International Journal of Applied Metaheuristic Computing
Volume 13 • Issue 1

A Novel Multi-Objective Nonlinear Discrete Binary Gaining-Sharing Knowledge-Based Optimization Algorithm:

Optimum Scheduling of Flights for Residual Stranded Citizens Due to COVID-19

Said Ali Hassan, Cairo University, Egypt
https://orcid.org/0000-0003-3682-2586

Prachi Agrawal, National Institute of Technology, Hamirpur, India
https://orcid.org/0000-0002-6492-3133

Talari Ganesh, National Institute of Technology, Hamirpur, India
https://orcid.org/0000-0003-4707-080X

Ali Wagdy Mohamed, Cairo University, The American University in Cairo, Egypt*

ABSTRACT

GSK algorithm is based on the concept of how humans acquire and share knowledge through their lifespan. Discrete binary version of GSK named novel binary gaining sharing knowledge-based optimization algorithm (DBGSK) depends on mainly two binary stages: binary junior gaining sharing stage and binary senior gaining sharing stage with knowledge factor 1. These two stages enable BGSK for exploring and exploitation of the search space efficiently and effectively to solve problems in binary space. One of these practical applications is to optimally schedule the flights for residual stranded citizens due to COVID-19. The problem is defined for a decision maker who wants to schedule a multiple stepped trip for a subset of candidate airports to return the maximum number of residuals of stranded citizens remaining in listed airports while comprising the minimization of the total travelled distances for a carrying airplane. A nonlinear binary mathematical programming model for the problem is introduced with a real application case study. The case study is solved using DBGSK.

KEYWORDS

Citizens Stranded Abroad, COVID-19, Gaining Sharing Knowledge-Based Optimization Algorithm, Nonlinear Binary Constrained Optimization, Scheduling of Flights

1. INTRODUCTION

Many citizens around the world want to return to their countries of origin as a result of many extremely difficult residence conditions. Many countries are planning to return their massive stranded citizens from different countries. But still, there is a problem when a small remaining number of stranded

DOI: 10.4018/IJAMC.290541

*Corresponding Author

people still there and scattered in several airports in different countries. The same situation appears in countries where tens of citizens resides. In such a case one searches for an optimal scheduling for a single plane's journey which aims to complete multiple flights in several airports so that its load of passengers is completed at the lowest travelled distances. Such a task is repeated until finishing the whole task of returning all the stranded citizens.

This paper addresses a fight scheduling problem in which a single flight is planned to pick up passengers in multiple airports and transport them to a destination airport under the current COVID-19 settings. The scheduling problem is formulated as a Nonlinear Binary Programming model and solved by a metaheuristic procedure so-called a Discrete Binary Gaining-Sharing Knowledge-based (DBGSK) algorithm.

The second section includes an overview of the new coronavirus (COVID-19). This information covers the COVID-19 that has infected millions of people in almost all countries

Section 3 is devoted to demonstrating the problem of returning stranded citizens in foreign countries as a result of the new Corona virus as most countries have planned to return their nationals on many planned flights. Nevertheless, at the end of the day, the problem is about the residual stranded people remaining in some scattered countries. As the number of stranded people in each country is less than the plane capacity, it is then required to schedule a stepped flight to multiple airports to carry out those people in an optimum way.

Section 4 presents a concise review of the problem of Travelling Salesman and related variations like: the problem of Traveling Salesman with Priority Prizes, Deliveries and Collections, Pickup and Delivery, Backhauls, Multiple depots, Specifications of salesmen number, Problems with time windows and that with Fixed charges. It deals also with problems of: Multiple Traveling Salesman, Generalized Travelling Salesman, Generalized Vehicle Routing and Traveling Repairman one.

The mathematical model of the problem is designed in section 5 including all needed formulations. The proposed formulation is a Multi-Objective Nonlinear Discrete Binary Mathematical Model with a dimension depending on the number of candidate airports to be visited, the steps of the solution procedure are also explained.

A real application case study for the problem in India for evacuating stranded citizens in the Arab Gulf countries is presented in section 6, and in section 7, a novel Discrete Binary version of a recently developed gaining-sharing knowledge-based optimization technique (GSK) is introduced for solving the problem. GSK cannot solve the problem with discrete binary space; therefore, a Discrete Binary-GSK optimization algorithm (DBGSK) is proposed with two new discrete binary junior and senior stages. These stages allow DBGSK to inspect the problem search space efficiently. Section 8 represents the experimental results of the problem obtained by DBGSK, and Section 9 summarizes the conclusions and the suggested points for future researches.

2. CORONAVIRUS (COVID-19): AN OVERVIEW

Currently, the entire world is suffering from a global epidemic of COVID-19 that has infected thousands of people in almost all countries, Sara Cleemput et al. (2020). In December last year, Wuhan in China, was the origin of a pneumonia of unknown cause. Cases of COVID-19 are not limited to this city, and by Jan in this year, assured cases were detected outside Wuhan, THE LANCET website (2020).

Nowadays, the new Coronavirus (COVID-19) put humans in all countries in front of the huge danger. To safeguard against disease, various centres of virus disinfection recommend many precautions among them to stay at home except in cases of necessity. The Centers for Decease Control and Prevention (CDC) declares the major signs of COVID-19 so that any individual can discover whether or not he has such symptoms, Centers for Decease Control and Prevention (2020) and Guan et al. (2019).

The risk in these diseases is that there is no vaccine for treatment yet; and antibiotics will not help with them. The matter is further complicated by the fact that the incubation period of the virus is up to 14 days; therefore, officials of the examination at airports and other examination places will not be able to discover all the possible patients carrying the disease.

The number of confirmed infected cases in all countries clarify that this is a vast evolving case, new situation changes may not be represented at once, Wikimedia Commons Website (2020). The confirmed number in Egypt is moderate till now, but numbers are expected to increase exponentially as new cases are discovered and since the daily increasing rate is about 12%, World Health Organization, (2020).

The greatest risk also lies in travelling from one country to another, Centers for Decease Control and Prevention (2020). Coronavirus Cases, Deaths and Recovered cases are declared regularly, Worldometer website (2020a).

The daily growth factor for new cases which is the factor by which a quantity multiplies itself over time shows a growth factor permanently greater than 1 in many countries indicating an exponentially growth, Worldometer website (2020b). Nowadays, it is shown clearly that the current and the near future situations are not quite right if the situation continues as it is now and if strict measures are not taken at the level of governments and peoples.

The rate of the virus spreading affirmed by its reproductive number, represented by the mean number of people for whom one infected person will transmit the decease. It was estimated in the early stages of the disease to be 2.2, Li et al. (2015).

3. THE PROBLEM OF CITIZENS STRANDED ABROAD DUE TO COVID-19

The problem of returning stranded citizens in foreign countries as a result of the new Corona virus is a general problem in all countries of the world. Many citizens want to return to their countries of origin as a result of their dismissal, migrant workers, non-permanent residents, those who face deportation, people with medical emergencies, the elderly, those who were on short-term visas, the people who died one of their family members, and students whose hotels or homes are closed.

Most countries have planned to return their nationals from foreign countries on many planned flights. But afterwards, the problem is about few residual remaining stranded people appears in some scattered countries. In case the number of stranded people in each airport is less than the airplane capacity, it is necessary to make a schedule for the plane's flight to pass through several airports in one country or in a group of countries trying to complete the plane's load and return them to their country of origin while travelling a reasonable total distances. Such trips are then repeated many times until the complete return of all stranded to their country.

The optimal planning for a single plane's journey aims to complete its multiple flight landing in several airports so that its load of passengers is the greatest at the lowest travelled distances. The plane will take off from the airport of the original country to the airports of the host countries and then return at the end of the flights to the airport from which it took off first.

In India for example, and according to official sources, over 4 lakh (a hundred thousand) have registered with the Indian missions abroad to return home. Out of these, over a lakh have registered from the Gulf countries alone. But the government will be bringing only these 15,000 Indians as of now who have "compelling grounds" to return, the sources added. The government planned to return them home via 64 flights from 12 countries in the period from 7 May to 13 May 2020 as part of the government's Mission. The second phase of the mission as part of this major repatriation exercise starts from 16th May, is expected to cover European nations and will bring almost 25,000 Indians from 28 countries. The government will operate over 100 flights to complete the mission. Some of the states where the Indians will be sent back are New Delhi, Kerala, Tamil Nadu, Uttar Pradesh, Karnataka, Jammu, Punjab, Maharashtra, Gujarat, Telangana and Kashmir.

The government asked Air India to bring back Indians wishing to return from the United States, United Kingdom, Singapore, and the Middle East. The first step of evacuations would bring back about 200,000 citizens by mid of May and then by the middle of June a total of 350,000-400,00 would be returned home. Moreover, a few numbers of ships will be sent to the United Arab Emirates (UAE) and the Maldives to bring about 3.4 million citizens.

The definition of the Scheduling of Flights for Stranded Citizens (SFSC) is somewhat like that of the Travelling Salesman Problem (TSP) and its variants. That proximity is useful for creating the mathematical model for the new proposed problem which differs from the famous and well-known TSP in the following main points:

1) In the SFSC problem, the airplane has a maximum capacity condition: The total number of stranded citizens that can be evacuated is equal to the maximum capacity of the airplane. While in the TSP, this condition doesn't hold.
2) In the TSP, the salesman will reach all customers, while in the SFSC, the disinfection-man will determine a route containing some or all the places which improve the utilization of the available predetermined airplane capacity.
3) In the TSP, the aim is the minimization of the travelling times, while the SFSC has two objectives: maximizing the total number of stranded citizens that can be evacuated and minimizing the total travelled distances through the whole journey.

4. THE TRAVELLING SALESMAN PROBLEM (TSP) AND ITS VARIATIONS

The Traveling Salesman Problem (TSP) is one of problems that are excessively considered in studying of networks, it possesses broad real-life applications, Applegate et al. (2006). TSP is summarised as a salesman visiting a number of cities, he begins in his hometown and next wants to visit each place on a collection of places only once. Finally, he returns into hometown. When the number of network nodes increases, the problem will possess a terrible number of possible solutions: finite, but enumeration intractable, Gleixner (2014). Droste (2017) stated that the number of different tours is very large, so one might not solve the problem by simple calculations but needs suitable algorithms to solve such situations.

Better and better algorithms were developed, the largest solved instance consisted of all 24,978 cities in Sweden, Applegate et al. (2009). Numerous variants of the TSP are considered in the publications. Sarubbi and Luna (2007) like:

The TSP with Priority Prizes (TSPPP), Pureza et. al. (2018); TSP with Pickup and Delivery or TSP with Deliveries and Collections (TSPDC), Baldacci et al. (2003); TSP with Backhauls (TSPB), Gendreau et. al. (1996), Aramgiatisiris (2004), Mosheiov (1994), Anily and Mosheiov (1994), Gendreau et al. (1999), Halse (1992) and Dumitrescu et. al. (2010); Generalized Travelling Salesman Problem (GTSP), Pop (2007); Generalized Vehicle Routing Problem (GVRP), Kara and Bektas (2003); Multiple Traveling Salesman Problem (*m*TSP), Bektas (2006); Multiple depots and *m*TSP with Time windows (*m*TSPTW), Oberlin et al. (2009); Double Traveling Salesman Problem (*d*TSP), Demiral and Şen (2016); Traveling Repairman Problem (TRP), Silva et. al. (2012). In this kind, customer latency is determined from tour start till the completion of the client's; the *m*TRP, Onder et al., (2016) and other variations.

Algorithms for solving TSP and its variations are divided into approximate and exact algorithms. An exact algorithm guarantees to ðnd the shortest tour. A heuristic algorithm will ðnd a good tour, but it is not guaranteed that this will be the best tour.

Orman and Williams (2005) survey eight models of the TSP as Integer Programs (IP). These models are then explained in: Fox, et al. (1980), Vajda (1961), Miller et. al. (1960), Sawik (2016), Gavish and Graves (1978), Finke et al. (1983) and Multi-Commodity. Dantzig et.al. (1954), Wong (1980) and Claus (1984) state the TSP Conventional Formulation.

5. MATHEMATICAL MODEL FOR THE OPTIMUM SCHEDULING OF FLIGHTS

The scheduling of airplane stepped tour to return back stranded citizen's problem is designated over a graph G with a set of n nodes V representing the airports planned to be visited, and an additional node denotes the origin airport where the air plane starts its stepped route, and a set of arcs representing the distances between each two distinct airports. The number of stranded citizens in each airport, the airplane capacity, and the transportation distance between each pair of airports are specified. The problem is then defined as:

- Each airport is visited only once for loading its passengers,
- The airplane route starts at an initial specific airport, then lands in the first determined airport for loading passengers there, then continue its route till the last scheduled airport in its composite route (not necessarily to visit all the candidate airports), and then returns back to the starting airport,
- The overall goal of the problem to be achieved is to evacuate the maximum number of stranded citizens limited by the airplane capacity, while minimizing the total travelled distance by the airplane.

Mathematical Model:

Decision Variables:

Let:

1, if airport i is approached by the transportation airplane on position m of the route, i and $m = 1, 2, \ldots, n$.

$x_i^m =$

0, otherwise.

Where: n = Number of candidate airports.

Constraints:

(1) Positions Constraints:

Each position m in the optimum chosen route has at most one airport:

$$\sum_{i=1}^{n} x_i^m \leq 1, \; m = 1, 2, \ldots, n. \tag{1}$$

(2) Airport Constraints:

Each airport i can be in one position of the airplane route or not visited:

$$\sum_{m=1}^{n} x_i^m \leq 1, i = 1,2,\ldots,n. \tag{2}$$

(3) Consecutive Positions Constraints:

A position (m+1) in the route cannot exist in the unless the preceding position m exists, this is achieved by the following set of constraints:

$$\sum_{i=1}^{n} x_i^{m+1} \le \sum_{i=1}^{n} x_i^{m}, \ m = 1, 2, \ldots, n\text{-}1 \tag{3}$$

If $\sum_{i=1}^{n} x_i^{m+1} = 1$, then $\sum_{i=1}^{n} x_i^{m} = 1$, m = 1, 2, …, n-1,

If $\sum_{i=1}^{n} x_i^{m+1} = 0$, then there is no restriction on the value of $\sum_{i=1}^{n} x_i^{m}$, $m = 1, 2, \ldots, n$-1.

(4) Maximum Airplane Capacity Constraint:

The total number of stranded citizens that can be evacuated is equal to the maximum capacity of the airplane C.

$$\sum_{i=1}^{n} n_i \cdot \sum_{m=1}^{n} x_i^{m} \text{ £ C} \tag{4}$$

Where:
n_i = The number of stranded citizens in airport i, $i = 1, 2, \ldots, n$.
C = Maximum passenger' capacity of the airplane.

(5) Binary Constraints:

$$x_i^{m} = 0 \text{ or } 1, \ \forall\, i,\, m \in V\ . \tag{5}$$

(6) Avoid the Trivial Solution

a) In order to avoid the trivial solution that the airplane will be saturated with passengers from one port only, the following condition should hold:
The number of stranded citizens to be returned home at any candidate airport should be smaller than the maximum carrying capacity of the used airplane. In case of violation, then an airplane will travel to that airport, take as much of passengers as its total capacity and no need to perform the scheduling process.

b) In order to avoid the trivial solution that the airplane can carry out all the stranded citizens abroad in the considered airports, the following condition should hold:
The total number of stranded citizens to be returned home in all candidate airports should be greater than the maximum carrying capacity of the used airplane. In case of violation, then an airplane will travel a stepped tour to all the considered airports and carryout all the stranded passengers there.

These two conditions should be checked before designing the mathematical model.

(7) The Objective Functions

The COVID-19 crisis operation room decided on two main competing objectives, the first is to minimize the total travelled distance throughout the whole stepped route of the airplane, and the second one is to maximize the total number of returned stranded citizens.

The problem is then a multi-objective one with two objectives, the motivation in Multi-Objective Optimization (MOO) is that it allows for a compromise (trade-off) on some contradictory issues. There is no single best solution for all purposes, but rather several solutions.

The Weighted Sum or scalarization method is one of the classic (MOO) methods, it puts a set of objectives into one by adding each objective pre-multiplied by a user-supplied weight. The weight of an objective is chosen in proportion to the relative importance of the objective.

The weighted sum method is simple, but it is difficult to set the weight vectors to obtain a Pareto-optimal solution in a desired region in the objective space and it cannot find certain solutions in case of a nonconvex objective space, Marler and Arora (2004). In the scalarization method, answer is a set of solutions that define the best trade-off between competing objectives that form in its entirety the non-dominated Pareto-optimal set for the problem, Gunantara (2018). The weighted sum approach treats the multi-objective optimization as composite objective function, Hemamalini and Simon (2010). The composite objective function is expressed as follows:

$$\text{Z} = \text{Maximize } \sum_{i=1}^{q} w_i \ . f_i\left(x\right)$$

Where w_i is the positive weight values, $f_i\left(x\right)$ is one of the objective functions and q is the number of objective functions. Maximizing Z will provide an enough condition for optimal multi-objective solution to be found. Since the objective of this research is to provide a compromise between minimizing the total transportation distances and maximizing the total number of stranded citizens, the following composite objective functions is considered:

$$\text{Z} = w_1 f_1(\text{x}) + w_2 f_2\ (\text{x})\ (i)$$

The weights w_1 and w_2 are related based on the following expression:

$w_2 = 1 - w_1,$ w_1 is chosen is in the range of [0–1].

The first objective function is to minimize the total distance travelled by the airplane while evacuating the stranded citizens. The total distance D travelled by the airplane is equal to three parts as:

$$\text{D} = D_1 + D_2 + D_3 \text{ (a)}$$

Where:

D_1 = Distance travelled from the starting airport to the first destination in the route,

D_2 = Total intermediate travelled distances between two adjacent airports in the route,

D_3 = Distance travelled back from the last visited airport to the starting airport.

$D_1 = \sum_{i=1}^{n} d_{0,i} x_i^1$ (b)

Where: d_{0i} = Transportation distance between the starting airport and airport i, $\forall\ i \in V$.

$$D_2 = \sum_{i=1}^{n} \sum_{\substack{j=1 \\ j \neq i}}^{n} d_{i,j} . (\sum_{m=1}^{n-1} x_i^m . x_j^{m+1}) \text{ (c)}$$

Where: $d_{i,j}$ = Distance between the two adjacent airports i and j, $\forall\ i, j \in V$.

Before adding D_3, it is necessary at first to determine exactly which airport is the last visited one in the route of the airplane taking into consideration (after avoiding the first trivial solution) that the first visited position airport in the solution route will not be the last visited airport.

The last visited airport position in the determined route is characterized by a unique particularity not available in other airports. The last visited airport doesn't have any adjacent subsequent positions except the case where the *n* airports are visited, Figure 1. This property will be used to determine the airport *i* which is located at the last position of the airplane route.

The airport following directly to any position *m* in the route is one of the following set of decision variables:

$$F^{m+1} = \sum_{i=1}^{n} x_i^{m+1}, \ m = 1, 2, \ldots, n\text{-}1$$

The expression (x_i^m).(1- F^{m+1}) $= 1$ only for the last position in the airplane route, and equals 0 for all other positions, then:

$$D_3 = \sum_{m=2}^{n-1}\sum_{i=1}^{n}(d_{0,i} \cdot \ x_i^m) \cdot \left(1 - \sum_{i=1}^{n} x_i^{m+1}\right) + \sum_{i=1}^{n} d_{i,0} \cdot \ x_i^n \text{ (d)}$$

Where: $d_{0,i}$ =Transportation distance between the starting airport and airport *i* and, $\forall \ i \in V$.

The second term in (d) is added such that in case the route will visit all the candidate *n* airports. In that case the corresponding distance between the airport in position *n* of the route and the starting airport will be added, otherwise it will not be added since in such a case $x_i^n = 0 \ \forall i \in V$.

From (a), (b), (c) and (d), the first objective function will have the form:

$$\text{Minimize } f_1\left(x\right) = \{\left(\sum\nolimits_{i=1}^{n} d_{0,i} x_i^1\right) + [\sum_{i=1}^{n}\sum_{\substack{j=1 \\ j\neq i}}^{n} d_{i,j} \cdot (\sum_{m=1}^{n-1} x_i^m . x_j^{m+1})] +$$

$$+ \sum_{m=2}^{n-1}[\sum_{i=1}^{n}(d_{i,0} \cdot \ x_i^m) \cdot \left(1 - \sum_{i=1}^{n} x_i^{m+1}\right)] + \left(\sum_{i=1}^{n} d_{i,0} \cdot \ x_i^n\right)\} \text{ (ii)}$$

Where: $d_{i,0}$ = Transportation distance between airport *i* and the starting airport, $\forall \ i \in V$.

Expression (*ii*) is a quadratic form in two variables, the first part is for the transportation distance from the starting airport to the first position airport in the route, the second part is the total travelled distance between intermediate airports in the route, the third part is the distance between the positions in the route and the starting airport (except the case where all the n airports are visited), the fourth part is the distance between the starting airport and the airport number *n* if it is in the last positions in the route.

The second objective function is to maximize the total number of returned stranded citizens

$$\text{Maximize } f_2\left(x\right) = \{\sum_{i=1}^{n} n_i \cdot \ (\sum_{m=1}^{n} x_i^m)\} \ (iii)$$

Where: n_i = Number of stranded citizens in airport *i*, *i* = 1, 2, …, n.

From (*i*), (*ii*) and (*iii*), the composite objective function will be:

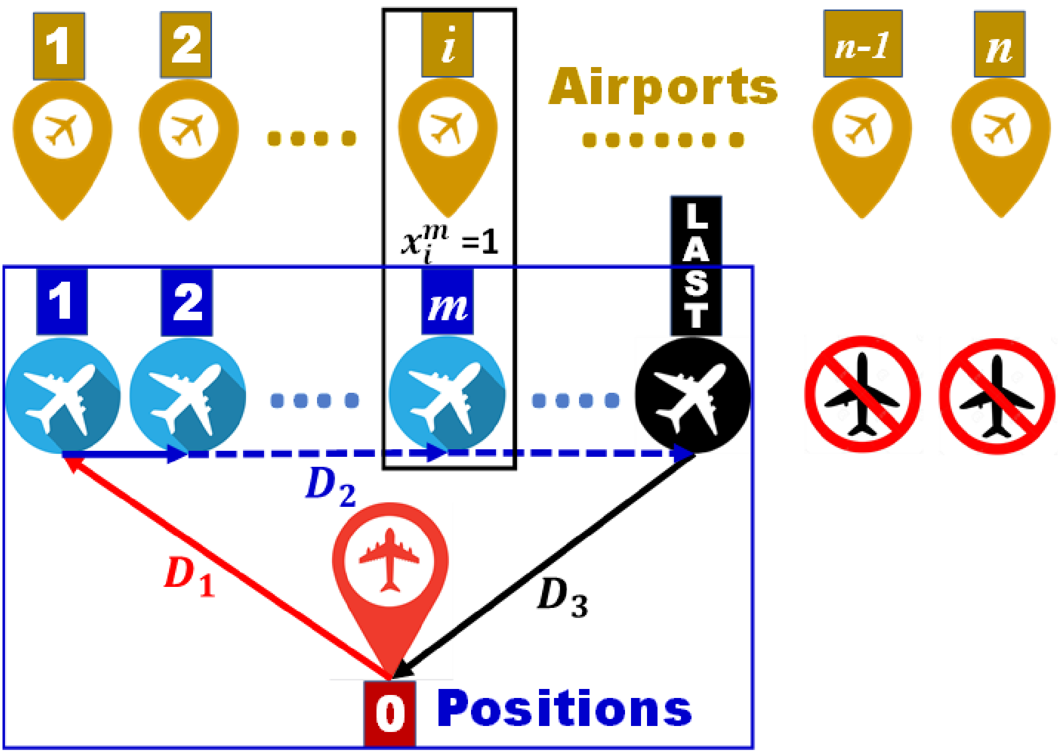
$$\text{Minimize Z} = w_1.\{\left(\sum_{i=1}^{n} d_{0,i} x_i^1\right) + [\sum_{i=1}^{n}\sum_{j=1}^{n} d_{i,j}.(\sum_{m=1}^{n-1} x_i^m . x_j^{m+1})] +$$

$$+ \sum_{m=2}^{n-1}[\sum_{i=1}^{n}(d_{i,0}.\ x_i^m).\left(1-\sum_{i=1}^{n} x_i^{m+1}\right)] + \left(\sum_{i=1}^{n\ j\neq i} d_{i,0}.\ x_i^n\right)\} -$$

$$- w_2.\ \{\sum_{i=1}^{n} n_i.\ (\sum_{m=1}^{n} x_i^m)\} \tag{6}$$

Finally, we have a suggested a model that contains (n^2) binary decision variables, and ($3n$) constraints.

Figure 1. Route of the airplane and categories of airports



The solution procedure is presented in Figure 2.

6. REAL APPLICATION CASE STUDY

About 15,000 Indian nationals stuck abroad due to COVID-19 pandemic will return home via tens of flights from many countries during May 2020 as part of the government's mission. As part of this major repatriation exercise, it is necessary to scheduling other special flights for carrying out some small remaining residual of citizens stranded in different countries.

In this case, an example is presented for an airplane planned to carry out 200 stranded citizens, that number is smaller than the maximum carrying capacity of the airplane due to necessary spacing to prevent transmission of infection between passengers. The airplane starts its route from the starting airport (Indira Gandhi International Airport, New Delhi, India), this airport is denoted by (0), the candidate airports having the stranded citizens are in Kuwait, Bahrain, Qatar, United Arab Emirate, and Oman (denoted by 1, 2, … and 5 respectively), Figure 3.

The data for the example is given in Table 1, where the first column contains the number of stranded citizens, the second column contains the countries and the symbols of the airports according to the International Air Transport Association (IATA) (2020). The numbers inside the cells (i, j) represent the transportation distances between each two airports (km), Prokerala Website (2020).

The mathematical formulation for the given case is worked out by substituting in the previously described model, formulas (1 to 7).

7. THE PROPOSED METHODOLOGY

Metaheuristic approaches are developed for the complex optimization problems with continuous variables. These metaheuristic algorithms include Genetic Algorithm (GA) (Wright (1991)), Differential Evolution (DE) (Storn and Price (1997)), Particle Swarm Optimization algorithm (PSO) (Kennedy and Eberhart (1995)), Grey Wolf Optimizer (GWO) (Mirjalili et al. (2014)), Water Cycle Algorithm (WCA) (Eskandar et al. (2012)), Teaching Learning based Optimization (TLBO) (Rao et al. (2011)), Bat Algorithm (BA) (Yang and Gandomi (2012)) and so on. They have successfully applied to many real-world problems. Mohamed et al. (2020) recently proposed a novel Gaining Sharing Knowledge-based optimization algorithm (GSK), setup on acquiring knowledge and share it with others throughout their lifetime. The original GSK solves optimization problems over continuous space, but it can't solve the problem with binary space. So, a new variant of GSK is introduced to solve the proposed problem. A novel Discrete Binary Gaining Sharing knowledge-based optimization algorithms (DBGSK) is proposed over discrete binary space with new binary junior and senior gaining and sharing stages.

On the other hand, there are many constraint handling techniques in the literature (Deb (2000), Cello (2002), Muangkote et al. (2019)). In their work, the augmented Lagrangian method is used in which an unconstrained optimization problem is obtained from a constrained optimization one, Long et al. (2013), Bahreininejad (2019)). The proposed methodology is described below:

7.1 Gaining Sharing Knowledge-Based Optimization Algorithm (GSK)

An optimization problem with constraints can be formulated as:

$$Min \quad f\left(X\right); \quad X = \left[x_1, x_2, \ldots, x_{Dim}\right]$$

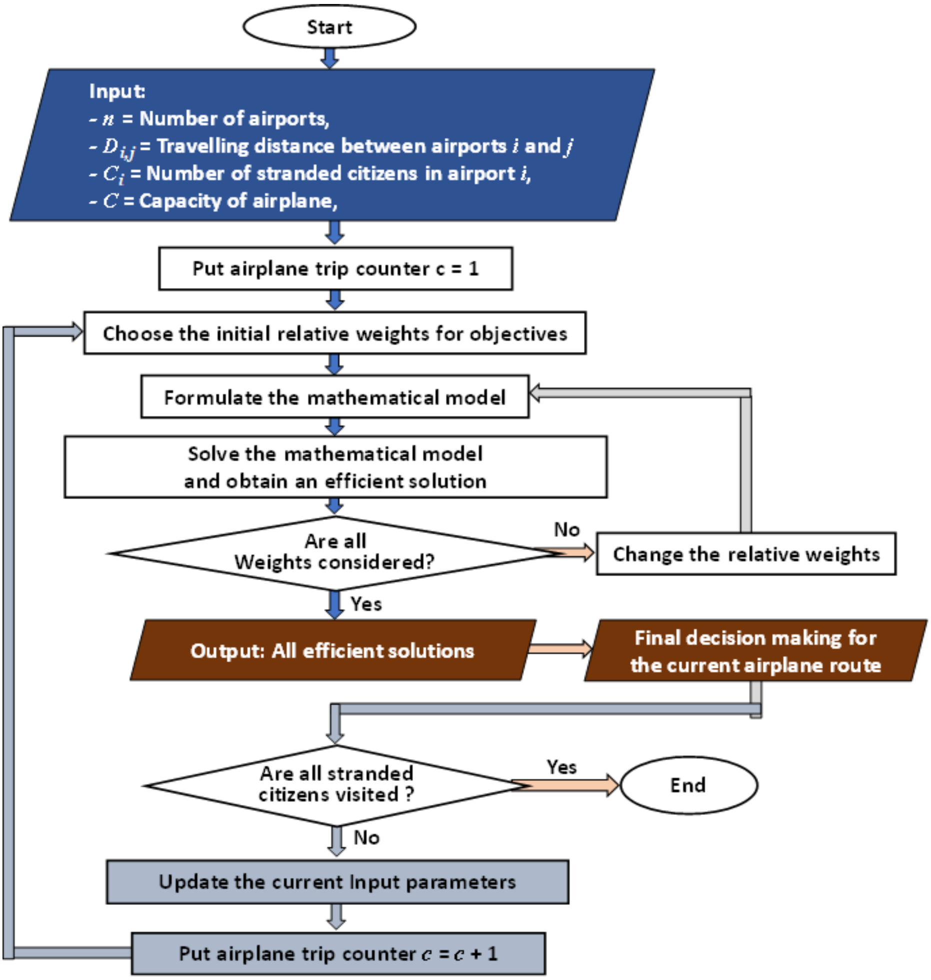
$$s.to. \quad g_i\left(X\right) \le 0; \quad i = 1, 2, \ldots, m$$

$$X \in \left[\alpha_p,\ \beta_p\right]; \quad p = 1, 2, \ldots, Dim$$

Where, *f* denotes the objective function; $X = \left[x_1, x_2, \ldots, x_{Dim}\right]$ are the decision variables; $g_i\left(X\right)$ are the inequality constraints and α_p, β_p are the lower and upper bounds of decision variables respectively and Dim represents the dimension of individuals. If the problem is in maximization form, then consider minimization = - maximization.

The human-based algorithm GSK is of two-stages: junior and senior gaining and sharing stage. All persons acquire knowledge and share their views with others. The people from early-stage gain knowledge from their small networks such as family members, relatives, neighbours, etc. and want to share their opinions with the others who might not be from their networks, due to curiosity of exploring others. These may not have the experience to categorize the people. In the same way, the people from the middle or later age enhance their knowledge by interacting with friends, colleagues,

Figure 2. Steps of the solution procedure for the problem



social media friends, etc. and share their views with the most suitable person, so that they can improve their knowledge. These people have the experience to judge other people and can categorize them (good or bad). The process mentioned above can be formulated mathematically in the following steps:

Step 1: To get a starting point of the optimization problem, the initial population must be obtained. The initial population is created randomly within the boundary constraints as:

$$x_{tp}^{0} = \alpha_p + rand_p \left(\beta_p - \alpha_p \right) \tag{7}$$

Where: t is for the number of populations; $rand_p$ denotes random number uniformly distributed between *0* and *1*.

Figure 3. Locations of the airports for the case study example

Table 1. Data for the Case Study Example

Number of stranded citizens		Airport				
	i j	**1**	**2**	**3**	**4**	**5**
	0 India, New Delhi (DEL)	**2820**	**2640**	**2560**	**2190**	**1930**
75	**1 Kuwait (KWI)**		421	566	854	1203
40	**2 Bahrain (BAH)**			146	487	827
50	**3 Qatar (DOH)**				382	705
120	**4 UAE (DXB)**					349
35	**5 Oman (MCT)**					

Step 2: At this step, the dimensions of junior and senior stages should be computed through the following formula:

$$Dim_J = Dim \times \left(\frac{Gen^{max} - G}{Gen^{max}} \right)^k \quad (8)$$

$$Dim_S = Dim - Dim_J \quad (9)$$

where, $k\ (>0)$ denotes the learning rate, that monitors the experience rate. Dim_J and Dim_S represent the dimension for the junior and senior stage, respectively. Gen^{max} is the maximum count of generations, and G is the count of generation.

Step 3: Junior gaining sharing knowledge stage: In this stage, the early aged people gain knowledge from their small networks and share their views with the other people who may or may not belong to their group. Thus, individuals are updated through as follows:

According to the objective function values, the individuals are arranged in ascending order. For every $x_t\left(t = 1,2,\ldots,NP\right)$, select the nearest best (x_{t-1}) and worst (x_{t+1}) to gain knowledge, also choose randomly (x_r) to share knowledge. Therefore, to update the individuals, the pseudo-code is presented in Figure 3, where: $k_f(>0)$ is the knowledge factor.

Figure 4. Pseudo-code for Junior gaining sharing knowledge stage

for $t=1:NP$
  for $p=1:Dim$
    if rand$\leq k_r$ (knowledge ratio)
      if $f(x_t) > f(x_r)$
        $x_{tp}^{new} = \left(x_t + k_f * \left((x_{t-1} - x_{t+1}) + (x_r - x_t)\right)\right)$
        else
        $x_{tp}^{new} = \left(x_t + k_f * \left((x_{t-1} - x_{t+1}) + (x_t - x_r)\right)\right)$
      end
    else $x_{tp}^{new} = x_{tp}^{old}$
  end
 end
end

Step 4: Senior gaining sharing knowledge stage: This stage comprises the impact and effect of other people (good or bad) on the individual. The updated individual can be determined as follows: The individuals are classified into three categories (best, middle and worst) after sorting individuals into ascending order (based on the objective function values).

Best individual = $100p\%$ (x_{best}), middle individual= $Dim - 2*100p\%$ (x_{middle}), worst individual = $100p\%$ (x_{worst}).

For every individual x_t, choose the top and bottom $100p\%$ individuals for gaining part and the third one (middle individual) is chosen for the sharing part. Therefore, the new individual is updated through the following pseudo-code dictated in Figure 4, where $p \in [0,1]$ is the percentage of best and worst classes.

Figure 5. Pseudo-code of Senior gaining sharing knowledge stage

for $t=1:NP$
  for $p=1:Dim$
    if rand$\leq k_r$ (knowledge ratio)
      if $f(x_t) > f(x_r)$
        $x_{tp}^{new} = \left(x_t + k_f * \left((x_{t-1} - x_{t+1}) + (x_r - x_t)\right)\right)$
        else
        $x_{tp}^{new} = \left(x_t + k_f * \left((x_{t-1} - x_{t+1}) + (x_t - x_r)\right)\right)$
      end
    else $x_{tp}^{new} = x_{tp}^{old}$
  end
  end
end

7.2 Discrete Binary Gaining Sharing Knowledge-based Optimization Algorithm (DBGSK)

For solving problems in discrete binary space, a novel Discrete Binary Gaining Sharing knowledge-based optimization algorithm (DBGSK) is suggested. In DBGSK, the new initialization and the working mechanism of both stages (junior and senior gaining sharing stages) are introduced over discrete binary space, and the remaining algorithms remain the same as the previous one. The working mechanism of DBGSK are presented in the following subsections:

Discrete Binary Initialization:

The initial population is obtained in GSK using Equation (18) and it must be updated using the following equation for binary population:

$$x_{tp}^{0} = round\left(rand\left(0,1\right)\right) \tag{10}$$

Where: the round operator is used to convert the decimal number into the nearest binary number.

Discrete Binary Junior gaining and sharing stage:

The discrete binary junior gaining and sharing stage is based on the original GSK with $k_f = 1$. The individuals are updated in original GSK using the pseudo-code (Figure 6) which contains two cases. These two cases are defined for discrete binary-stage as follows:

Case 1. When $f(x_r) < f(x_t)$: There are three different vectors (x_{t-1}, x_{t+1}, x_r), which can take only two values (0 and 1). Therefore, a total of 2^3 combinations are possible, which are listed in Table 3. Furthermore, these eight combinations can be categorized into two different subcases [(a) and (b)] and each subcase has four combinations. The results of each possible combination are presented in Table 2.

Subcase (a): If x_{t-1} is equal to x_{t+1}, the result is equal to x_r.

Subcase (b): When x_{t-1} is not equal to x_{t+1}, then the result is the same as x_{t-1} by taking -1 as 0 and 2 as 1.

The mathematical formulation of Case 1 is as follows:

$$x_{tp}^{new} = \begin{cases} x_r \ ; & if\, x_{t-1} = x_{t+1} \\ x_{t-1} \ ; & if \ x_{t-1} \neq x_{t+1} \end{cases}$$

Table 2. Results of the discrete binary junior gaining and sharing stage of Case 1 with $k_f = 1$.

	x_{t-1}	x_{t+1}	x_r	Results	Modified Results
Subcase (a)	0	0	0	0	0
	0	0	1	1	1
	1	1	0	0	0
	1	1	1	1	1
Subcase (b)	1	0	0	1	1
	1	0	1	2	1
	0	1	0	-1	0
	0	1	1	0	0

Case 2. When $f(x_r) \geq f(x_t)$: There are four different vectors ($x_{t-1}, x_t, x_{t+1}, x_r$), that consider only two values (0 and 1). Thus, there are 2^4 possible combinations that are presented in Table 3. Moreover, the 16 combinations can be divided into two subcases [(c) and (d)] in which (c) and (d) has four and twelve combinations, respectively.

Subcase (c): If x_{t-1} is not equal to x_{t+1}, but x_{t+1} is equal to x_r, the result is equal to x_{t-1}.

Subcase (d): If any of the condition arise $x_{t-1} = x_{t+1} \neq x_r$ or $x_{t-1} \neq x_{t+1} \neq x_r$ or $x_{t-1} = x_{t+1} = x_r$, the result is equal to x_t by considering -1 and -2 as 0, and 2 and 3 as 1.

The mathematical formulation of Case 2 is as

$$x_{tp}^{new} = \begin{cases} x_{t-1} \ ; & if\, x_{t-1} \neq x_{t+1} = x_r \\ x_t \ ; & Otherwise \end{cases}$$

Table 3. Results of the discrete binary junior gaining and sharing stage of Case 2, $k_f = 1$.

	x_{t-1}	x_t	x_{t+1}	x_r	**Results**	**Modified Results**
Subcase (c)	1	1	0	0	3	1
	1	0	0	0	1	1
	0	1	1	1	0	0
	0	0	1	1	-2	0
Subcase (d)	0	0	0	0	0	0
	0	1	0	0	2	1
	0	0	1	0	-1	0
	0	0	0	1	-1	0
	1	0	1	0	0	0
	1	0	0	1	0	0
	0	1	1	0	1	1
	0	1	0	1	1	1
	1	1	1	0	2	1
	1	0	1	1	-1	0
	1	1	0	1	2	1
	1	1	1	1	1	1

Discrete Binary Senior Gaining and Sharing Stage:

The working mechanism of discrete binary senior gaining and sharing stage is the same as the binary junior gaining and sharing stage with value of $k_f = 1$. The individuals are updated in the original senior gaining sharing stage using pseudo code (Figure 7) that contain two cases. The two cases further modified for binary senior gaining sharing stage in the following manner:

Case 1. $\boldsymbol{f}\left(\boldsymbol{x}_{\boldsymbol{middle}}\right) < \boldsymbol{f}\left(\boldsymbol{x}_{\boldsymbol{t}}\right)$: It contains three different vectors ($x_{best}, x_{middle}, x_{worst}$), and they can assume only binary values (0 and 1), thus, the total eight combinations are possible to update the individuals. These total eight combinations can be classified into two subcases [(a) and (b)] and each subcase contains only four different combinations. The obtained results of this case are presented in Table 4.

Subcase (a): If x_{best} is equal to x_{worst} then the obtained results are equal to x_{middle}.

Subcase (b): On the other hand, if x_{best} is not equal to x_{worst} then the results are equal to x_{best} with assuming -1 or 2 equivalent to their nearest binary value (0 and 1 respectively).

Case 1 can be mathematically formulated in the following way:

$$x_{tp}^{new} = \begin{cases} x_{middle} \;; & if\, x_{best} = x_{worst} \\ x_{best} \;; & if\, x_{best} \neq x_{worst} \end{cases}$$

Case 2. $\boldsymbol{f}\left(\boldsymbol{x}_{\boldsymbol{middle}}\right) > \boldsymbol{f}\left(\boldsymbol{x}_{\boldsymbol{t}}\right)$:

Table 4. Results of discrete binary senior gaining and sharing stage of Case 1 with $k_f = 1$

	x_{best}	x_{worst}	x_{middle}	Results	Modified Results
Subcase (a)	0	0	0	0	0
	0	0	1	1	1
	1	1	0	0	0
	1	1	1	1	1
Subcase (b)	1	0	0	1	1
	1	0	1	2	1
	0	1	0	-1	0
	0	1	1	0	0

It consists of four different binary vectors ($x_{best}, x_{middle}, x_{worst}, x_t$), and with the values of each vector, a total of sixteen combinations are presented. The sixteen combinations are also divided into two subcases [(c) and (d)]. The subcases (c) and (d) further contain four and twelve combinations respectively. The subcases are explained in detail in Table 5.

Subcase (c): When x_{best} is not equal to x_{worst} and x_{worst} is equal to x_{middle}, then the obtained results are equal to x_{best}.

Subcase (d): If any case arises other than (c), then the obtained results is equal to x_t by taking -2 and -1 as 0 and 2 and 3 as 1.

The mathematical formulation of Case 2 is given as

$$x_{tp}^{new} = \begin{cases} x_{best} \ ; \ \ if\, x_{best} \neq x_{worst} = x_{middle} \\ x_t \ ; \qquad\qquad Otherwise \end{cases}$$

The Pseudo code of DBGSK is presented in Figure 5.

8. EXPERIMENTAL RESULTS

The problem is handled by using the proposed novel DBGSK algorithm, the used parameters are presented in Table 6. DBGSK runs over personal computer Intel ® CoreTM i5-7200U CPU @ 2.50GHz and 4 GB RAM and coded on MATLAB R2015a. To get the optimal solutions, 30 independent runs are complete, and the obtained statistics are provided in Table 7, including the best, median, average, worst solutions and the DBGSK standard deviations. Moreover, Figure 6 shows the convergence graph of the solutions using DBGSK. From the figure, it can be observed that after the 216^{h} iteration, it converges to the global optimal solution (20.658), which shows the robustness of the DBGSK.

The efficient solutions of the application case study are shown in Table 8, two efficient solutions are found for different relative weights for the two objective functions. The first efficient solution has x_5^1, x_4^2, x_2^3 = 1, this means that the route starts from New Delhi, India then continue to transport to Oman, United Arab Emirate, Bahrain and then returns to the starting airport (or vice versa). The total number of stranded citizens in this solution = 195, and the total travelled distances = 5406 km. The second efficient solution has x_1^1, x_2^2, x_3^3, x_5^4, this means that the route starts from New Delhi, India then continue to transport to Kuwait, Bahrain, Qatar, Oman and then returns to the starting

Table 5. Results of discrete binary senior gaining and sharing stage of Case 2 with $k_f = 1$

	x_{best}	x_t	x_{worst}	x_{middle}	Results	Modified Results
Subcase (c)	1	1	0	0	3	1
	1	0	0	0	1	1
	0	1	1	1	0	0
	0	0	1	1	-2	0
Subcase (d)	0	0	0	0	0	0
	0	1	0	0	2	1
	0	0	1	0	-1	0
	0	0	0	1	-1	0
	1	0	1	0	0	0
	1	0	0	1	0	0
	0	1	1	0	1	1
	0	1	0	1	1	1
	1	1	1	0	2	1
	1	0	1	1	-1	0
	1	1	0	1	2	1
	1	1	1	1	1	1

Figure 6. Pseudo Code for DBGSK

Start

- **Initialize the value of parameters (Gen^{max}, NP, k_r, k, p)**
- **Initialize the generation ($G = 0$)**
- **Create discrete binary population using equation (21)**
- **Evaluate $f(x_t)$.**
- **For $G = 1$ to Gen^{max}**
  - **Compute the dimensions of both stages (Discrete Binary junior and senior gaining sharing stage)**
  - **Apply Discrete Binary Junior gaining sharing stage**
  - **Apply Discrete Binary Senior gaining sharing stage**
  - **Update the population**
  - **Select the global best solution**
- **End**

End

Table 6. Numerical Values of parameters.

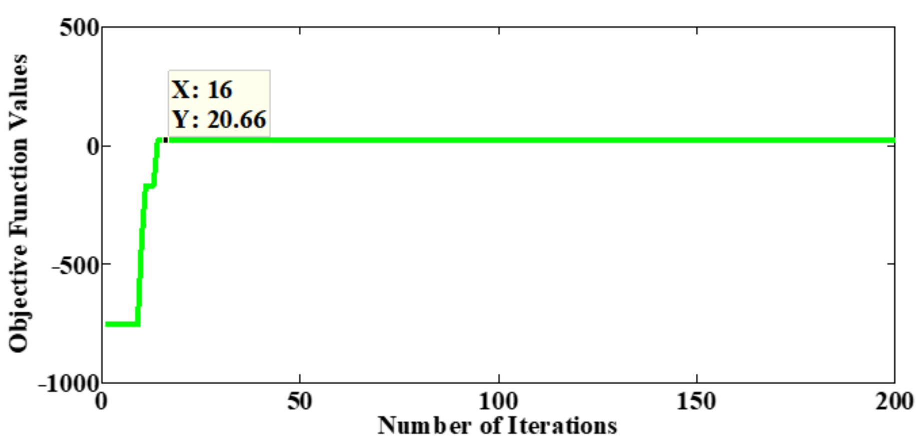
Parameters of DBGSK	Considered Values
NP	800
k	10
k_r	0.9
p	0.1
k_f	1

Table 7. Statistical results using DBGSK

Algorithm	Best (Maximum)	Median	Average	Worst (Minimum)	Standard Deviation
DBGSK	20.658	20.658	20.658	20.658	0.00

Parameters of DBGSK	Considered Values
Max number of iterations	200

Figure 7. Convergence graph of DBGSK



airport (or vice versa). The total number of stranded citizens in this solution = 200, and the total travelled distances = 6022 km. The decision maker can compare between the two efficient solutions to choose the most convenient one. But after discussions with the experts in the field, most of them prefer to choose the first solution since the second needs one more flight for only 5 additional stranded citizens, the first convenient solution is depicted in Figure 7. To complete another journey for the airplane, the visited airports and the evacuated citizens are removed, and an updated list of airports and relative stranded citizens is prepared for another route for the airplane.

Table 8. Efficient solutions of the application case study

w_1	w_2	x **Values = 1**	$f_1(x)$	$f_2(x)$
0.9	0.1	--------------	0	0
0.8	0.2			
0.7	0.3	x_5^1, x_4^2, x_2^3 x_2^1, x_4^2, x_5^3	195	5406
0.6	0.4			
0.5	0.5			
0.4	0.6	$x_1^1, x_2^2, x_3^3, x_5^4$ $x_5^1, x_3^2, x_2^3, x_1^4$	200	6022
0.3	0.7			
0.2	0.8			
0.1	0.9			

Figure 8. Optimum solution for the case study example

9. CONCLUSIONS AND POINTS FOR FUTURE RESEARCH

The main conclusions for this paper can be summarized as follows:

1. An optimum scheduling of a stepped route flights for residual stranded citizens due to COVID-19 is presented. The distribution aims at returning the maximum number of those citizens while minimizing the total travelled distances for the whole flights.
2. A multi-objective nonlinear binary constrained mathematical programming model is formulated for the given problem. The binary decision variables represent the candidate airports allocated to positions in the designed airplane route.
3. The mathematical model and the solution method are used to solve a real application case study for an airplane starting from a specific airport in New Delhi, India to 5 candidate airports in 5 countries (United Arab Emirate, Qatar, Bahrain, Kuwait and Oman) where the stranded citizens reside.
4. Many application problems like this one are formulated as nonlinear binary mathematical programming models which are hard to be solved using exact algorithms specially in large dimensions.
5. The proposed problem is solved by a novel Discrete Integer Gaining Sharing Knowledge based Optimization algorithm (DBGSK), which involves two main stages: Discrete Binary Junior and Senior gaining and sharing stages with a knowledge factor $k_f = 1$. DBGSK is discrete binary variant of GSK, that solves the problem with binary decision variables.
6. DBGSK shows that it has the ability of finding the solutions of the introduced problem, and the obtained results demonstrates the robustness and convergence of DBGSK towards the efficient optimal solutions.

The points for future researches can be stated in the following points:

1. To propose other mathematical models' formulation for the same problem comprising designing of the objective function(s), decision variables and the constraints, and then comparing the effectiveness of computations for each model.
2. To apply the same problem formulation to other similar fields that can show up in many other logistic application domains like: industry, agriculture, business, social and community services, medical, tourism, sales, and others.
3. To check the performance of the DBGSK approach in solving different complex optimization problems, and further works can be investigated by the extension of DBGSK with different kinds of constraint handling methods.

REFERENCES

Anily, S., & Mosheiov, G. (1994). The traveling salesman problem with delivery and backhauls. *Operations Research Letters*, *16*(1), 11–18. doi:10.1016/0167-6377(94)90016-7

Applegate, D. L., Bixby, R. E., Chva'tal, V., Cook, W., Espinoza, D. G., Goycoolea, M., & Helsgaun, K. (2009). Certiðcation of an optimal TSP tour through 85,900 cities. *Operations Research Letters*, *37*(1), 11–15. doi:10.1016/j.orl.2008.09.006

Applegate, D. L., Bixby, R. E., Chvatal, V., & Cook, W. J. (2006). *The Traveling Salesman Problem: A Computational Study*. Princeton University Press.

Aramgiatisiris, T. (2004). An exact decomposition algorithm for the traveling salesman problem with backhauls, Operations Research and Management Science Units, Department of Industrial Engineering, Kasetsart University, Bangkok, Thailand. Journal of Research in Engineering and Technology, 1(2).

Bahreininejad, A. (2019). Improving the performance of water cycle algorithm using augmented Lagrangian method. *Advances in Engineering Software*, *132*, 55–64. doi:10.1016/j.advengsoft.2019.03.008

Baldacci, R., Hadjiconstantinou, E., & Mingozzi, A. (2003). An exact algorithm for the traveling salesman problem with deliveries and collections. *Networks*, *42*(1), 26–41. doi:10.1002/net.10079

Bektas, T. (2006). The multiple traveling salesman problem: An overview of formulations and solution procedures. OMEGA. *International Journal of Management Sciences*, *34*(3), 209–219. doi:10.1016/j.omega.2004.10.004

Centers of Disease Control and Prevention (CDC) Website. (2020). *Coronavirus disease 2019*. Retrieved on April 11, 2020 at: https://www.cdc.gov/

Cleemput, Dumon, Fonseca, Karim, Giovanetti, Alcantara, Deforche, & de Oliveira. (2020). Genome Detective Coronavirus Typing Tool for rapid identification and characterization of novel coronavirus genomes. *Bioinformatics*. 10.1093/bioinformatics/btaa145

Dantzig, G. B., Fulkerson, D. R., & Johnson, S. M. (1954). Solutions of a large scale travelling salesman problem. *Ops. Res.*, *2*, 393–410.

Deb, K. (2000). An efficient constraint handling method for genetic algorithms. *Computer Methods in Applied Mechanics and Engineering*, *186*(2-4), 311–338. doi:10.1016/S0045-7825(99)00389-8

Demiral, M. F., & Şen, H. (2016). Integer Programming Model for Two-Centered Double Traveling Salesman Problem. *European Journal of Economics and Business Studies, 2*(2).

Droste, I. (2017). *Algorithms for the travelling salesman problem* (Bachelor Thesis). Utrecht University.

Dumitrescu, I., Ropke, S., Cordeau, J., & Laporte, G. (2010, February). The traveling salesman problem with pickup and delivery: Polyhedral results and a branch-and-cut algorithm. *Mathematical Programming*, *121*(2), 269–305. doi:10.1007/s10107-008-0234-9

Eskandar, H., Sadollah, A., Bahreininejad, A., & Hamdi, M. (2012). Water cycle algorithm–A novel metaheuristic optimization method for solving constrained engineering optimization problems. *Computers & Structures*, *110*, 151–166. doi:10.1016/j.compstruc.2012.07.010

Finke, G., Claus, A., & Gunn, E. (1983). A two-commodity network flow approach to the travelling salesman problem, Combinatorics, Graph Theory and Computing. In *Proc. 14th South Eastern Conf.* Atlantic University.

Fox, K. R., Gavish, B., & Graves, S. C. (1980). An n-constraint formulation of the (time dependent) travelling salesman problem. *Ops. Res.*, *28*(4), 1018–1021. doi:10.1287/opre.28.4.1018

Gavish, B., & Graves, S. C. (1978). *The travelling salesman problem and related problems*. Working Paper OR-078-78, Operations Research Center, MIT.

Gendreau, M., Hertz, A., & Laporte, G. (1996). The travelling salesman problem with backhauls. *Computers & Operations Research*, *23*(5), 501–508. doi:10.1016/0305-0548(95)00036-4

Gendreau, M., Laporte, G., & Vigo, D. (1999). Heuristics for the traveling salesman problem with pickup and delivery. *Computers & Operations Research*, *26*(7), 699–714. doi:10.1016/S0305-0548(98)00085-9

Gleixner, A. M. (2014). Introduction to Constraint Integer Programming. *5th Porto Meeting on Mathematics for Industry.* Zuse Institute Berlin, MATHEON, Berlin Mathematical School.

Guan, W., Ni, Z., Hu, Y., Liang, W., Ou, C., He, J., Liu, L., Shan, H., Lei, C., Hui, D. S. C., Du, B., & Li, L. (2019). Clinical Characteristics of Coronavirus Disease 2019 in China. *The New England Journal of Medicine*. https://www.nejm.org/doi/full/10.1056/NEJMoa200203210.1056/NEJMoa2002032

Gunantara, N., (2018). A review of multi-objective optimization: Methods and its applications. *Cogent Engineering, 5*. 10.1080/23311916.2018.1502242

Halse, K. (1992). *Modelling and solving complex vehicle routing problems* (Ph.D. thesis). IMSOR, Technical University of Denmark.

Hemamalini, S., & Simon, S. P. (2010). Economic/emission load dispatch using artificial bee colony algorithm. ACEEE International Journal on Electrical and Power Engineering, 1.

International Air Transport Association (IATA). (2020). Retrieved at: https://www.iata.org/en/about/

Kara, I., & Bektas, T. (2003). *Integer linear programming formulation of the generalized vehicle routing problem*. Presented in 5th EURO/INFORMS Joint International Meeting, İstanbul, Turkey.

Kennedy, J., & Eberhart, R. (1995, November). Particle swarm optimization. In *Proceedings of ICNN'95-International Conference on Neural Networks* (Vol. 4, pp. 1942-1948). IEEE. doi:10.1109/ICNN.1995.488968

Li, J., Li, W., & Wang, H. (2015). *The multiple knapsack problem with compatible bipartite graphs*, The 12th International Symposium on Operations Research and its Applications in Engineering, Technology and Management (ISORA 2015), Luoyang, China.

Long, W., Liang, X., Huang, Y., & Chen, Y. (2013). A hybrid differential evolution augmented Lagrangian method for constrained numerical and engineering optimization. *Computer Aided Design*, *45*(12), 1562–1574. doi:10.1016/j.cad.2013.07.007

Marler, R.T., & Arora, J.S. (2004). *Survey of multi-objective optimization methods for engineering, structural and multidisciplinary optimization*. 10.1007/s00158-003-0368-6

Miller, C. E., Tucker, A. W., & Zemlin, R. A. (1960). Integer programming formulation of travelling salesman problems. *Journal of the Association for Computing Machinery*, *3*(4), 326–329. doi:10.1145/321043.321046

Mirjalili, S., Mirjalili, S. M., & Lewis, A. (2014). Grey wolf optimizer. *Advances in Engineering Software*, *69*, 46–61. doi:10.1016/j.advengsoft.2013.12.007

Mohamed, A. W., Hadi, A. A., & Mohamed, A. K. (2020). Gaining-sharing knowledge based algorithm for solving optimization problems: A novel nature-inspired algorithm. *International Journal of Machine Learning and Cybernetics*, *11*, 1501–1529.

Mosheiov, G. (1994). The travelling salesman problem with pick-up and delivery. *European Journal of Operational Research*, *79*(2), 299–310. doi:10.1016/0377-2217(94)90360-3

Muangkote, N., Photong, L., & Sukprasert, A. (2019). *Effectiveness of Constrained Handling Techniques of Improved Constrained Differential Evolution Algorithm Applied to Constrained Optimization Problems in Mechanical Engineering*. Academic Press.

Oberlin, P., Rathinam, S., & Darbha, S. (2009). A transformation for a heterogeneous, multi-depot, multiple traveling salesman problem. *Proceedings of the American Control Conference*, 1292-1297.

Onder, G., Kara, I., & Derya, T. (2016). New integer programming formulation for multiple traveling repairmen problem. *19th EURO Working Group on Transportation*. https://mycurvefit.com/

Orman, A. J., & Williams, H. P. (2005). *A survey of different integer programming formulations of the travelling salesman problem. Operational Research working papers, LSEOR 04.67. Department of Operational Research, London School of Economics and Political Science*.

Pop, P. C. (2007). New Integer Programming Formulations of the Generalized Travelling Salesman Problem. *American Journal of Applied Sciences, 4*(11), 932-937.

Pureza, V., Morabito, R., & Luna, H. P. (2018). Modelling and solving the Traveling Salesman Problem with Priority Prizes. doi: 10.1590/0101-7438.2018.038.03.0499

Rao, R. V., Savsani, V. J., & Vakharia, D. P. (2011). Teaching–learning-based optimization: A novel method for constrained mechanical design optimization problems. *Computer Aided Design*, *43*(3), 303–315. doi:10.1016/j.cad.2010.12.015

Sarubbi, J. F. M., & Luna, H. P. L. (2007). The multi-commodity traveling salesman problem. *INOC – International Network Optimization Conference*. http://www.poms.ucl.ac.be/ inoc2007/Papers/author.68/paper/paper.68.pdf

Sawik, T. (2016). A note on the Miller-Tucker-Zemlin model for the asymmetric traveling salesman problem. *Bulletin of the Polish Academy of Sciences. Technical Sciences*, *64*(3), 2016. doi:10.1515/bpasts-2016-0057

Silva, M. M., Subramanian, A., Vidal, T., & Ochi, L. S. (2012). A Simple and Effective Metaheuristic for the Minimum Latency Problem. *European Journal of Operational Research*, *221*(3), 513–520. doi:10.1016/j.ejor.2012.03.044

Storn, R., & Price, K. (1997). Differential evolution–a simple and efficient heuristic for global optimization over continuous spaces. *Journal of Global Optimization*, *11*(4), 341–359. doi:10.1023/A:1008202821328

The Lancet website. (2020). *A novel coronavirus outbreak of global health concern*. Retrieved on March 30, 2020 at: https://www.thelancet.com/journals/lancet/article/PIIS0140-6736(20)30185-9/fulltext

Vajda, S. (1961). *Mathematical Programming*. Addison-Wesley.

Website, P. (2020). *Airport Distance Calculator, Calculate Airport to airport distance*. https://www.prokerala.com/travel/airports/distance/

Wikimedia Commons Website. (2020). Retrieved on April 15, 2020 at: https://commons.wikimedia.org/wiki/File:COVID-19_Outbreak_World_Map.svg

Wong, R. T. (1980). Integer programming formulations of the travelling salesman problem. *Proc. IEEE Conf. on Circuits and Computers*, 149-152.

World Health Organization. (2020). *Coronavirus disease 2019 (COVID-19) Situation Report – 85*. Retrieved on 25 April 2020 at: https://www.who.int/docs/default-source/coronaviruse/situation-reports/20200414-sitrep-85-covid-19.pdf?sfvrsn=7b8629bb_4

Worldometer Website. (2020a). *COVID-19 Coronavirus pandemic*. Retrieved on April 30, 2020 at: https://www.worldometers.info/coronavirus/#ref-13

Worldometer Website. (2020b). *Coronavirus Cases*. Retrieved on April 30, 2020 at: https://www.worldometers.info/coronavirus/coronavirus-cases/#total-cases

Wright, A. H. (1991). Genetic algorithms for real parameter optimization. In *Foundations of genetic algorithms* (Vol. 1, pp. 205–218). Elsevier.

Yang, X. S., & Gandomi, A. H. (2012). Bat algorithm: A novel approach for global engineering optimization. *Engineering Computations*.

Said Ali Hassan received the PhD. degree in Informatics from National Institute Polytechnic, Toulouse, France, 1981. He is a full professor in Department of Operations Research and Decision Support, Faculty of Computers and Artificial Intelligence, Cairo University, Egypt. His research interests lie broadly in decision sciences and optimization applications. Prior to his current position, he was a staff member in the Military Technical College, Cairo from (1971–1993). He was the chairman of Operations Research Department in Maritime Research and Consultation Center (MRCC), Arab Academy for Science and Technology, Alex., Egypt, (1993–1994). He was Vice Dean, Arab Development Institute, Jeddah, Kingdom of Saudi Arabia (2004-2005). He was professor at the Industrial Engineering Dept., Faculty of Engineering, King Abdulaziz University, Jeddah, Kingdom of Saudi Arabia (2005–2018). He published more than 100 research papers in National and International Conferences and Journals.

Prachi Agrawal is a PhD Research Scholar in the Department of Mathematics and Scientific Computing, National Institute of Technology Hamirpur, Himachal Pradesh India. She did her Masters of Science in Mathematics from Indian Institute of Technology Delhi in 2014 and Bachelor of Science in Mathematics from Ramjas College, Delhi University in 2012. Her main research interests are in the areas of Operations Research and Statistics. Her research area includes optimization, metaheuristic algorithms, evolutionary programming. She has published research papers in journals and, International conferences.

Talari Ganesh is an Assistant Professor in the Department of Mathematics and Scientific Computing, National Institute of Technology, Hamirpur (Himachal Pradesh). He did his Masters of Science and PhD in Statistics from Sri Venkateswara University, Tirupati, Andhra Pradesh. He worked as an Assistant Professor in Seshadripuram Institute of Management Studies, Bangalore and also worked as a Guest Faculty at Department of Statistics in Pondicherry Central University, Puducherry. His main research interests are in the areas of Multi-Criterion Decision Aid, Operations Research, Statistics, Big Data and Data Science. He has worked on stochastic modelling, time series analysis and forecasting and he has published various papers in the field of distribution theory, convolution and mixture distribution. He is currently working on classification techniques, data mining and its applications to the wide varieties of high-volume data which comes under big data analytics and data science. His current research is focused on multi-choice stochastic transportation problem involving fuzzy programming and evolutionary algorithms. He has published more than 12 papers in reputed international and national journals and presented more than 10 papers in various international and national conferences.

Ali Wagdy received his B.Sc., M.Sc. and PhD. degrees from Cairo University, in 2000, 2004 and 2010, respectively. Ali Wagdy is an Associate Professor at Operations Research department, Faculty of Graduate Studies for Statistical Research), Cairo University, Egypt. Currently, He is an Associate Professor of Statis-tics at Wireless Intelligent Networks Center (WINC), Faculty of Engineering and Applied Sciences, Nile University. He serves as reviewer of more than 40 international accredited top-tier journals and has been awarded the Publons Peer Review Awards 2018, for placing in the top 1% of reviewers worldwide in assorted field. He is editor in more than 5 journals of information sciences, applied mathematics, Engineering, system science and Operations Research. He has presented and participated in more than 5 international conferences. He participated as a member of the reviewer committee for 25 different conferences sponsored by Springer and IEEE. He has Obtained Rank 3 in CEC'17 competition on single objective bound constrained real-parameter numerical optimization in Proc of IEEE Congress on Evolutionary Computation, IEEE-CEC 2017, San Sebastián, Spain. Besides, Obtained Rank 3 and Rank 2 in CEC'18 competition on single objective bound constrained real-parameter numerical optimization and Competition on Large scale global optimization, in Proc of IEEE Congress on Evolutionary Computation, IEEE-CEC 2017, Sao Paolo, Brazil. He published more than 45 papers in reputed and high impact journals like Information Sciences, Swarm and Evolutionary Computation, Computers & Industrial Engineering, Intelligent Manufacturing, Soft Computing and Inter-national Journal of Machine Learning and Cybernetics. He is interested in mathematical and statistical modeling, stochastic and deterministic optimization, swarm intelligence and evolutionary computation. Additionally, he is also interested in real world problems such as industrial, transportation, manufacturing, education and capital investment problems.