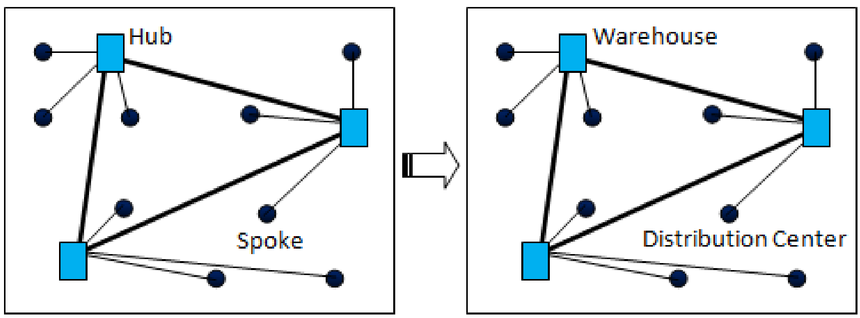
E-commerce is booming exponentially due to increase in online business platforms and has become a part of our daily life (Mangiaracina et al., 2015). Logistics is an important activity of the e-commerce, because it is a point where an online transaction gets transformed into an offline one. In other terms, logistics involves transporting the goods from the business store to the customer. According to KPMG Report (2016), the Indian e-commerce logistics industry was valued at USD 0.46 billion in 2016 and is projected to grow by 48% in the next five years to reach USD 2.2 billion by 2020. This statistic signifies the importance of logistics in e-commerce business.

The major challenges in the logistics business are seamless transportation and timely delivery of goods. The optimal total cost of goods transportation is another major challenge. Overcoming these challenges requires a well-planned logistics process between the cities housing the stores (Mangiaracina et al., 2015).

The most efficient way to solve these challenges is to develop a warehouse-and-distribution centre (W&DC) network between the cities which is commonly termed as a logistics network. The warehouse acts as a sortation centre/transhipment point/distribution point to others or to final destination/shipment delivery centre. The distribution centre (DC) acts as the origin or destination city of the goods (Yu et al., 2016). The W&DC network is similar to the hub-and-spoke (H&S) network

(Goldman, 1969) which is illustrated in Figure 1. The H&S network is a topology of arranging the nodes/locations/cities in which few nodes act as a hub and remaining nodes act as a spoke. Spokes are connected to the hubs in a way that ensures that all flow passes through the hub to reach the other spokes. It is economical, reliable and has better performance compared to other solutions like, complete graph (CG), minimum spanning tree (MST), travelling salesman (TS) and all pair shortest path (APSP). This is because, these solutions do not incorporate the impact of various factors like, economical benefits, type of transportation link between the cities, demand and supply of goods between the cities and transportation cost of goods between the cities. The overall objective of this logistics planning is to reduce the operational costs, capital investment and improve profitability of the company. This logistics planning problem is named as the e-commerce logistics problem (ECLP).

Figure 1 (a) H&S and (b) W&DC network (see online version for colours)



(a) (b)

The ECLP is a real world application of hub location problem (HLP) (Ishfaq and Sox, 2011; Gelareh and Nickel, 2011). HLP deals with identifying the hubs and associating spokes to hubs in order to route the flow between the Origin (O) – Destination (D) pairs. The objective of HLP is to develop an H&S network, which has optimal total cost of the given network (Campbell and O'Kelly, 2012).

In the past, several HLP's mathematical formulations have been proposed by various researchers (Hekmatfar and Pishvaee, 2009). Operation research methods are best suited to solve small HLPs, but in the case of large HLPs (means a large number of nodes in problem), meta-heuristic methods are mostly used because of computational complexity of HLPs. Many researchers have used various meta-heuristic algorithms to solve the HLPs. These algorithms are genetic algorithm (GA) (Topcuoglu et al., 2005), particle swarm optimisation (PSO) (Yang et al., 2013), simulating annealing (SA) (Abdinnour-Helm, 2001), ant colony optimisation (ACO) (Randall, 2008), Tabu search (Klincewicz, 1992) and many others.

The proposed work aims to solve the ECLP using recently proposed anti-predatory NIA (APNIA) (Sachan and Kushwaha, 2019). Here, APNIA is used to solve a problem involving 10 cities which is same as Qin and Gao (2017). The proposed solution utilises the APNIA for evaluation based on experiments. These experiments validate the correctness and sustainability of APNIA for solving the ECLP and also investigate the sensitivity of discount factor (α) and number of warehouses (P) in the ECLP. The obtained experimental results are evaluated against genetic algorithm based expected cost minimisation model (GA-ECMM) (Qin and Gao, 2017).

Rest of the study is organised as follows: in consequent sections related work, ECLP, APNIA and APNIA for ECLP are presented. The experimental evaluations are discussed in Section 7. Section 8 contains concluding remarks.

2 Related work

This section discusses previous scientific research and development related to the HLP and ECLP. The concept of H&S network was introduced by Goldman (1969) and first mathematical formulation of H&S network was proposed by O'Kelly (1987). This is a quadratic integer programming model for single allocation of spokes to hub with unlimited capacity of hubs. Campbell (1992) proposes a linear integer programming formulation for HLPs for multiple allocations of spokes to multiple hubs. In subsequent work, O'Kelly (1992) extends his previous work and incorporates the impact of fixed cost of hub establishment in HLP model. Based on the work of O'Kelly, Campbell (1994, 1996) proposes a model for multiple allocations with a fixed cost.

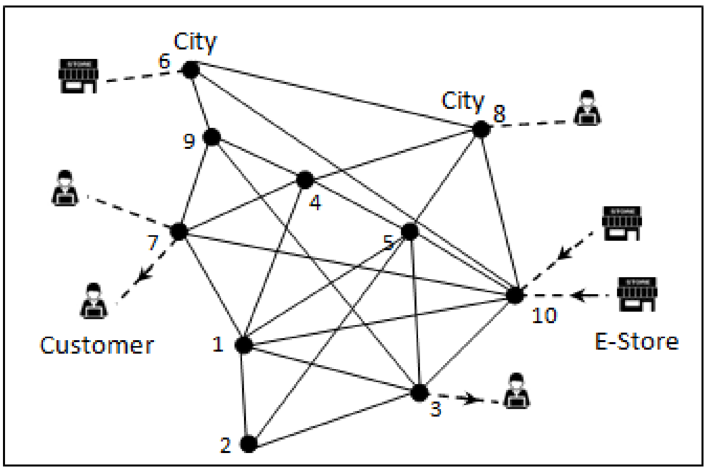
Many researchers have proposed various applications-based mathematical formulations for HLP. These applications are transportation networks (Gelareh and Nickel, 2011), cargo applications (Alumur and Kara, 2009), postal delivery system (Çetiner et al., 2010), telecommunication network (Carello et al., 2004) and many others (Jaillet et al., 1996; Klose and Drexl, 2005). These mathematical formulations are based on application-specific assumptions.

ECLP is an application of HLP which comes under the domain of commodity transportation system. Li et al. (2013) propose a hybrid meta-heuristic algorithm for routing the returned inventory in e-supply business. This algorithm is a hybrid of GA and SA. In another work, Liu (2014) proposes a GA based model for optimising the network site for the reverse logistics in e-commerce business. Subsequently, Liu et al. (2015) develop a parallel algorithm for managing the returns in e-commerce, which is based on the GA and SA. In Ambrosino and Sciomachen (2016), the authors propose a mixed-integer programming model for a freight logistics problem. The developed model minimises the location and shipping cost. Qin and Gao (2017) propose two models for handling the uncertain flows in HLP and solve the HLP using the GA. Masaeli et al. (2018) propose three models for shipment scheduling and investigates the impact of network configuration on holding cost, total cost and routing decision. In Bidani and Frikha (2018), authors present a hybrid multi-criteria approach to solve the logistics outsourcing problem. Rokbani et al. (2019) present a hybrid of gravitational PSO, ACO and local search approach to solve the travelling salesman problem. These are some of the recent developments in the field of commodity transportation system.

3 E-commerce logistics problem (ECLP)

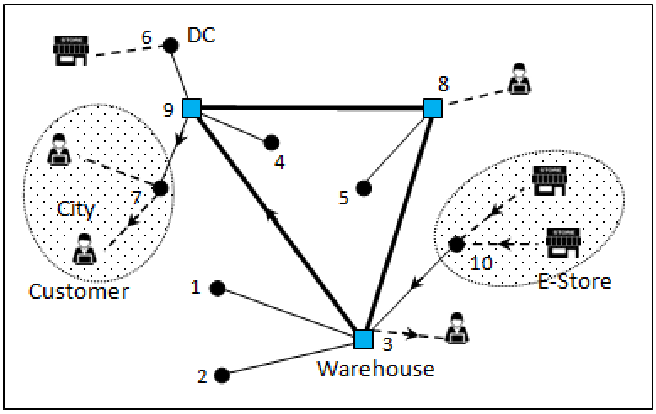
In today's competitive e-business era, e-commerce logistics require fast, efficient and on-time goods delivery system. To establish such system requires a lot of effort and planning. One of the simplest solutions of this problem is to create direct goods transportation link between every pair of O-D city. But this is not a practically feasible solution for an e-commerce company. An alternate and more efficient solution is to develop a H&S network (Goldman, 1969) between the cities in which hubs act as a cities where warehouse can be established and spokes act as a cities where distribution centres are positioned. Figure 2 illustrates an ECLP. It illustrates that, there exist multiple transportation links between cities, not all of which are optimal. An optimal logistics network for transporting goods will save financial expenses for the e-commerce company and increased satisfaction for the customer.

Figure 2 Diagram of ECLP



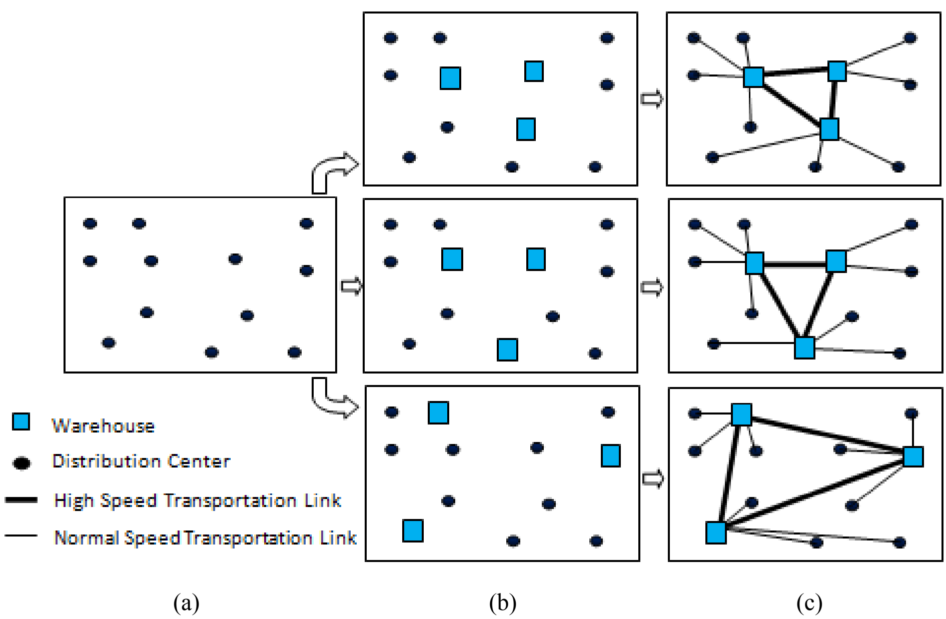
For the best possible solution, the logistics company establishes the warehouses and DCs in different cities. The selection of city, where warehouse can be established, is a complex and subjective assessment process which depends on various factors like, renting value or land price, facility development cost, amount of goods flow (demand and supply), unit cost transportation and many others. Warehouses are special cities equipped with special facilities and works as a transhipment point, sortation centre and distribution point for other warehouse or to final destination. These warehouses are connected via high speed transportation links like, air freight, high speed railways and highways. The high speed transportation link provides economical benefits by the discounted transportation cost of goods. Economical benefits are incorporated in the ECLP in terms of discount factor and its value always lies in between [0, 1] (Nickel et al., 2001). The value of α depends on the type of transportation link between the warehouses. The lower value implies the higher economical transportation link. The DCs are connected with warehouses via a normal transportation link. The number of warehouses also influences the optimal arrangement of W&DC network. The advantage of such transportation network is that logistics companies may increase their presence in a larger number of cities and even across the country with minimum expenditure. A possible solution/arrangement of ECLP (as represented in Figure 2) is illustrated in Figure 3 where the rectangles represent the warehouse and dark dots represent the DCs. The thick line represents a high speed transportation link, thin line represents normal transportation link and the dotted line represents local transportation link from store to DC or DC to store. Figure 3 shows that, all goods are collected in the origin DC from where they are transported to the destination DC via warehouses. At the end, destination DC delivers the goods to customers.

Figure 3 A possible solution (W&DC network) of ECLP (see online version for colours)



ECLP consists of two sub-problems: first one is to locate cities where warehouse and DC can be established and the second one is to allocate DC to warehouses (Alumur and Kara, 2009). Our objective is to solve this problem so in order minimise the total cost of goods transportation. The basic steps to solve an ECLP are shown in Figure 4.

Figure 4 Basic problem solving steps to solve an ECLP: (a) given cities; (b) warehouse and DC and (c) DC allocation (see online version for colours)



The underlying assumptions are detailed in mathematical formulation of the problem in Section 3.2. The components and characteristics of ECLP are discussed in continuous section.

3.1 Components and characteristics of ECLP

The main components of the ECLP are:

- *Warehouse*: A special kind of city which collects goods from other warehouse, and regroups and distributes it to other warehouses or to their final destination. In other terms, it works as a sortation centre/transhipment point/distribution point/shipment delivery centre.
- *Distribution centre*: The remaining cities which are not selected as a warehouse, are known as DC. These are the initial source/origin city or final destination city of the goods. DCs are responsible for collecting the goods from the local business stores, transporting the goods to nearest warehouse and delivering the goods to customers.
- *Transportation network*: There are two-levels of network:
  - *warehouse level network*: This connects the warehouses among each other.
  - *distribution centre level network*: This connects the DC to warehouse.

The general characteristics of ECLP are:

- The number of cities in a logistics network is defined in the problem.
- A fixed number of warehouses are required to be established which is defined in the problem.
- The flow of goods between the cities is uncertain. The minimum, most possible, maximum flow between the cities is given in the problem.
- The capital investment is required to establish the warehouse at every city.
- All goods require transportation expenses (unit cost of transportation).
- The warehouse level networks have economical benefits in transportation expense (discount factor).

3.2 Mathematical modelling of ECLP

The ECLP is similar to the uncapacitated single allocation p-hub location problem with fixed cost (USApHLP-FC) (Qin and Gao, 2017). This section discusses various assumptions that are considered for the mathematical formulation of ECLP. The objective function of problem with various constraints is also discussed here, including the input and output variables.

Assumptions

The assumptions which are considered during the formulation are:

- The objective function is considered as a MiniSum.
- The solution space of the model is discrete and finite.
- The number of warehouse cities is fixed and known (exogenous).
- The capacity of the warehouses is considered as unlimited (uncapacitated).
- Every city has a fixed cost of warehouse establishment.
- The symmetrical unit transportation cost matrix of goods is considered.
- The flow of goods between the cities is considered to be uncertain which is represented by 3-tuples (minimum, most possible, maximum).
- All the warehouse cities are connected to each other (fully connected network).
- Every DC is connected to a single warehouse (single allocation).
- The direct connection between the DC is not allowed.
- All decision variables are binary variable (0-1).

Input variables

The input variables are:

- N: number of cities
- P: number of warehouses
- UW_{ij}: uncertain flow of goods between pair of O-D cities
- C_{ij}: unit cost of goods transportation between the pair of O-D cities
- F_k: fixed cost of warehouse establishment at city k
- α: discount factor for transportation between warehouse ($0 < \alpha < 1$)

Output variables (or decision variables)

The output variables are:

- Y_k: warehouse allocation variables
- X_{ij}: DC to warehouse allocation variable

$$Y_k = \begin{cases} 1, & \text{if a warehouse is located at node } k \\ 0, & \text{otherwise} \end{cases} \quad (1)$$

$$X_{ij} = \begin{cases} 1, & \text{if city } i \text{ is connected to a warehouse located at city } j \\ 0, & \text{otherwise} \end{cases} \quad (2)$$

Objective function and its constraints

Objective function is the sum of warehouse establishment cost and transportation cost of goods. Mathematical formulation of objective function and its related constraints are:

$$\text{Minimise} \sum_{k=1}^{N} F_k Y_k + \sum_{i=1}^{N}\sum_{j=1}^{N} W_{ij} g_{ij}(x) \tag{3}$$

where $g_{ij}(x) = \sum_{k=1}^{N}\sum_{m=1}^{N} X_{ik} X_{mj} \left(C_{ik} + \alpha C_{km} + C_{mj}\right)$

Subject to

$$\sum_{j=1}^{N} X_{ij} = 1 \quad \forall i \tag{4}$$

$$\sum_{k=1}^{N} Y_k = P \tag{5}$$

$$Y_k \text{ and } X_{ij} \in \{0,1\} \tag{6}$$

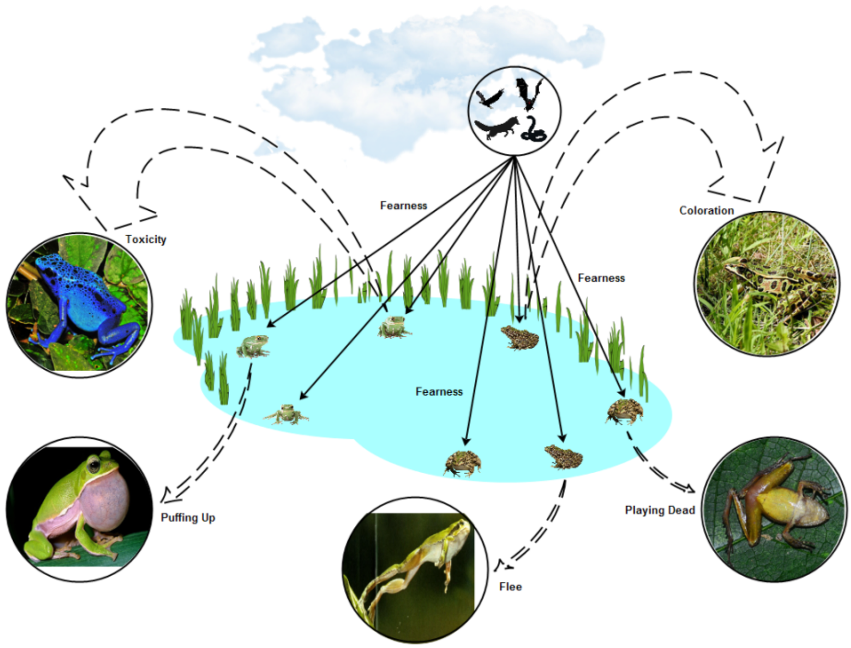
$$X_{ijkm} \geq 0 \tag{7}$$

The objective function (3) represents the total cost of goods transportation between all pairs of O-D cities. It is the sum of two terms: a fixed cost of establishing warehouse and the total transportation cost of goods between city *i* to city *j* via warehouse *k* and *m*. Constraint (4) ensures that every DC will be assigned to exactly one warehouse and constraint (5) ensures that exactly *p* warehouses are selected. Equations (6) and (7) are the standard integrity constraints.

4 Anti-predatory NIA (APNIA)

APNIA (Sachan and Kushwaha, 2019) is one of the efficient and recently proposed nature-inspired meta-heuristic algorithm. It is inspired by the anti-predatory behaviour of frogs in which frogs protect themselves from the predators (Sachan and Kushwaha, 2019). It considers three groups of anti-predatory mechanisms, namely, "colouration and playing dead", "toxin secretion and puffing up" and "flee towards a safe position" (Sachan and Kushwaha, 2019). The algorithm considers that all these mechanisms have equal probability of occurrence based on 'fearness' factor arising from the presence of a predator. Based on this '*fearness*' value, any one of the mechanisms can be executed. The current traits of the frog are successively improved using one of the anti-predatory mechanisms in each iteration, followed by new generation with improved traits. This choreograph situation that mimics the APNIA is illustrated in Figure 5 (Sachan and Kushwaha, 2020).

Figure 5 The concept of APNIA (see online version for colours)



Based on the '*fearness*' value, a frog tries to protect itself by 'colouration', 'toxin secretion', 'flee towards safe a position', 'puffing up' and 'playing dead' (Sachan and Kushwaha, 2020). These anti-predatory mechanisms are modelled by mathematical equations (Sachan and Kushwaha, 2019). This section explains these mathematical equations. In the following equations, X_t represents current traits of the frog, X_s represents current strength of the frog and X_t' represents the new traits of frog. $Peer_t$ and $Peer_s$ represent the traits and strength of the peer frog respectively.

Colouration and playing dead mechanism

$$\text{if } \mathrm{Avg}_s < X_s, \quad \text{then } X_t' = X_t^{AF} + \mathrm{rand}\left(\mathrm{Avg}_t - X_t\right) \tag{8}$$

$$\text{if } X_s < \mathrm{Avg}_s, \quad \text{then } X_t' = X_t^{AF} + \mathrm{rand}\left(\mathrm{Best}_t - \mathrm{Avg}_t\right) \tag{9}$$

$$\text{if } X_s == \mathrm{Avg}_s, \quad \text{then } X_t^{'} = pd \times X_t \tag{10}$$

$$AF = \frac{X_s}{\mathrm{Avg}_s} \tag{11}$$

where AF is colour adaption factor and pd is the playing dead capability of frog which lies between [–1, 1]. *rand* in a random variable between [0, 1].

Toxin secretion and puffing up mechanism

$$\text{if } \mathrm{Peer}_s < X_s, \quad \text{then } X_t' = X_t + TF \times \mathrm{rand}\left(\mathrm{Peer}_t - X_t\right) \tag{12}$$

$$\text{if } X_s < \mathrm{Peer}_s, \quad \text{then } X_t' = X_t + TF \times \mathrm{rand}\left(\mathrm{Best}_t - \mathrm{Peer}_t\right) \tag{13}$$

$$\text{if } X_s == \text{Peer}_s, \quad \text{then } X'_t = pu \times X_t \tag{14}$$

$$TF = \frac{T_0}{1 + r^2_{\text{peer},X}} \tag{15}$$

$$T_0 = \frac{\text{Peer}_s}{X_s} \tag{16}$$

where *TF* is toxicity factor and *pu* is the puffing up capability of frog which lies between [1, 2]. *rand* is a random variable between [0, 1].

Flee towards safe position mechanism

$$X'_t = X_t + \text{rand}\left(\text{Peer1}_t - \text{Peer2}_t\right) \tag{17}$$

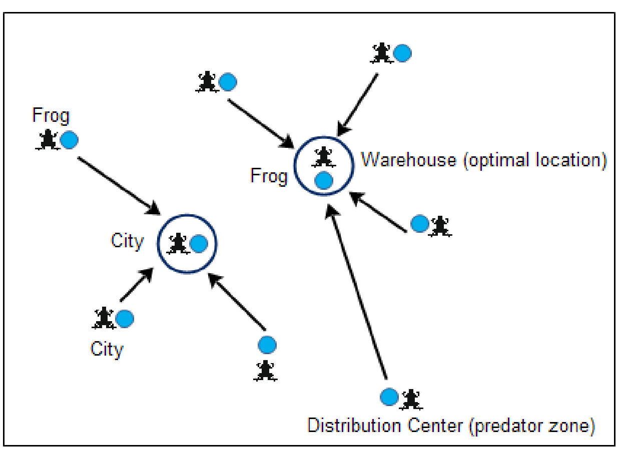
$$X'_t = \text{flee in between}\left[\left(X_t - ws\right)\left(X_t + ws\right)\right] \tag{18}$$

where *ws* is window size and *rand* in a random variable between [0, 1]. The window size is a range in which frog can jump. This APNIA is used to solve the ECLP.

5 Anti-predatory NIA for e-commerce logistics problem

In ECLP, cities (warehouse and distribution centre) are similar to the frog's position in APNIA. In APNIA, frogs improve their anti-predatory strength by improving their traits in order to increase their fitness. Similarly, cities try to improve their fitness (total cost of goods transportation) value in order to act as a warehouse. This is the motivation for applying APNIA for ECLP. This concept is illustrated in Figure 6.

Figure 6 An analogy between the anti-predatory and e-commerce logistics problem (see online version for colours)



Original APNIA is a real-coded algorithm (Sachan and Kushwaha, 2019) and ECLP requires a binary-coded algorithm. It can be used for ECLP by converting the real values to binary values through programming logic.

APNIA models the behaviour of a group of frogs where a frog's traits are represented by an $N \times N$ matrix, N being the number of cities in ECLP. Every frog represents a solution of ECLP. The anti-predatory strength of frog represents the total cost of goods transportation (fitness). An ECLP solution consists of two matrices: matrix $Y\ [1 \times N]$ and $X\ [N \times N]$. These two matrixes evolve from $N \times N$ matrix of the frog's traits. Matrix Y represents the cities where warehouses and DC are positioned; and matrix X indicates the assignment of DC to warehouse.

During the initialisation phase, initial population of frogs (solutions) is randomly generated. From the diagonal values of solution ($N \times N$ matrix), first matrix $Y\ [1 \times N]$ is generated, which shows the selected warehouse and DC cities and then each DC is assigned to a selected warehouse in matrix $X\ [N \times N]$.

The anti-predatory strength of frog (total cost of goods transportation) is calculated using equation (3) with Y and X as input values. In the next step, the frogs move in any other city based on the value of '*fearness*' and improve their traits towards minimum total cost of goods transportation by using any one of the anti-predatory mechanisms. During the successive iteration, each frog will improve its anti-predatory strength.

6 Mathematical model for handling the uncertain flow

A mathematical model is required to convert the uncertain flow of goods (UW_{ij}) to the expected flow of goods (W_{ij}). The uncertain flow of goods between cities is represented by the triple (τ, ξ, η) where τ represents the minimum flow of goods, ξ represents the most possible flow of goods and η represents maximum flow of goods between the pair of O-D cities. We use a simple and well-establish probabilistic weighted mean approach for handling the uncertain flow. This idea is taken from the PERT networks (Fulkerson, 1962). The mathematical model of this approach is given in equation (19).

$$W_{ij} = \frac{\tau_{ij} + 4 \times \xi_{ij} + \eta_{ij}}{6\xi_{ij}} \tag{19}$$

7 Experimental evaluation

In this section, we validate the correctness and sustainability of APNIA for solving the ECLP and also investigate the sensitivity of ECLP on the value of α and P. For that, we solve a numerical problem of the ECLP using APNIA taken from Qin and Gao (2017). During experimental evaluation, we conduct three experiments. In the first experiment, we solve the expected cost minimisation model (ECMM) model using APNIA and obtained results are compared with GA-ECMM (Qin and Gao, 2017) in terms of total cost and gap value. Gap is an error metric used to measure the accuracy of proposed model and is calculated using equation (20) (Qin and Gao, 2017).

$$\text{GAP} = \frac{(\text{Obtained total cost} - \text{Optimal total cost})}{\text{Optimal total cost}} \times 100\% \tag{20}$$

In the second experiment, the expected flow of goods from the uncertain flow is computed using equation (19) and later we apply APNIA to solve the same problem. The third experiment investigates the impact of *α* and *P* on the total cost of goods transportation. This investigation is useful for finding the best suited value of *P* for that ECLP has an optimal total cost of goods transportation. Because in a real world ECLP, finding the value of *P* is itself a part of the problem. A problem which is used for the experimental and illustration purpose is discussed next.

7.1 Numerical problem

For experimental purpose, we consider an e-commerce logistics numerical problem of 10 cities (Qin and Gao, 2017). Our aim is to find an optimal arrangement of W&DC network for the given problem. The values of the different input parameters are listed in Tables 1–4. These parameters are number of cities (*N*), number of warehouses (*P*), discount factor (*α*), fixed cost of warehouse establishment (F_k), unit cost of goods transportation (C_{ij}) and uncertain flow of goods (UW_{ij}). The possible arrangement of cities is shown in Figure 7. The edges are labelled with attributes which is represented by 3-tuple {unit cost of goods transportation, (uncertain flow from the city *i* to city *j*), (uncertain flow from the city *j* to city *i*)}. The uncertain flow is represented by the triple (minimum, most possible, maximum). Fully connected cities in Figure 7 do not mean that a city has a direct transportation link between all other cities. Rather, it represents the business activity between the cities. Table 1 lists the basic input parameters of the problem, like *N*, *P* and *α*.

Figure 7 An illustration of cities in e-commerce logistics numerical problem

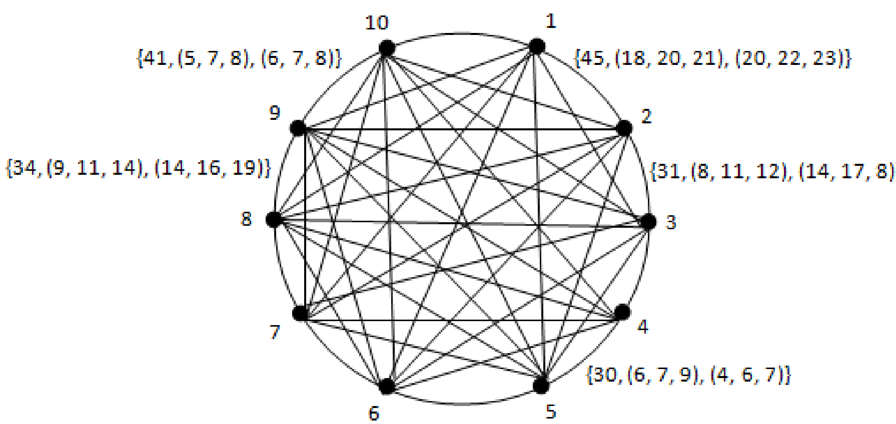


Table 1 Basic input parameters of problem

Number of cities (*N*)	10
Number of warehouse (*P*)	3
Discount factor (*α*)	0.30

Table 2 tabulates the fixed cost of warehouse establishment at each city. This cost include the infrastructure and facilities development cost at the city.

Table 2 Fixed cost of warehouse establishment (F_k)

City No.	*City 1*	*City 2*	*City 3*	*City 4*	*City 5*
Fixed establishment cost	9000	12,500	9500	11,700	12,500
City No.	*City 6*	*City 7*	*City 8*	*City 9*	*City 10*
Fixed establishment cost	14,500	13,500	9200	8400	11,400

Table 3 lists the unit cost of goods transportation between the pair of O-D cities, which is named as a unit cost matrix. It is a symmetrical matrix because problem assumes the same unit cost of goods transportation for pair O-D and D-O cities. All diagonal values are 0 because unit cost of transportation within the city is considered as negligible.

Table 3 Unit cost matrix of goods transportation (C_{ij})

	City 1	*City 2*	*City 3*	*City 4*	*City 5*	*City 6*	*City 7*	*City 8*	*City 9*	*City 10*
City 1	0	45	24	22	44	33	49	49	35	43
City 2	45	0	31	45	33	39	45	37	47	31
City 3	24	31	0	50	48	49	37	35	29	38
City 4	22	45	50	0	30	28	43	39	31	35
City 5	44	33	48	30	0	33	28	30	50	49
City 6	33	39	49	28	33	0	49	49	25	31
City 7	49	45	37	43	28	49	0	50	23	44
City 8	49	37	35	39	30	49	50	0	34	47
City 9	35	47	29	31	50	25	23	34	0	41
City 10	43	31	38	35	49	31	44	47	41	0

Table 4 presents the uncertain flow of goods between the each pair of O-D cities. This uncertain flow is represented by triple (τ, ξ, η), which is known as an uncertain flow matrix of goods. The triple (τ, ξ, η) represents the (minimum, most possible, maximum) flow of goods.

Table 4 Uncertain flow matrix of goods (UW_{ij})

	City 1	*City 2*	*City 3*	*City 4*	*City 5*
City 1	–	(18, 20, 21)	(19, 20, 23)	5	(10, 13, 14)
City 2	(20, 22, 23)	–	(8, 11, 12)	(6, 8, 9)	(17, 22, 23)
City 3	(12, 14, 15)	(14, 17, 18)	–	(20, 23, 24)	9
City 4	(13, 15, 19)	(16, 19, 20)	(14, 15, 18)	–	(6, 7, 9)
City 5	(15, 18, 20)	(5, 8, 9)	10	(4, 6, 7)	–
City 6	(14, 19, 22)	(17, 18, 19)	(17, 19, 20)	(9, 11, 12)	(13, 15, 18)
City 7	(6, 8, 9)	(13, 16, 17)	(9, 11, 14)	(9, 11, 14)	(18, 21, 23)
City 8	7	(21, 24, 27)	(21, 23, 25)	(21, 23, 25)	10
City 9	(3, 5, 7)	(20, 21, 24)	(12, 14, 15)	(6, 7, 9)	(13, 17, 19)
City 10	(18, 20, 22)	(19, 23, 25)	13	5	(21, 24, 26)

Table 4 Uncertain flow matrix of goods (UW_{ij}) (continued)

	City 6	*City 7*	*City 8*	*City 9*	*City 10*
City 1	(19, 22, 24)	13	(9, 11, 12)	(5, 6, 7)	(20, 21, 23)
City 2	12	6	(5, 7, 8)	8	(7, 8, 10)
City 3	5	(8, 11, 13)	(7, 8, 9)	(19, 21, 24)	(4, 5, 7)
City 4	(4, 5, 7)	(21, 24, 26)	8	(20, 24, 26)	14
City 5	(19, 21, 22)	(16, 19, 21)	(14, 16, 18)	(9, 12, 14)	(20, 24, 30)
City 6	–	(10, 12, 13)	(21, 23, 25)	(11, 14, 16)	(17, 19, 23)
City 7	12	–	(14, 17, 19)	9	(18, 20, 22)
City 8	(22, 25, 27)	(20, 25, 29)	–	(9, 11, 14)	(17, 20, 23)
City 9	(10, 12, 15)	(13, 16, 17)	(14, 16, 19)	–	(5, 7, 8)
City 10	(20, 23, 25)	6	(6, 7, 8)	(6, 7, 8)	–

Experiment 1. Validation of correctness of anti-predatory NIA

In this experiment, we validate the correctness of APNIA for solving the above discussed problem and find an optimal arrangement of logistics network. The first step is to convert an uncertain flow matrix to expected flow matrix. Here, we use same expected flow matrix which is obtained by ECMM (Qin and Gao, 2017), which is shown in Table 5.

Table 5 Expected flow matrix of goods (W_{ij}) obtained by ECMM

	City 1	*City 2*	*City 3*	*City 4*	*City 5*	*City 6*	*City 7*	*City 8*	*City 9*	*City 10*
City 1	–	19.75	20.5	5	12.5	21.75	13	10.75	6	21.75
City 2	21.75	–	10.5	7.75	21	12	6	6.75	8	8.25
City 3	13.75	16.5	–	22.5	9	5	10.75	8	21.25	5.25
City 4	15.5	18.5	15.5	–	7.25	5.25	23.75	8	23.5	14
City 5	17.75	7.5	10	5.75	–	20.75	18.75	16	11.75	24.5
City 6	18.5	18	18.75	10.75	15.25	–	11.75	23	13.75	19.5
City 7	7.75	15.5	11.25	11.25	20.75	12	–	16.75	9	20
City 8	7	24	23	23	10	24.75	24.75	–	11.25	20
City 9	5	21.5	13.75	7.25	16.5	12.25	15.5	16.25	–	6.75
City 10	20	22.5	13	5	23.75	22.75	6	7	7	–

The next step solves the problem using APNIA. This approach is named as anti-predatory NIA based expected cost minimisation model (APNIA-ECMM). The initial values of simulation parameters for APNIA-ECMM are the same as in Qin and Gao (2017). These values are listed in Table 6.

Table 6 Parameters of anti-predatory NIA

Number of runs	10
Number of generation	100, 500, 1000, 2000
Number of population	40

APNIA-ECMM is executed 10 times independently for different number of generations. The obtained results are shown in Table 7 in terms of total cost. In results, smaller value of total cost represents a better solution.

Table 7 Obtained results of 10 independent runs by APNIA

	100 generation	*500 generation*	*1000 generation*	*2000 generation*
	Total cost	*Total cost*	*Total cost*	*Total cost*
Run 1	90349.23	90349.23	88608.3	88608.3
Run 2	90349.23	88608.3	90349.23	88608.3
Run 3	88608.3	88608.3	88608.3	88608.3
Run 4	89291.7	89291.7	88608.3	88608.3
Run 5	88608.3	88608.3	88608.3	88608.3
Run 6	89291.7	88608.3	88608.3	88608.3
Run 7	88608.3	90349.23	88608.3	88608.3
Run 8	90349.23	88608.3	88608.3	88608.3
Run 9	88608.3	90349.23	88608.3	88608.3
Run 10	88608.3	88608.3	88608.3	88608.3

To validate the correctness of APNIA, we compare the obtained results by APNIA-ECMM and GA-ECMM in terms of total cost and gap value. This comparison is shown in Tables 8 and 9. Table 8 shows the comparison for 100 and 500 generation while a comparison for 1000 and 5000 generations are shown in Table 9. The gap is calculated by the Formula (20) and the results of the GA-ECMM are taken from Qin and Gao (2017). GA-ECMM (Qin and Gao, 2017) uses an ECMM for handling uncertainty in the flow of goods and the optimal solution of the problem is obtained by genetic algorithm.

Table 8 Comparative analysis of results of 10 independent runs for 100 and 500 generation

	100 generation				*500 generation*			
	GA-ECMM		*APNIA-ECMM*		*GA-ECMM*		*APNIA-ECMM*	
	Cost	*Gap*	*Cost*	*Gap*	*Cost*	*Gap*	*Cost*	*Gap*
Run 1	91016.1	2.72	90349.23	1.965	89291.7	0.77	90349.23	1.965
Run 2	90349.2	1.96	90349.23	1.965	88608.3	0	88608.3	0
Run 3	90963.1	2.66	88608.3	0	90349.2	1.96	88608.3	0
Run 4	91354.1	3.1	89291.7	0.771	90783.7	2.46	89291.7	0.771
Run 5	91655	3.44	88608.3	0	90783.7	2.46	88608.3	0
Run 6	92134.7	3.98	89291.7	0.771	90349.2	1.96	88608.3	0
Run 7	88608.3	0	88608.3	0	88608.3	0	90349.23	1.965
Run 8	91354.1	3.1	90349.23	1.965	90963.1	2.66	88608.3	0
Run 9	88608.3	0	88608.3	0	88608.3	0	90349.23	1.965
Run 10	92388.4	4.27	88608.3	0	88608.3	0	88608.3	0

Table 9 Comparative analysis of results of 10 independent runs for 1000 and 2000 generation

	1000 generation				*2000 generation*			
	GA-ECMM		*APNIA-ECMM*		*GA-ECMM*		*APNIA-ECMM*	
	Cost	*Gap*	*Cost*	*Gap*	*Cost*	*Gap*	*Cost*	*Gap*
Run 1	88608.3	0	88608.3	0	88608.3	0	88608.3	0
Run 2	88608.3	0	90349.23	1.965	88608.3	0	88608.3	0
Run 3	88608.3	0	88608.3	0	88608.3	0	88608.3	0
Run 4	88608.3	0	88608.3	0	88608.3	0	88608.3	0
Run 5	88608.3	0	88608.3	0	88608.3	0	88608.3	0
Run 6	88608.3	0	88608.3	0	88608.3	0	88608.3	0
Run 7	88608.3	0	88608.3	0	88608.3	0	88608.3	0
Run 8	89291.7	0.77	88608.3	0	88608.3	0	88608.3	0
Run 9	88608.3	0	88608.3	0	88608.3	0	88608.3	0
Run 10	88608.3	0	88608.3	0	88608.3	0	88608.3	0

Tables 8 and 9 show that maximum gap value is 4.27 in GA-ECMM and 1.96 in APNIA-ECMM. The lower gap value indicates higher accuracy of APNIA-ECMM. This comparative analysis also establishes that APNIA-ECMM produces optimal results for more number of cases as compared to that obtained with GA-ECMM. For instance, from Table 8, we observe that in case of 100 generation, GA-ECMM gives optimal results for two runs, while the APNIA-ECMM achieves optimal results for five runs. Similarly for the 500 generation, the proposed APNIA-ECMM gives optimal results for six runs while GA-ECMM gives optimal results for only four runs. Similarly for 1000 generation and 2000 generation (from Table 9), both approaches give optimal results for the same number of times. These performance differences are quantified in Table 10.

Table 10 The performance differences between APNIA-ECMM and GA-ECMM

	GA-ECMM		*APNIA-ECMM*	
Number of generations	*Number of times optimal solution achieved*	*Percentage*	*Number of times optimal solution achieved*	*Percentage*
100 generation	2 out of 10	20%	5 out of 10	50%
500 generation	4 out of 10	40%	6 out of 10	60%
1000 generation	9 out of 10	90%	9 out of 10	90%
5000 generation	10 out of 10	100%	10 out of 10	100%

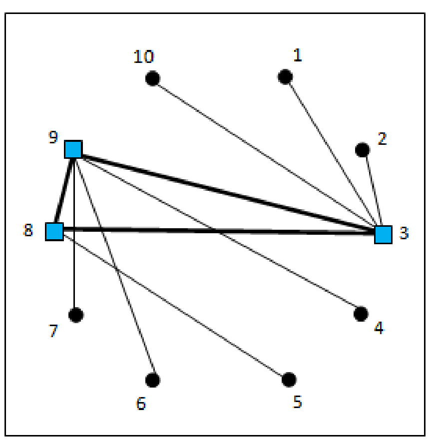
The observation of Table 10 is showing a clear consistency gain by 30% in case of 100 generation and 20% in case of 500 generation. It means APNIA can be used as an efficient algorithm for solving the ECLP. The obtained value of output variables (Y and X) for this e-commerce logistics numerical problem is shown in Table 11.

Table 11 Decision variables of an optimal logistics network obtained by APNIA

(i) Warehouse location decision variable										
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Y_k	0	0	1	0	0	0	0	1	1	0
(ii) DC allocation decision variable										
X_{ij}	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1	0	0	1	0	0	0	0	0	0	0
2	0	0	1	0	0	0	0	0	0	0
3	0	0	1	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	1	0
5	0	0	0	0	0	0	0	1	0	0
6	0	0	0	0	0	0	0	0	1	0
7	0	0	0	0	0	0	0	0	1	0
8	0	0	0	0	0	0	0	1	0	0
9	0	0	0	0	0	0	0	0	1	0
10	0	0	1	0	0	0	0	0	0	0

Decision variable Y represents the cities which are selected for warehouse establishment and variable X represents the allocation of DC to warehouses. The variable Y has the value 1 at 3rd, 8th, 9th index and value 0 at the remaining indices. This implies that cities {3, 8, 9} are selected for warehouse establishment and others cities are used for DC. Similarly, variable X_{13} equals to 1 means that DC 1 is allocated to warehouse 3 and X_{49} equals to 1 means that DC 4 is allocated to warehouse 9. The optimal arrangement of logistics network is {3: 1, 2, 3, 10; 8: 5, 8; 9: 4, 6, 7, 9}. This arrangement signifies that warehouse is established at city 3, 8 and 9. The DC city 1, 2, 3 and 10 are allocated to warehouse 3; DC city 5, 8 is allocated to warehouse 8; and DC city 4, 6, 7 and 9 are allocated to warehouse 9. The optimal cost of this arrangement is 88,608.3. This logistics network is graphically represented in Figure 8.

Figure 8 An optimal solution of this ECLP (P = 3 and α = 0.3) (see online version for colours)



Experiment 2. Validation of sustainability of anti-predatory NIA

In this experiment, we validate the sustainability of APNIA for solving the same problem with different uncertain flow handling method. Due to uncertainty the expected flow of goods may change. Here, we use a simple probabilistic weighted mean approach (see Section 6) for handling the uncertain flow. We first convert uncertain flow matrix (given in Table 6) to expected flow matrix by using equation (19), which is shown in Table 12.

Table 12 Expected flow matrix of goods (W_{ij}) obtained by equation (19)

	City 1	*City 2*	*City 3*	*City 4*	*City 5*	*City 6*	*City 7*	*City 8*	*City 9*	*City 10*
City 1	–	19.83	20.33	5	12.67	21.83	13	10.83	6	21.17
City 2	21.83	–	10.67	7.83	31.33	12	6	6.83	8	8.17
City 3	13.83	16.67	–	22.67	9	5	10.83	8	21.17	5.17
City 4	15.33	18.67	15.33	–	7.17	5.17	23.83	8	23.67	14
City 5	17.83	7.67	10	5.83	–	20.83	18.83	16	11.83	24.33
City 6	18.67	18	18.83	10.83	15.17	–	11.83	23	13.83	19.33
City 7	7.83	15.67	11.17	11.17	20.83	12	–	16.83	9	20
City 8	7	24	23	23	10	24.83	24.83	–	11.17	20
City 9	5	21.33	13.83	7.17	16.67	12.17	15.67	16.17	–	6.83
City 10	20	22.67	13	5	23.83	22.83	6	7	7	–

After conversion, APNIA is applied to solve the same e-commerce logistics numerical problem. The same simulation parameter setup is used for this experiment, which is listed in Table 6. Again, APNIA is executed 10 times independently for different number of generations. The obtained results are shown in Table 13 in terms of total cost and gap value. The lower value of cost and gap represents the better solution.

Table 13 Obtained results of 10 independent runs by APNIA

	100 generation		*500 generation*		*1000 generation*		*2000 generation*	
	Cost	*Gap*	*Cost*	*Gap*	*Cost*	*Gap*	*Cost*	*Gap*
Run 1	89456.39	0.000	89456.39	0.000	89456.39	0.000	89456.39	0.000
Run 2	89456.39	0.000	89456.39	0.000	89456.39	0.000	89456.39	0.000
Run 3	89456.39	0.000	89456.39	0.000	89456.39	0.000	89456.39	0.000
Run 4	89456.39	0.000	89456.39	0.000	89456.39	0.000	89456.39	0.000
Run 5	91159.94	1.904	89456.39	0.000	89456.39	0.000	89456.39	0.000
Run 6	91159.94	1.904	89456.39	0.000	89456.39	0.000	89456.39	0.000
Run 7	89456.39	0.000	91159.94	1.904	89456.39	0.000	89456.39	0.000
Run 8	89456.39	0.000	89456.39	0.000	89456.39	0.000	89456.39	0.000
Run 9	89456.39	0.000	91159.94	1.904	89456.39	0.000	89456.39	0.000
Run 10	89456.39	0.000	89456.39	0.000	89456.39	0.000	89456.39	0.000

Table 12 shows that the optimal cost is 89,456.39 and associated solution is {3: 1, 2, 3, 10; 8: 5, 8; 9: 4, 6, 7, 9}. The obtained solution is same as the APNIA-ECMM. This result indicates that if in this e-commerce logistics numerical problem, the logistics network arrangement is {3: 1, 2, 3, 10; 8: 5, 8; 9: 4, 6, 7, 9}, then the obtaining an optimal solution is highly probable. The cost value has been increased due to the higher numeric value in the expected flow matrix. The gap value indicates the consistency in results. The same logistics network implies the sustainability of APNIA.

Experiment 3. Investigation of the sensitivity of α and P

In this experiment, we investigate the sensitivity of value of discount factor (α) and number of warehouses (P) for solving the ECLP. This is useful for finding the best suitable value of P for the problem. For that, we run APNIA for 1000 generations for different combination of values of α and P. The obtained results are shown in Table 14.

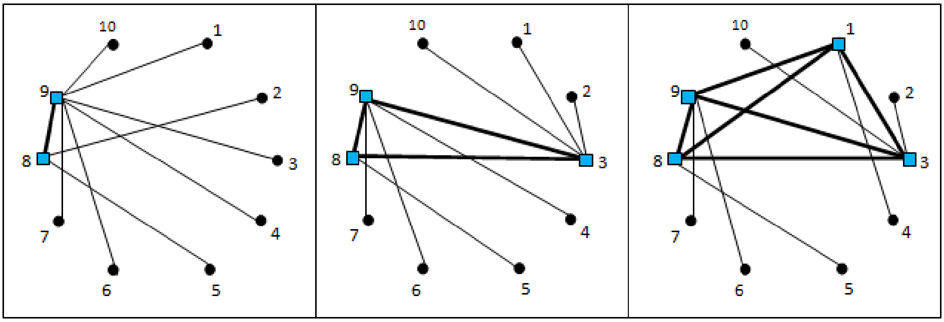
Table 14 Computational results of experiments with different α and P by APNIA

α	*P*	*Cost*	*Warehouse*	*DC to warehouse assignment*
0.05	2	84648.994	8 9	{8: 2, 5, 8; 9: 1, 3, 4, 6, 7, 9, 10}
0.1	2	85746.888	8 9	{8: 2, 5, 8; 9: 1, 3, 4, 6, 7, 9, 10}
0.2	2	87942.676	8 9	{8: 2, 5, 8; 9: 1, 3, 4, 6, 7, 9, 10}
0.3	2	90138.464	8 9	{8: 2, 5, 8; 9: 1, 3, 4, 6, 7, 9, 10}
0.4	2	92334.252	8 9	{8: 2, 5, 8; 9: 1, 3, 4, 6, 7, 9, 10}
0.02	3	80942.114	1 8 9	{1: 1, 3, 4; 8: 2, 5, 8; 9: 6, 7, 9, 10}
0.05	3	82030.074	3 8 9	{3: 1, 2, 3, 10; 8: 5, 8; 9: 4, 6, 7, 9}
0.1	3	83515.338	3 8 9	{3: 1, 2, 3, 10; 8: 5, 8; 9: 4, 6, 7, 9}
0.2	3	86485.866	3 8 9	{3: 1, 2, 3, 10; 8: 5, 8; 9: 4, 6, 7, 9}
0.3	3	89456.394	3 8 9	{3: 1, 2, 3, 10; 8: 5, 8; 9: 4, 6, 7, 9}
0.4	3	92426.922	3 8 9	{3: 1, 2, 3, 10; 8: 5, 8; 9: 4, 6, 7, 9}
0.05	4	81213.973	1 8 9 10	{1: 1, 3, 4; 8: 5, 8; 9: 6, 7, 9; 10: 2, 10}
0.1	4	83398.227	1 8 9 10	{1: 1, 3, 4; 8: 5, 8; 9: 6, 7, 9; 10: 2, 10}
0.2	4	87766.734	1 8 9 10	{1: 1, 3, 4; 8: 5, 8; 9: 6, 7, 9; 10: 2, 10}
0.3	4	92128.551	1 3 8 9	{1: 1, 4; 3: 2, 3, 10; 8: 5, 8; 9: 6, 7, 9}
0.4	4	95742.648	1 3 8 9	{1: 1, 4; 3: 2, 3, 10; 8: 5, 8; 9: 6, 7, 9}

Figure 9 shows the obtained optimal logistics network by the APNIA for solving the ECLP for different value of P (and $\alpha = 0.3$).

This investigation reveals that the total cost of goods transportation is directly proportional to discount factor, i.e., cost increases with an increases in α and results are optimal for the number of warehouses (P) equal to 3. It means this ECLP has a minimum cost for three warehouses. If we consider higher or lower value number of warehouses, then the optimal cost will increase.

Figure 9 Optimal logistics network of ECLP for different value of P (and $\alpha = 0.3$): (a) $P = 2$; (b) $P = 3$ and (c) $P = 4$ (see online version for colours)



(a) (b) (c)

8 Conclusion

This study presents a novel and optimised solution of an ECLP using APNIA. The proposed approach is designed to find an optimal arrangement of warehouses and distribution centres with an optimal total cost of goods transportation. It can also be used to find the optimal number of warehouses that can be established in order to optimise the cost of capital investment and operational cost. A numerical problem is considered to illustrate the ECLP and evaluate the performance of APNIA. Experimental results reveal that the gap value of proposed APNIA-ECMM is 2.30% lower than existing GA-ECMM. This implies about 2–3% reduction in the operational cost of an e-commerce company which directly improves profitability. The proposed APNIA-ECMM produces 20% more consistent optimal solutions than GA-ECMM. The sustainability of APNIA for solving the ECLP is validated based on the probabilistic weighted mean approach for handing the uncertain flow of goods. The experimental evaluation also investigates the sensitivity of discount factor and number of warehouses on ECLP. The results reveal that the total cost of goods transportation is proportional to value of discount factor and the best suitable value of P is 3 for this problem. All experiments establish the worthiness of APNIA and motivates its use for different real world application by the research community. In the future, we may use APNIA for an ECLP with large number of cities.

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