LOCATION-ALLOCATION USING BEE COLONY OPTIMIZATION (ABC) ALGORITHM: A CASE STUDY BASED ON SCHOOLS OF ENSCHEDE

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March, 2014

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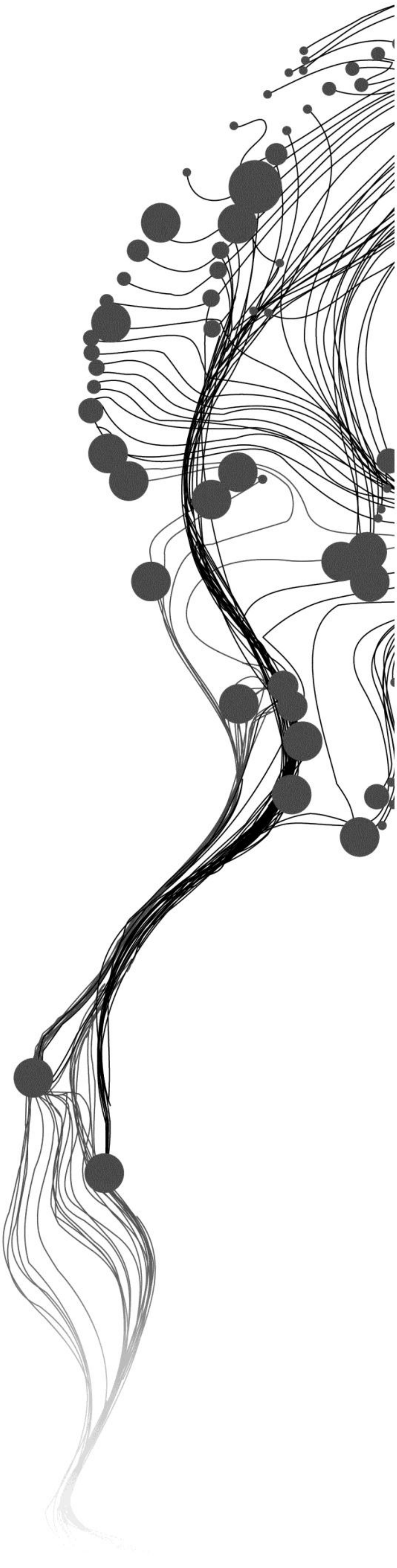

LOCATION-ALLOCATION USING ARTIFICIAL BEE COLONY OPTIMIZATION (ABC) ALGORITHM: A CASE STUDY BASED ON SCHOOLS OF ENSCHEDE

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Enschede, the Netherlands, March, 2014

Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
Specialization: Geoinformatics

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ABSTRACT

Location-Allocation (LA) is the process of finding the best location for one or more facilities to provide services for a given set of points which are called demand points. LA can be considered as a combinational optimization problem that has been studied for almost a century. Besides distance, different factors and criteria can be taken into account for solving LA problem like user preferences, costs, time and so on.

Various methods are applied to solve LA problems, one class of which is the meta-heuristic optimization methods inspired by the natural life of some animals and insects. One of these, inspired by honey bees foraging behaviour is called Artificial Bee Colony algorithm or ABC algorithm. ABC algorithm is a new optimization algorithm that was first proposed in year 2005 and there is a lot to do to discover its vast domains of usage.

The aim of this study is to assign the children of Enschede, a town in the Netherlands, to primary schools based on four different criteria, consisting of distance, religion, Cito score and capacity of schools. This problem is an allocation problem that is going to be solved using ABC algorithm.

Since this allocation problem is multi-objective, we have to use some methods besides ABC in order to achieve logical and reasonable answers. One of these approaches is applying Analytic Hierarchy Process (AHP) to define the objective functions' weight and to convert the multi-objective problem to a single-objective one and solve it like single-objective problems. The other approach is to use pareto optimal method that helps us to find a set of non-dominated answers. In a multi-objective problem a non-dominated answer is the one that is not worse than any other answer in all objective functions. This answer can be located in pareto optimal frontier as an acceptable answer.

ABC algorithm is applied to solve the allocation problem. Its answers are qualified using two methods of AHP and Pareto optimal. Each of these two methods has its own advantages and disadvantages that will be discussed later on.

ACKNOWLEDGEMENTS

I'd like to thank my both supervisors Dr. M.S. Mesgari and Ir.P.W.M (Ellen-Wien) Augustijn for their kind and generous guidance all along the process of this study. My deepest appreciation goes to Mr. H.Motyeian and M.Raeesi who helped me a lot.

I'd like to thank my parents for providing a peaceful and safe space to continue my studies. And finally I wish to thank the kindest and best friend of mine Elham Ronaghi who stood by me every single day in last two years and was the biggest motivation for me to continue my studies and walk in the road to success.

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1. INTRODUCTION

1.1. Motivation and problem statement

It's important for almost everybody to choose a good school for his/her child. All around the world people decide about this issue based on different factors according to cultural and social differences. Some governments and municipalities have designed some consulting systems which help the parents to choose the right school for their children based on their desired parameters.

As the population in some of Europe countries like Netherlands gets old and the rate of children decreases, many schools in those countries have few students and it's not economically justified for the governments to pay for all of those schools. Therefore they should decrease the number of schools and change the school systems in a way that satisfies the desires of the majority.

For solving both of the above mentioned problems, a system is going to be made in this research to help both parents and governments for location-allocation of schools.

Location-Allocation (LA) is the process of finding the best location(s) for one or more facilities to service the demands of a given set of points (demand points) considering some factors like distance, capacity, population density and costs. LA can be based on either a single criterion or multiple criteria, depending on the requirements. LA is a decision making problem that should be solved in order to minimize the costs. Bad location of a facility can cause inefficiency in provided services. Facilities should be located in an optimal distance from the demand points to have the maximum efficiency. When the facilities have a limited capacity, they should be well-distributed to satisfy all of the demand points of the region. Therefore decision makers need some decision support tool in order to locate facilities considering multiple factors such as the type of facility, different services provided by facility, working time of the facility etc. Currently many non-distance factors are considered besides distance-based factors that were the only criteria for facilities location. In general terms it can be mentioned that people choose a facility to get service from according to multi-criteria.

Meta-heuristic methods are widely used for solving combinational optimization problems. Bianchi et al. (2009) Define meta-heuristic methods as often nature inspired algorithmic frameworks that are designed to solve complicated optimization problems and are alternatives for classical approaches of solving optimization problems. It includes genetic algorithm, ant colony optimization, bee colony optimization etc. Petrowski and Taillard (2006)mentioned the meta-heuristic methods' common properties such as being used for solving both discrete and continuous problems and the property of being probabilistic that helps them not to be trapped in local optima.

Bee colony Optimization is a meta-heuristic, population based, nature inspired algorithm for solving combinational optimization problems first addressed byD. Karaboga (2005). It is also developed by D. Karaboga and Basturk (2007b) .They compared ABC's performance with other meta-heuristic methods like genetic algorithm and particle swarm optimization (PSO) and it's been concluded that ABC can be used for multi-modal, multi-variable function optimization. The initial local search of ABC is completely random. Tabu search algorithm is a meta-heuristic local search algorithm that can be used for solving combinational optimization problem. Local searches find a potential solution to a problem and check its neighbours in order to find an improved solution. Local search methods may stick in suboptimal parts where many solutions are equally suitable. Glover (1989) said Tabu search improves the performance of these methods by using memory structures that present the visited solutions or user-provided sets of rules. If a potential solution has been previously found in a certain short period of time or it has violated a rule, it is marked as tabu (taboo) Therefore it doesn't revisit it repeatedly.

This proposal aims to solve the Location-allocation problem of schools in Enschede considering multiple criteria which are based on people preference by using a Bee Colony algorithm.

1.2. Research identification

1.2.1. Research Objectives

The main research objective is to solve multi-criteria location and allocation problem of schools, using ABC algorithm. For achieving this objective, I should solve LA problem of schools in Enschede. Then the objective is being divided to two sub-objectives:

- To assign children of Enschede to existing schools by applying ABC method, considering multi-criteria like schools' capacity, users' preference, distance, costs, etc.
- To prepare data for ABC algorithm to solve the location-allocation problem.

1.2.2. Research Questions

1. How does Analytic hierarchy process (AHP) prepares the data for Bee Colony algorithm?
2. How does Pareto front method prepare data for Bee Colony algorithm?
3. What are the advantages and disadvantages of both AHP and Pareto front for this case-study?
4. How does ABC algorithm work in this case study?
5. What are the most important factors based on which people in Enschede decide about their children?

1.2.3. Innovation aimed at

The intended innovation is:

- It is the first time that multi-criteria Artificial Bee Colony Optimization is used for location-allocation of schools.

1.3. Related work

Location and allocation of facilities has been an important issue in decision making. Therefore various models and algorithms has been applied to solve the problem. For the first time LA problem was proposed by Cooper (1963). Many meta-heuristic algorithms were designed to solve this problem like simulated annealing (Murray & Church, 1996) and Tabu search (Ohlemüller, 1997). Genetic algorithm was used for solving LA problem of schools in Enschede by Arifin (2011). Bee Colony Optimization is a new method for location problem that was first proposed by D. Karaboga (2005). It is a new method that has not been widely used for solving LA problem. It was used by Abu-Mouti and El-Hawary (2011) to solve Optimal Distributed Generation Allocation problem in distribution systems. Tuncbilek et al. (2012) used BCO for incapacitated facility location problem. BCO was developed to solve the reliability redundancy allocation problem by Yeh and Hsieh (2011). And finally Ozcan and Esnaf (2011)used heuristic approach based on ABC to solve shelf space allocation problem.

Before applying the Bee Colony Optimization (BCO) method to solve LA problem, the multi-criteria problem should be translated to a realizable set of data for BCO algorithm. There are two different methods for this process. The first one is to use Analytic hierarchy process (AHP). AHP first divides the decision problem into a hierarchy of more easily comprehended sub-problems, each of which can be analysed independently. Then the decision makers evaluate its various elements by comparing them to one another simultaneously, concerning their impact on an element above them in the hierarchy and then a summation function of weighted data is made to find the best solutions(Saaty, 2008). The other solution is to use Pareto optimal method which gives us a set of optimal answers, In the Pareto front optimization method, all individual objective functions are considered in the optimization process simultaneously, and a set of global optima is calculated. Then, the user can decide and select the best optimal solution based on the problem conditions, constraints and his/her experiences(Saadatseresht et al., 2009). There are some advantages and disadvantages for each of these methods. Both of them will be applied to be evaluated and to find out which one is more suitable.

2. LOCATION-ALLOCATION

2.1. Introduction

There are some analyses and activities that GIS can manage them better than every other information system. One of these analyses is Location-allocation (LA) which only can be done by GIS. The main goal of LA is to find the best location for one or more facilities in a way that satisfies all requirements(ESRI 2014). In fact solving LA problem is a process in which a decision will be made about the location of facilities in a way that minimizes the summation of distance between the customers and facilities. Many researches have been done about LA problem and here some of them will be mentioned.

When there are some facilities and some demand points, a function is needed to find the optimal ways for accessing the facilities. This issue is very important in third world countries. Especially in countries that there is a vast and increasing demand to the facilities like electricity, water resources, educational facilities, hospitals etc.

In most cases, the location of a facility is one of the most important factors that make the business successful. Whether it's a small supermarket with local customers or an international network of factories with well distributed centres all over the world with chain stores, position is the most important factor for customers to have a cheap and fast access to a facility.

Starting a new business needs some high investment. Therefore choosing the right location is very important and furthermore, the changes in population pattern may cause the location to change, starting the business in some extra new locations or omitting some of the existing locations.

Although we know that the location of a facility should be somewhere close to demand points, finding this location is a complicated issue. Using visual or simple techniques can give us an answer but it can be totally different from the reality. Therefore the best and cheapest way is to use location-allocation (LA) techniques.

According to the search space, Location-Allocation process can be divided into Continuous and discrete spaces. For example we can search everywhere in a continuous space to find an optimum location for a store but in a discrete space we just search in a pre-defined set of locations.

In this chapter, first some terms and concepts will be introduced and then different situations of LA problem will be discussed. It's about a century that LA problem has been considered by researchers. It was mentioned by Weber for the first time in 1909. We try to discuss about the strength points and weaknesses of the Location-Allocation problem in this chapter.

2.2. Common terms

There are some common terms in different researches that are done about LA that here we introduce some of them. Azarmand and Neishabouri (2009) point that Facilities, facilities' location, customers or demand points and network impedance are the main components of LA.

Facility: in an LA problem, facility is an object that its location must be determined using some models or algorithms to have the maximum interaction with a set of objects. Chain stores, schools, universities, fire stations, hospitals or even objects like police vehicles and ambulances are some examples for facility. A facility can be introduced by some other features like type, number, and cost(Scaparra & Scutellà, 2001).

Scaparra and Scutellà (2001)mention that one of the facility's features in many LA problems is the number of facilities. Therefore a single-facility problem is a simple LA problem that can be modelled easily. While a more complicated problem is the multi-facility problem that new facilities are located simultaneously in order to cover the maximum area.

The type and the number of services are other features of a facility. Therefore a facility can be capacitated or incapacitated and also it can offer a single-service e.g. restaurant or multi-service e.g. fire station.

The cost is another feature that can distinguish LA problems(Scaparra & Scutellà, 2001).The cost of the facilities is divided to two different parts:

- Fixed costs: The needed cost for setting up the facility.
- Variable costs: The needed costs for providing services for customers.
- Demand (customers): Customers are another main parameter of LA problem(Redondo et al., 2009). Demand points or customers are people who need to have access to a service or a product(Scaparra & Scutellà, 2001). Since LA problem is related to customers' satisfaction, it's important to know the customers number, features and distribution. The distribution of customers in our space can be assigned uniformly in the whole space (network) or it can be assigned to one point by Geocoded format (Comber et al., 2010) (Sasaki et al., 2010) . Also we can assign the distribution to the centroid of the area(Neema et al., 2011).

In classic LA problem, demand is used as a weighted value assigned to an existing node (Gong et al., 1997) (Correa et al., 2004). Since LA is a nonlinear and complicated problem (NP-Hard) as the number of demands decrease, the complexity of the problem reduces and vice versa.

Location or space of a facility: There are three ways for presenting space in a LA problem. Continuous, discrete or network based. In discrete representation the assumption is that we have important information about the selected locations. Since the location of the facilities will be chosen based on these selected location this method is called site selection.

Some of LA problems are related to continuous space and locations (M. Neema & A. Ohgai, 2010) (Neema et al., 2011) (Salhi & Gamal, 2003). In this situation all places and locations can be chosen as facility locations and it is called site generation. In this model there is no presumption for choosing locations.

And the third way of space presentation is network based presentation that is dependent to graph theory and the models based on this approach can solve the problems of the vast areas. Network based models can be used both in continuous and discrete spaces.in a discrete network, facilities are considered as nodes and in continuous networks, network edges are considered as a presentation of a set of locations for facilities (Azarmand & Neishabouri, 2009)

For solving a LA problem, some locations can be determined as prohibited that no facility can be located on it e.g. lakes.

Network Impedance: network impedance is the cost of using facilities by the means of network. Distance and travel time are general impedances.

2.3. Location

Location is the process of finding a proper place for executing a determined activity according to effective parameters and criteria. The final goal of all the problems which are related to locating a facility is to find the best place for that specific facility but for finding the best place, some questions should be answered first. Some of these questions are:

- What are the characteristics of a good location?
- What are the most important factors affecting the location?

The answer of these questions depends on the type of facility which is going to be located and the people who want to manipulate that facility. Considering these facts, Location process has been categorized into four different groups:

- Private sector Location: Private sector is classified into two groups of retail sales and manufacturing sales. Retail sales include banks, restaurants and every other store. They can be successful only when they have a large number of costumers. Location models can help them to locate or move their facility to somewhere that becomes accessible for a larger number of customers. Manufacturers on the other hand supply the items needed by retail sales and stores. Transportation costs are a large part of a manufacturer expenses. Therefore they need to build their facilities in a location that minimize their transportation costs and Location models can help to find that optimal location(Sanaei Nejad, 2002).

- Public sector Location: Public sector includes libraries, schools, post offices, parks, bus stations and so on. The main goal of public sector LA is to maximize the number of customers that can be served by it (Sanaei Nejad, 2002).

Emergency departments Location: It includes hospitals, fire stations, police stations and etc. They should help people in emergency situations. Sanaei Nejad (2002) claims that the main goal of emergency departments' location-allocation is to make them being prepared for providing their services as soon as possible for people around them.

- Location for the facilities that have limitations in distance parameter: No student goes to a school too far away from his/her home (Sanaei Nejad, 2002).

2.4. Allocation

Allocation is the process of assigning some parts of a network or some nodes in an area to a service centre considering some predefined conditions (Fotheringham & Wegener, 1999).

A good allocation happens when demand rate has an efficient proportion with the performance of service centre. Also the impedance of the network must be taken into account. As an instance consider a school as a service centre. This school has some classrooms and desks and so on. It represents its capacity. The students who live in the school's neighbourhood represent the demand rate and the streets represent the network. In this current example, the impedance of the network is distance or travel time to school that can be estimated using streets as network. Allocation starts assigning students to school considering the impedance of the streets till the demand rate and facilities of the school become equal or the allocation process passes impedance limitations. Sometimes it happens that demand rate and facility capacity are not equal but the allocation is finished. In this example the cause can be small number of students in the streets that are less than 20 minutes far from the school.

2.5. LA problems in literatures

In this chapter some well-known LA problems will are introduced and discussed. There are three famous models, P-centre problem, P-median problem and covering problem.

2.5.1. P-centre problem:

It was proposed by Hakimi (1964) for the first time. In this problem the main aim is to minimize the maximum distance between demand points and the nearest service centre (facility). In P-centre problem, the number of facilities that are being located is predefined. This problem is divided to two classes. Convex P-centre which restricts the problem to some candidate locations for locating the facility and absolute P-centre in which facilities cannot be located everywhere. If the problem is weightless, all demand points are considered to have the same value. But in weighted problems, the weight of the demand points will be multiplied by the distance between the demand point and the school.

Parameters:

W: the maximum distance between the demand point and the assigned facility.

P: The number of facilities to be located

d_{ij}: The distance between location i and location j.

h_i: Demand rate in location i.

Variables:

$$y_{ij} = \begin{cases} 1 & \text{If demand i is assigned to facility j} \\ 0 & \text{If not} \end{cases}$$

P-centre problem is modelled as follows:

Minimize W

Subject to

$$\sum_{j \in J} x_j = P$$

$$\sum_{j \in J} y_{ij} = 1 \quad , \forall i \in I$$

$$y_{ij} - x_j \leq 0, \forall i \in I, j \in J$$

$$W - \sum_{j \in J} h_i \, d_{ij} y_{ij} \geq 0, \forall i \in I$$

$$x_j \in \{0,1\}, \forall i \in I$$

$$y_{ij} \in \{0,1\}, \forall i \in I, \forall j \in J$$

The objective function minimizes the maximum distance between each demand point and the nearest facility to it. The first constraint guarantees that the number of facilities is equal to P. The second one represents that each demand point will be assigned to just one facility. The third one says that demand points will be assigned only to open facilities (facilities that are not full yet). The fourth constraint defines the lower limit of the weighted distance for the demand points. The fifth and sixth constraints are binary ones and the sixth constraint can be replaced by $y_{ij} \geq 0$ because the second constraint guarantees that $y_{ij} \leq 0$.

2.5.2. P-median problem:

P-median is a classic location allocation problem which has been proposed by Hakimi in 1964, 1965. The aim in this problem is to locate P centres in a way that minimizes the summation of weighted distance between demand points and related facilities.

Related parameters and variables are defined the same as P-centre problem and it can be modelled as follows:

Minimize

$$\sum_{i \in I} \sum_{j \in J} h_i \, d_{ij} y_{ij}$$

Subject to

$$\sum_{j \in J} x_j = P$$

$$\sum_{j \in J} y_{ij} = 1 \quad , \forall i \in I$$

$y_{ij} - x_j \leq 0, \forall i \in I, j \in J$

$x_j \in \{0,1\}, \forall i \in I$

$y_{ij} \in \{0,1\}, \forall i \in I, \forall j \in J$

The objective function minimizes the summation of weighted distance of demand points. The constraints of P-median problem are almost the same as P-centre problem with one exception. The exception is that it doesn't have the fourth constraint of P-centre problem.

2.5.3. Literatures about P-median

According to given explanations, Brandeau and Chiu (1989)say that Weber located a warehouse in a way that minimizes the travel distance among warehouse and the locations of distributed customers. Weber extended his research from one warehouse to multiple warehouses till he finally introduced P-median problem (Cooper, 1963).

Hakimi (1964) considered facilities as nodes on graph network. In his model, demand points were in discrete format. Thus possible ways to reach to the optimum condition become discrete too.

In some literatures, continuous space has been used in order to locate facilities optimally instead of using nodes. Gong et al. (1995) claim that Facilities might be located on prohibited locations like water sources. To avoid this kind of mistake, before starting location process prohibited areas must be determined.

Although network distance is very useful in some software like ArcGIS for solving LA problems (ESRI 2014), in classic LA problems, distance is being used in Euclidean format and network distance isn't being used (Min et al., 1998). Network distance is very useful especially for services like ambulance that must reach to the patients as soon as possible. But in some cases like villages roads that road networks which constantly change, using network distance is not logical. Also when we use small vehicles like bicycle for offering service, using main road network can't be useful.

In classic LA models, customers always get services from the closest facility. For example a patient will go to the closest hospital. But sometimes being close is not the only factor and the quality and the type of services being provided in a specific facility is important too. In hospital example, the specialty of the hospital can be important or in school case, it's important that whether school is public or private.

2.5.4. Covering problem:

Covering problem is one of the optimization problems which have many applications in different themes like transportation, network, linear programming and allocation. In covering problem there is a zero matrix and a $(a_{ij})_{m,n}$ matrix in which $i \epsilon I = \{1, \dots, m\}, j \in J = \{1, \dots, n\}$. If the row i is being covered by column j, the element $a_{ij} = 1$ and if not $a_{ij} = 0$. Every column j has its own costs (c_j) and its own cardinality ($Card_j$). A column's cardinality is equal to the number of rows being covered by it. In covering problem, we're looking for subsets of columns which have minimum costs meanwhile cover all the rows. Covering problem can be explained using the following function which must be minimized (Talbi, 2009).

$$f = \sum_{j=1}^{n} c_j \, x_j$$

Subject to

$$\sum_{j=1}^{n} a_{ij}\, x_j \geq 1, i = 1, \dots, m$$

$$x_j \in \{0,1\}, j = 1, \dots, n$$

In this problem x_j is called decision variable. It means that if column j exists in problem's answer, $x_j = 1$ and if not $x_j = 0$. Problem's constraint guarantees that each row is covered by at least one column (Talbi, 2009).

2.6. Location-Allocation Models

Location-Allocation models determine the location of facilities and assign demands to facilities according to some specific factors. There are six LA models in ArcInfo and each of them can solve some specific type of problem. As it was mentioned before, LA models can be classified to three general groups according to the type of problems that they can solve.

2.6.1. Private sector LA models

These models are applied when the aim is minimizing the costs and maximizing efficiency.

- MIDDISTANCE model: Minimizes the total travel distance between demand points and facility.

2.6.2. Public sector LA models

When the aim is providing equal service for all demand points and maximizing efficiency, public sector LA models are used.

- MAXATTEND model: Maximizes the number of demand points assigned to each facility while the number of demand points assigned to the facility linearly decrease as the distance increases.

- MINDISTPOWER model: Minimizes the total travel distance between demand points and facility when distance is taken into account with a higher potential (2nd or 3rd power).

- MINDISTANCE-CONSTRAINED model: minimizes the total distance between demand points and facility while no demand point is further than a limited distance to the closest facility.

2.6.3. Emergency sector LA models

The aim is to provide services for as large as possible number of people while a limited travel time or distance is the limitation for providing service.

- MAXCOVER model: Maximizes the number of demand points covered by the facility in a limited distance or travel time from the facility.

- MAXCOVER-CONSTRAINED model: Maximizes the number of demand points covered by the facility in a limited distance or travel time while makes sure that there is no demand point out of that limitation.

It should be considered that in all these six models, demand points are assigned to the closest facility regardless of facility's capacity. Therefore when the facilities are full to their capacity, above mentioned models cannot work anymore. For instance capacity of a school is 200 while 250 students are assigned to it because of using these above mentioned models and the capacity cannot increase.

2.7. Location-Allocation Models classification

Combination of two or more LA models makes them much more similar to reality. For instance when P-median problem is being converted to capacitated P-median, it is going to be a closer simulation of reality because every facility has a limited capacity. This kind of LA models has been proposed in many researches (Correa et al., 2004) (Gong et al., 1997).

For getting closer to reality, the problem might change from single-objective to multi-objective and becomes more complicated in calculation and computation part.

The first classification of LA models according to researches done up to 1989 was made by Brandeau and Chiu (1989). They studied 54 different LA models and classified them based on their objectives, decision variables and system parameters.

Li and Yeh (2005) claim that Church divided LA models into four classes of Covering, Median, Capacitated and Competitive. Capacitated models determine the capacity of facilities based on the rate of demand and thus helps decision makers to decide about their facilities and its capacity based on the location of their rivals' facilities. In his classification, competitive class is a combination of other models. For example it can be a combination of maximal covering and P-median. LA problems can be solved using heuristic and meta-heuristic techniques.

According to the calculation complexity, the problems are classified into Polynomial (P) and Non-deterministic Polynomial (NP) classes. P complexity class includes a set of decisions that can be solved in a deterministic polynomial time algorithm. If the complexity of the problem in the worst condition has been limited using a polynomial P(n), in which n is the input size, the problem can be solved in time O(n^k) where k is a constant and n is the input size. The shortest path problem, the maximum flow problem and continuous linear programming models are some of famous problems in P class(Talbi, 2009).

Complexity class NP includes decision making problems that can be solved using nondeterministic polynomial algorithms. Nondeterministic polynomial problems include two-phase algorithms. In the first phase one candidate solution will be made randomly. In second phase, the found solution will be tested. If it's a solution for the problem, value "Yes" would be returned as the final solution for the decision making problem and if not, value "No" will return (Talbi, 2009).

One common mistake that some people make is that they think NP stands for non-polynomial time problems while it stands for non-deterministic polynomial time problems (Talbi, 2009).

It's clear that every class P problem has a non-deterministic polynomial time algorithm as a solution. Because the problems which can be solved using deterministic polynomial time algorithms, can be solved using non-deterministic polynomial time algorithm too. $P \subseteq NP$. Figure 2.1 shows the relationship between P and NP classes.

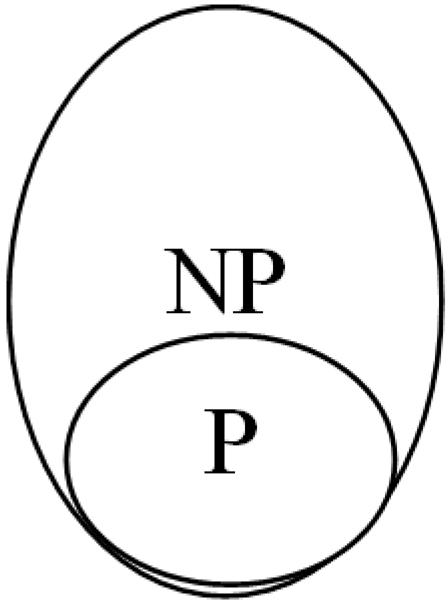

Figure 2.1: The relation between class P and class NP problems.

The third class of problems is NP-complete which means complete non-deterministic problems with polynomial time. NP-complete problems are the most complicated ones in NP class.

$NP - complete \subseteq NP.$

The fourth class is NP-hard problems. There is no deterministic polynomial algorithm for solving this class of problems and time for solving the problem exponentially increases as the dimensions of the problem increases. $NP - complete \subseteq NP - hard.$ Figure 2.2 represents the relationship among four classes of P, NP, NP-complete and NP-hard

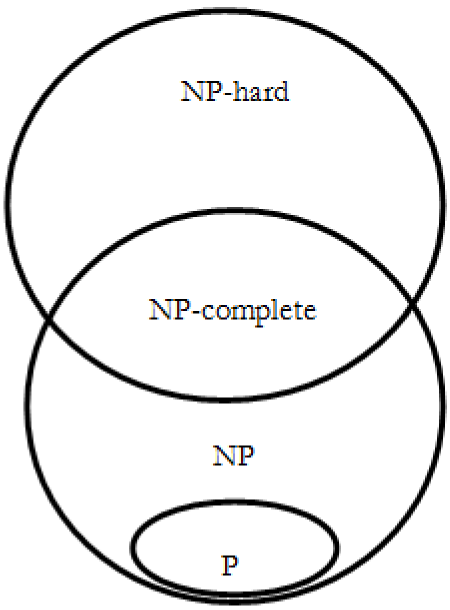

Figure 2.2: The relations among P, NP, NP-complete and NP-hard classes.

Meta-heuristic algorithms are introduced for solving NP-hard problems in an acceptable time length (Talbi, 2009).

Heuristic algorithms tend to find the answers close to optimum solutions in an acceptable time length but they can't guarantee that their solutions are the optimum ones(Dorigo & Stutzle, 2004).

Many heuristic approaches are made for solving combinational optimization problems. They find solutions close to optimum answers. But their problem is that they are useful only for a specific problem and they are not general (Dréo, 2006).

One of the heuristic approach problems is producing one or a set of limited solutions that may fall in local optima with a low quality. Meta-heuristic methods are suggested for resolving such problems in heuristic methods (Dorigo & Stutzle, 2004).

Meta-heuristic approaches confront this problem using some systematic principles to avoid falling in local optima. The common property of all meta-heuristic methods is the mechanisms for escaping of local optima (Petrowski & Taillard, 2006). Figure 2.3 represents the optimization problems flowchart.

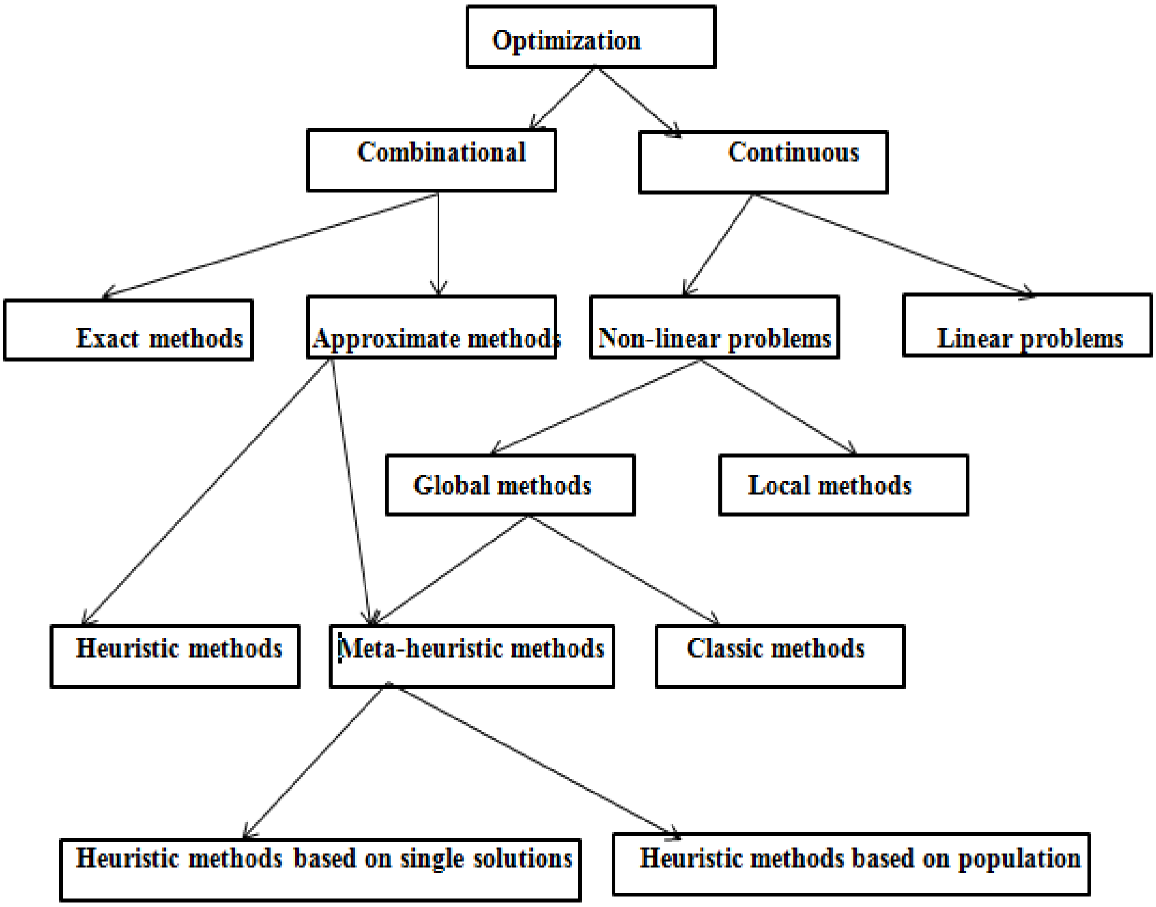

Figure 2.3: Optimization flowchart.

2.8. Meta-heuristic Algorithms

Meta-heuristic algorithms are heuristic methods which can search solution space to find the answers with high quality. Using meta-heuristic algorithms increases the chance of finding a good solution in combinational optimization problems. Their common goal is to solve NP-hard problems (Dorigo & Stutzle, 2004). Petrowski and Taillard (2006) say that meta-heuristic methods' properties are as follows:

- These methods are probabilistic. Being probabilistic helps them not to fall in local optima trap.
- They are represented for solving discrete problems but they can also help to solve continuous problems.
- They are usually inspired by biology, physics and animal behaviour studies.
- One of the common problems in using meta-heuristic algorithms is adjustment and adaptation of their parameters.

There are various factors for meta-heuristic methods classification (Avazbeigi, 2009).

- Based on a single solution or population: Single solution-based algorithms change one solution in searching process but population-based solutions change a population of solution in searching process. The characteristics of these two types of algorithm are complementary. Meta-heuristic methods based on single solution can focus on local search while the algorithms based on population can lead the searching process to various locations of solution space.
- Inspired by nature or not: Lots of meta-heuristic algorithms are inspired by nature. Ant colony and bee colony are inspired by collective intelligence in different species of animals.
- With or without memory: Some of meta-heuristic methods don't have any memory which means they don't use any gathered information achieved by search process. Some examples are simulated annealing and greedy adaptive search. There are some other meta-heuristic methods which have some kind of memory. This memory saves the gathered information in searching process.
- Deterministic and probabilistic: A deterministic meta-heuristic algorithm solves the problem using deterministic decisions while in probabilistic ones a set of probabilistic rules are used in search process. In deterministic algorithms the final solutions will be the same if we start from an equal initial answer while in probabilistic algorithms we may have different final answers although we have had equal initial answers.
- Greedy and frequent: The frequent algorithms start with a set of complete solutions and in each repetition they change the solutions using some search operators. Greedy algorithms start with an empty solution and in each repetition they initialize one of the decision variables till have a complete solution.

3. COLLECTIVE INTELLIGENCE AND BEE COLONY

3.1. Introduction

The insects which live in groups like ants and bees are on earth for millions of years and they are busy building nest, gathering food and so on. Insect colonies are flexible and can adapt themselves with environmental changes. Interactions among colony members are done by various types of chemical and physical signs. Interaction systems among single members of insect colonies finally cause a collective intelligence to exist.

Bees' behaviour is self-organized by a simple set of rules. Bees' behaviour in nature was studied by Frisch and Frisch (1974)for the first time. Its artificial algorithm was introduced by D. Karaboga (2005). Honey bees search the flowers in groups and store flowers' nectar in their hive. Artificial be colony have similarities and differences with natural bee colony.

3.2. Intorduction of natural bee colony

Bees are social insects. A bee colony is made up of lots of bees cooperating in activities such as making nest, food gathering and raising infants. Each bee has a predetermined duty and every colony has a queen and 50 to 60 thousands workers and in the end of spring and summer there are 100 to 200 male bees. None of these three groups (queen, workers, and males) can do anything alone and the performance of bee colony depends on the cooperation of three groups. A custom dance called waggle dance is the mechanism to control the collective behaviour. Division of labour is done among bees based on the age and it can change according to colony's requirements. The power of colony and its reconstruction capability depend on the queen, the quality of food resources and the number of worker bees. Each colony has three groups of bees:

- Queen: Queen comes to existence from fertilized larvae. It lives longer than other types of bees in colony. Queen's body is larger than others. she eats royal jelly that its quality is higher than honey. Queen's duty is spawning and the number of larvae that she can make depends on the quality of the royal jelly that she eats.

- Male bees: They are born from unfertilized larvae. They are identified in colony by their eyes' size that is twice bigger than worker bees' and also their body size is larger than worker bees. They don't have sting and their most important activity is fertilizing queen.

- Worker bees: They are the smallest bees in colony and they make the most population of colony. They are female bees that are not enabled to fertilize. Therefore they can't do the spawning. Their duty is to clean the cells, feed the infants, caress queen, remove garbage, make combs and avoid strangers to come in hive and out of hive their duty is food gathering.

3.3. Bees foraging

3.3.1. Foraging in nature

Studies represent that honey bees forage for the food in flowers around in a way that they can take and store the maximum amount of nectar in a limited time length. D. Karaboga and Basturk (2007a) claim that there are two types of bees in foraging algorithm:

- Employed foragers: They exploit a specific food source and gather information about its location and quality and share that information with other bees in the nest

- Unemployed foragers: There are two groups of unemployed foragers. The first group is scout bees group which search randomly around the hive to find new food sources and the second group is onlooker bees which stay at hive and choose a food source according to the information shared by employed foragers.

Initially some bees search the food resources stochastically. When return to hive, the bees which found proper food sources do a so-called waggle dance and satisfy other bees to follow them and go to the found food source. This dance shows the distance from food source to hive, the quality of food source and its direction compared to sun. Food source direction is represented by the direction of bee's dance compared to sun and the distance is represented by time length of dance. As a bee dances longer the food source is further (Quan & Shi, 2008) (Teodorovic et al., 2011). Figures 3.1 and 3.2 show the features of waggle dance of bees.

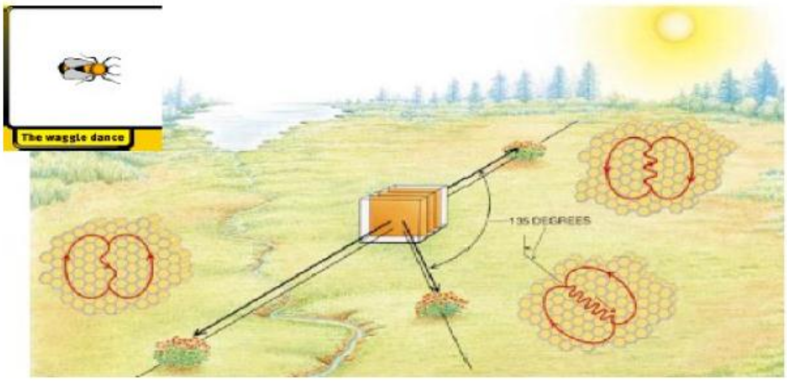

Figure 3.1: Waggle dance of bees.

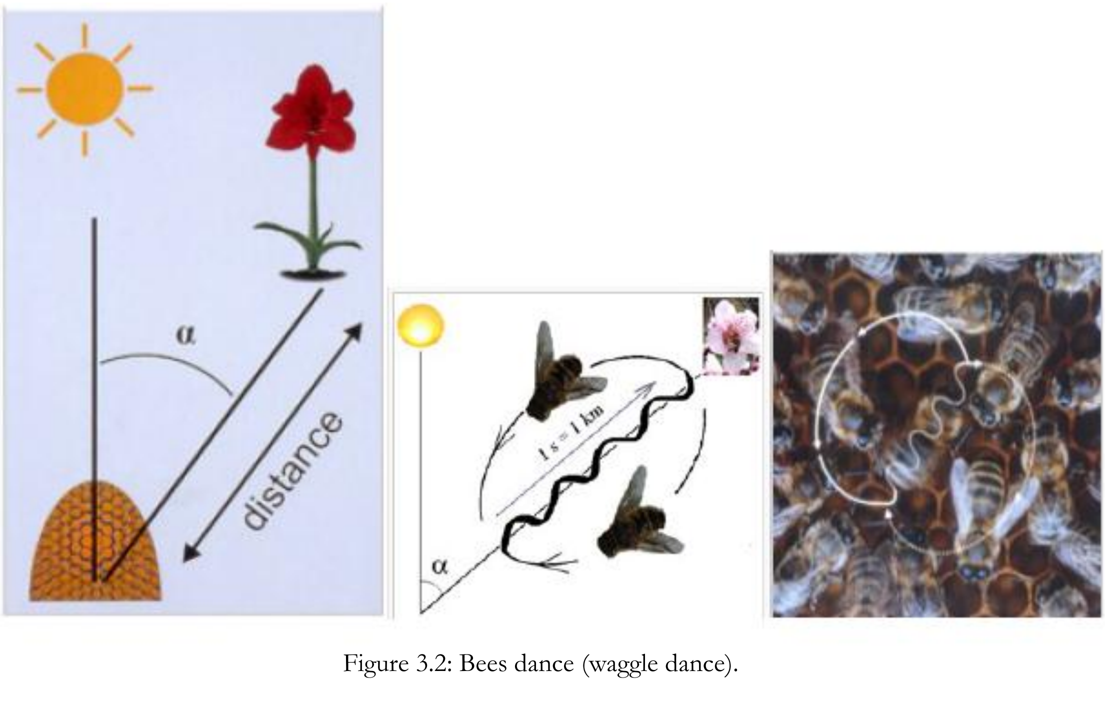

Figure 3.2: Bees dance (waggle dance).

Assume that there are two food sources A and B. a forager begins to work. It doesn't have any information about food sources around the hive. Therefore it has two solutions:

- It can be a scout bee and search around the hive for food sources. (S in Figure 3.3)

- It can go to a food source after watching the waggle dance of other bees.in this situation it would be a recruit bee. (R in Figure 3.3)

After the bee found the food source, it stores the information about the location in its memory and then starts collecting the nectar of flowers. Forager bees take some of the existing nectar in food source to the hive and after storing it in hive one of these three choices happen:

- Becoming a scout bee and search for new food sources. (UF in figure 3.3)
- Doing waggle dance and make other bees to follow her to the existing food source. (EF1 in figure 3.3)
- Returning to the previous source and gather nectar. (EF2 in figure 3.3)

Bees choose each of these three choices based on a specific probability which directly depends on the quality of food source. Various food sources are introduced to all the bees in waggle dance. The mechanism based on which bees decide about the quality of food sources is not identified completely yet but it’s obvious that bees choose the food sources with higher qualities (Gong et al., 1997).

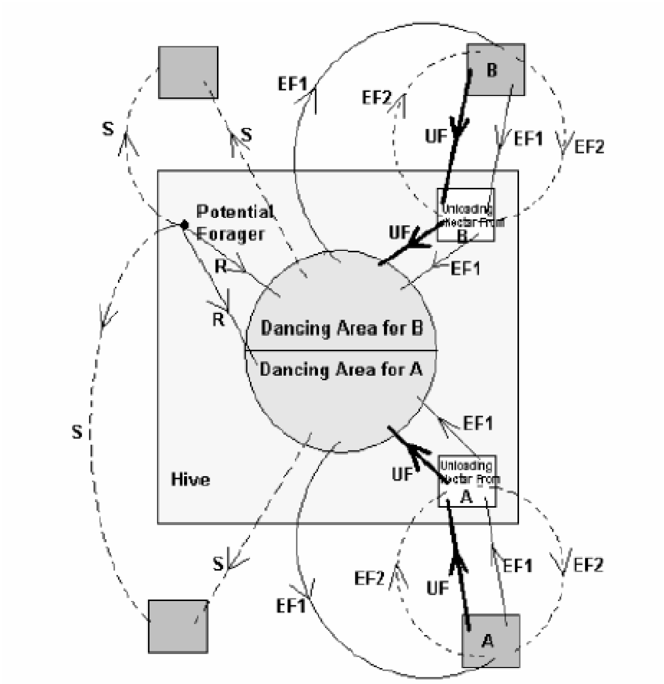

Figure 3.3: Bees behaviour in foraging in nature (D. Karaboga, 2005).

3.3.2. Artificial Bee Colony (ABC) optimization or bees foraging algorithm

ABC algorithm is a collective intelligence algorithm. It was first proposed by D. Karaboga (2005). It is inspired by foraging behaviour of honey bees. In this algorithm, some parameters should be introduced as initials. The number of scout bees (n), the number of food sources chosen among n locations (m), the number of best locations from m chosen locations (e), the number of assigned bees to the best locations (nep), the number of assigned bees to the other m-e locations (nsp) and initial patch size (ngh) that includes desired location, its neighbourhood and the termination condition (Pham et al., 2006).

Its program code can be represented as follows (Pham et al., 2006):

1. Initialize population with random solutions.
2. Evaluate fitness of the population.
3. While (stopping criterion not met) //Forming new population.
4. Select sites for neighbourhood search.
5. Recruit bees for selected sites (more bees for best e sites) and evaluate fitness.
6. Select the fittest bee from each patch.
7. Assign remaining bees to search randomly and evaluate their fitness.
8. End While.

In the first step the problem starts with (n) scout bees that randomly go to search space. In second step, the suitability of the sites visited by scout bees is calculated. In fourth step, the most suitable sites are chosen and a neighbourhood is defined around them for local search. In fifth and sixth step, the local search around the best sites is done and the numbers of bees that go to each site depend on the quality of the site. Each of bees chooses a site to visit based on the following formula:

$$P_i = \frac{fit_i}{\sum_{i=1}^{SN} fit_i}$$

In which fit (i) is fitness of i[th] source and SN is the number of food sources or possible solutions. In sixth step just the bees with highest suitability are chosen for the next generation. This limitation doesn't exist in nature and it's used to avoid too many sites to search. In seventh step remained bees randomly go to the search space to find new solutions. These steps are repeated till the termination condition is met. After each repetition, colony becomes two parts of new population. The ones who represent the best of patch and the ones who are sent to sites randomly (Pham et al., 2006). This algorithm's flow chart is shown in Figure 3.4:

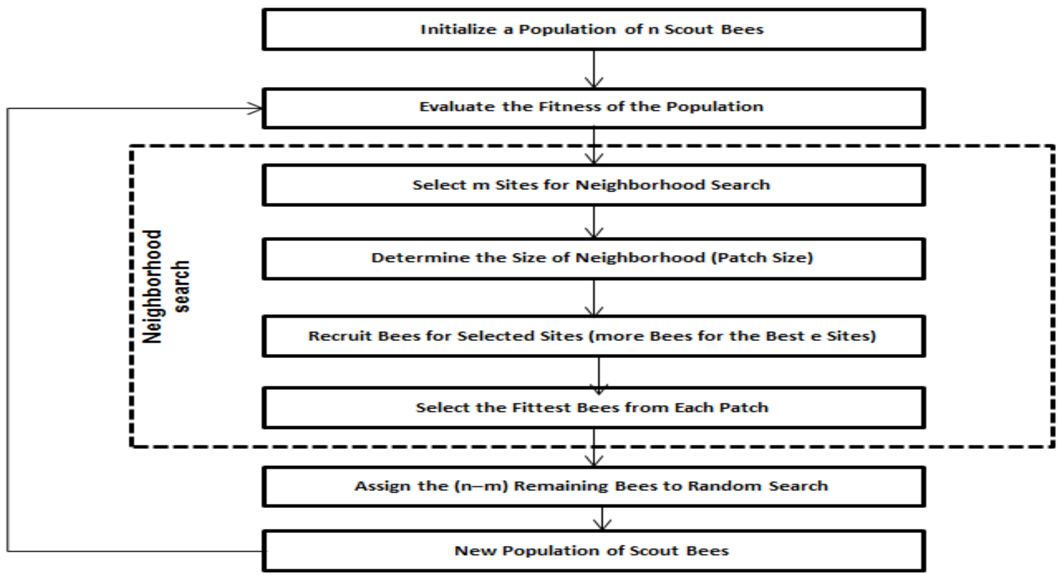

Figure 3.4: ABC algorithm.

3.3.3. ABC in literatures

ABC algorithm was first developed and evaluated by (D. Karaboga, 2005) applying multi-dimensional multi-variable problems. Later on its application was compared with Genetic Algorithm (GA) on numeric function optimization by(D. Karaboga & Basturk, 2007b). Its performance on different optimization problems was studied and it was compared with other well-known algorithms like GA, Particle Swarm Optimization (PSO), Different Evolution (DE) and Back Propagation (BP)(D. Karaboga & Basturk, 2007a). Later on some researchers decide to modify and hybridize ABC algorithm (Pulikanti & Singh, 2009) (Akay & Karaboga, 2009)to solve new optimization problems in various branches like engineering (Kang et al., 2009) (Udgata et al., 2009), digital image processing (N. Karaboga, 2009) (Chidambaram & Lopes, 2009), information technology (D. Karaboga & Ozturk, 2011) (Marinakis et al., 2009) and so on.

4. MULTI-OBJECTIVE OPTIMIZATION

4.1. Introduction

There are many optimization problems that have more than one objective and some of those objectives may be opposite or inconsistent. Although methods for solving multi-objective problems have been studied for two decades, variety of advanced methods for solving multi-objective problems is not comparable with single-objective problems solution methods.

Unlike single-objective methods, multi-objective methods do not provide a single optimized answer but they give back a set of optimum answers that satisfies all of the objectives with a proper balance. These answers are called trade-off that decision makers can choose one of them according to problem's condition.

4.2. Multi-objective optimization solution approaches

There are two general approaches for solving multi-objective problems. The first method is to change the multi-objective problem to a single-objective one and the second method is to find a set of pareto-optimal answers. The first method was commonly used before the development of the second one and still it's being used when there is a need to simplify the problem and decrease the calculation costs. One of the easiest ways to change the multi-objective problem to single-objective is to weight the objective functions. The main problem in implementing this approach is to give a proper weight to each objective function based on decision maker's priorities. It's practically difficult to weight the objective functions precisely and properly even if we completely know the priority of objectives in comparison with each other. In some problems the final optimal answer might be too sensitive to the weights of the objective functions and little changes in weights may cause big changes in final optimal answers.

4.2.1. Functions aggregation approach

It's one of the methods to change a multi-objective optimization problem to a single-objective one. The summation of all objective function in a single function is called functions aggregation. The following equation is an example.

$$Min \sum_{i=1}^{k} [w_i f_i(x)]$$

In which $wi \geq 0$ is the weighted coefficient that represent comparative priority of the objective functions. It's assumed that (M. N. Neema & A. Ohgai, 2010):

$$\sum_{i=1}^{k} w_i = 1$$

For the calculation of weights of this function we can use a method called analytic hierarchy process (AHP).

4.2.1.1. Analytic hierarchy process (AHP)

This approach is made based on human's analysis method for solving complicated fuzzy problems. It was first suggested by Thomas L. Saaty in 1970s and was used for various applications up to now. AHP helps decision makers to translate a complicated problem to a hierarchical structure in order to clarify and prioritize their goals and solutions. In AHP method, the problem is divided to three levels of

1. Goal: is the main priority of the decision makers

2. Objectives and sub-objectives (criteria): are the criteria which should be considered.

3. Alternatives: the available alternatives for reaching the goal. (Adamcsek, 2008).

AHP and its applications are based on three following principles (Adamcsek, 2008):

1. Decomposition

2. Comparative judgment

3. Hierarchic composition

Decomposition principle changes a complicated problem to a hierarchy of clusters. Second principle is used to compare the priority of all combinations of elements pairwisely in a cluster regarding the parent cluster. The third principle helps to multiply the local priorities of a cluster by the priorities of the parent clusters and make the global priority (Adamcsek, 2008). AHP has four fundamental steps:

1. Making AHP diagram: Figure 4.1 is an example of AHP diagram.

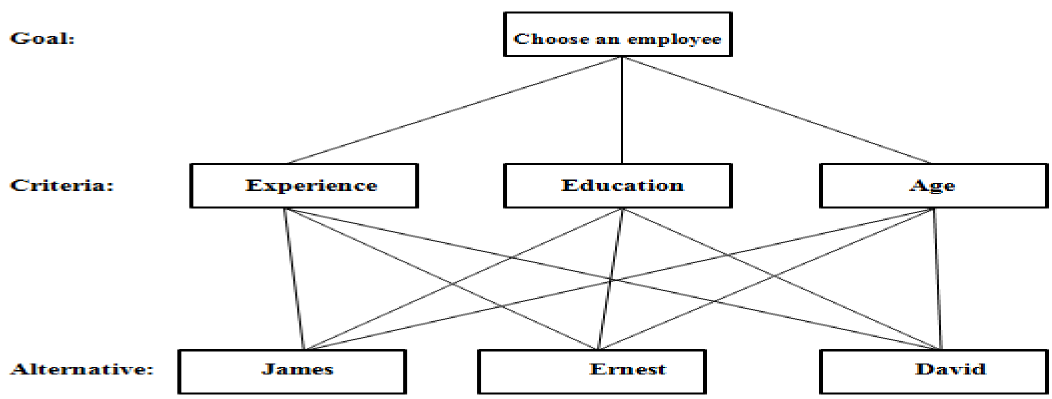

Figure 4.1: AHP diagram for choosing an employee.

2. Making pairwise comparison matrix: In this step elements of each level are compared to upper level elements pairwisely and their weights are calculated. The assigned weight is called local priority. In table 4.1, we can see the pairwise comparison of alternatives for Age criterion in above example. Using this pairwise comparison matrix and applying eigenvector, least square or logarithmic least square method, local priority of each alternative will be calculated.

Age	James	Ernest	David
James	1	3	5
Ernest	1/3	1	2
David	1/5	1/2	1

Table 4.1: Pairwise comparison matrix of alternatives in Age criterion

3. Elements' weight calculation: The final weight, called global priority, is achieved by multiplying each criterion's local priority by local priority of the alternative related to that specific criterion.

4. Consistency test: One of the advantages of AHP method is that we can control inconsistency of decision by checking the weights relations logically and through simple formulas. Then we can decide whether it's acceptable or not.

4.2.2. Pareto optimal front approach

Figure 4.2, represents a two-objective problem in which the aim is maximization of both objectives. The vertical and horizontal axis represents our two objective functions. One point dominates another one if its better in all objective functions (dimensions) and the optimal front is a set of non-dominated points (answers). The final goal of a multi-objective optimization algorithm is to recognise eligible answers in pareto-optimal front (Konak et al., 2006). The pareto-optimal front is shown by black circles in the figure 4.2:

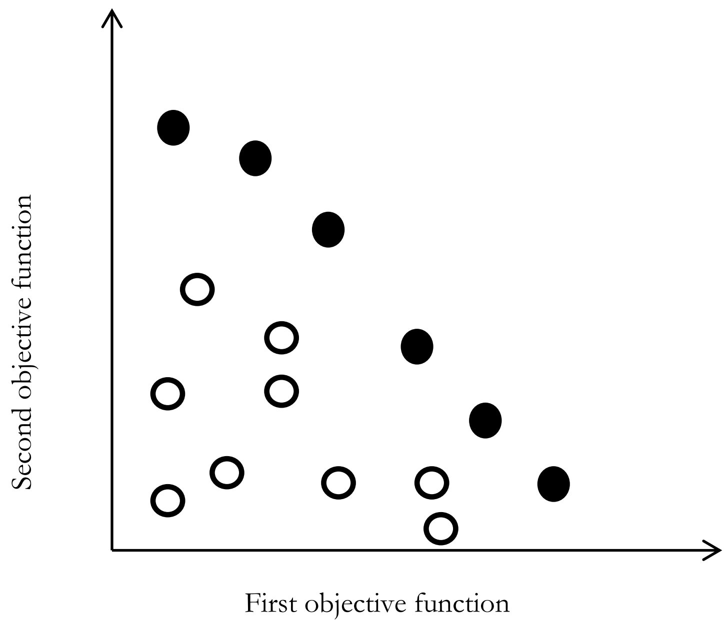

Figure 4.2: A multi-objective maximization problem.
(●) shows optimal answers and (○) represents dominated answers

5. MATERIALS, METHODS AND IMPLEMENTATION

5.1. Introduction

In this chapter inputs, outputs, and the way ABC is used to solve the considered location allocation problem will be discussed. For the beginning input data will be represented.

5.2. Materials

In this research, the aim is to assign primary school children to schools based on four criteria of distance, religion, cito score of schools and capacity of schools. Therefore we need data about the number of children, schools, capacity of schools and so on. Some of these datasets was collected from Enschede municipality website (Municipality.Enschede, 2012).

As it was mentioned before, two important components for allocation are facility and demand points. Since in this research our facility is capacitated, we need the capacity of schools too. And as distance is one of our criteria, we need to have the road network of the city in order to calculate the network distance. For calculating the network distance we use the tools related to OD cost matrix tool in ArcGIS software

5.2.1. Facility

Primary schools of Enschede are the facilities in this research and there are 64 primary schools based on the gathered data. A shape file of the location of these schools is available in figure 5.1, each school's capacity is stored in its attribute table.

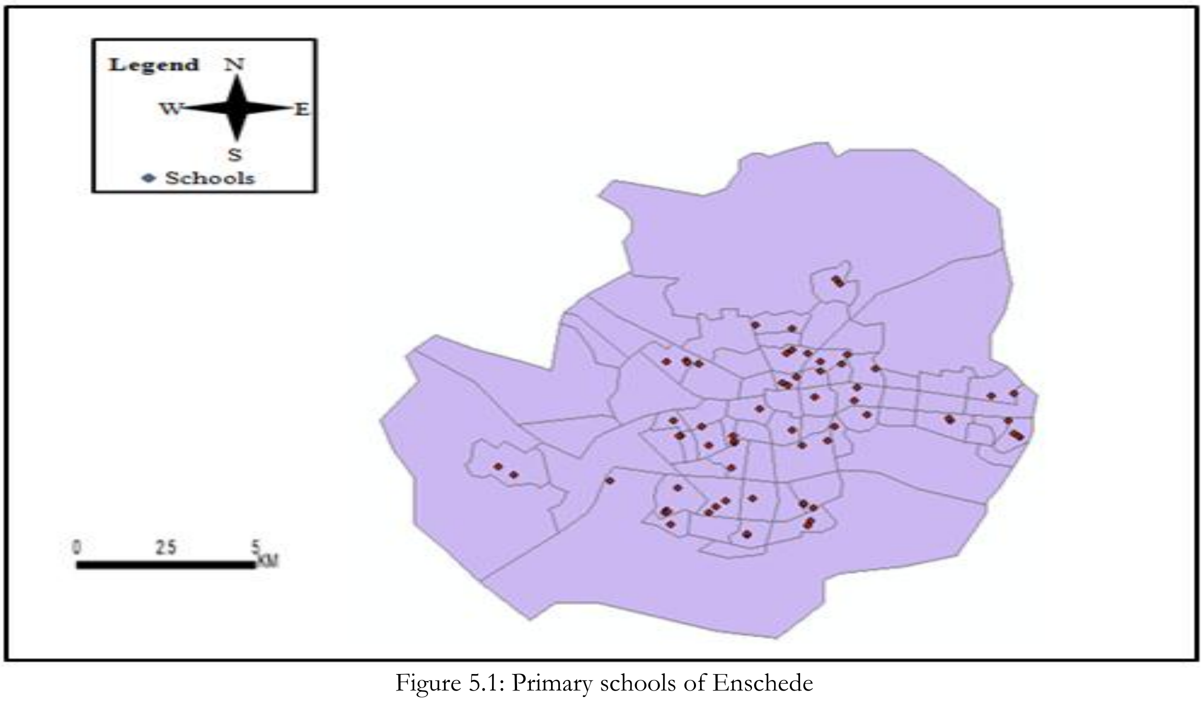

Figure 5.1: Primary schools of Enschede

5.2.2. Demand

There are about 14000 children between 5 and 12 years old in Enschede according to (Municipality.Enschede, 2012). After collecting this data, merging it with buildings of Enschede shape file, a shape file for primary school children house was made (Figure 5.2). Since their large number cause a low computational speed, we put them into 400 clusters using K-means clustering method in Matlab software. Every cluster has a population that will be used in calculations. Then we made another shape file of clusters centroids (Figure 5.2). Finally we used the coordinates of clusters centroid for computing network distance.

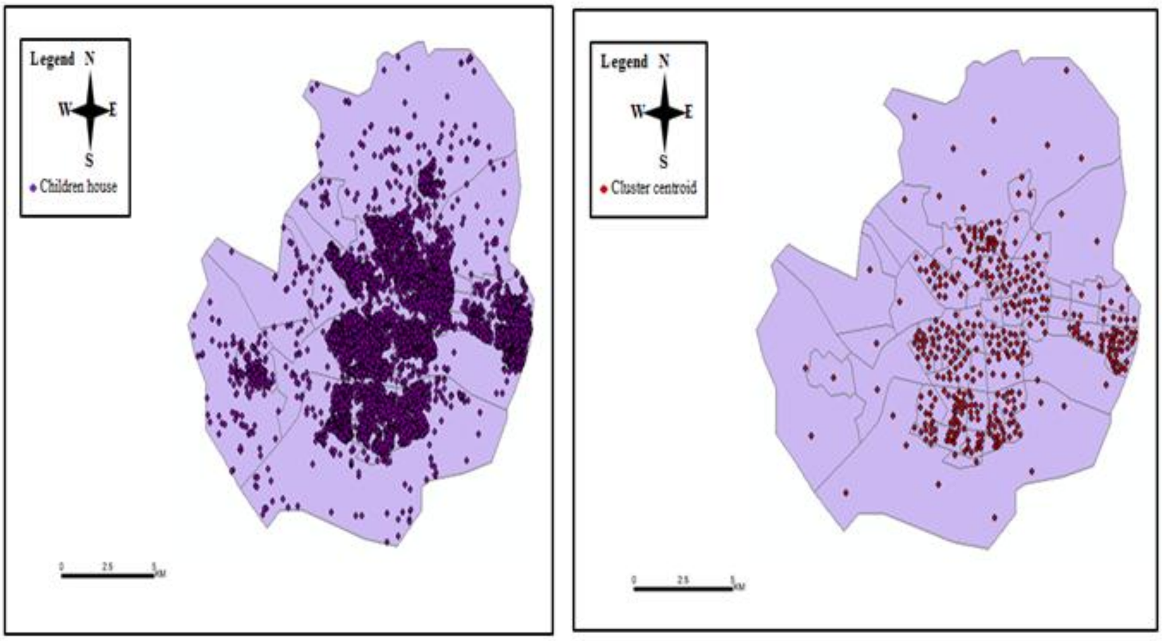

Figure 5.2: Children house (left one) Cluster centroid (right one).

5.2.3. Road network

A network of main roads of Enschede was available (Figure 5.3) and we used it in order to calculate the network distance between demands and facilities.

Figure 5.3: Main roads network of Enschede.

5.2.4. Cito score

Cito score is a grading system for the quality of schools in the Netherlands. It is between 0 and 10. This data is achieved from rtlnieuws (2013) (Figure 5.4).

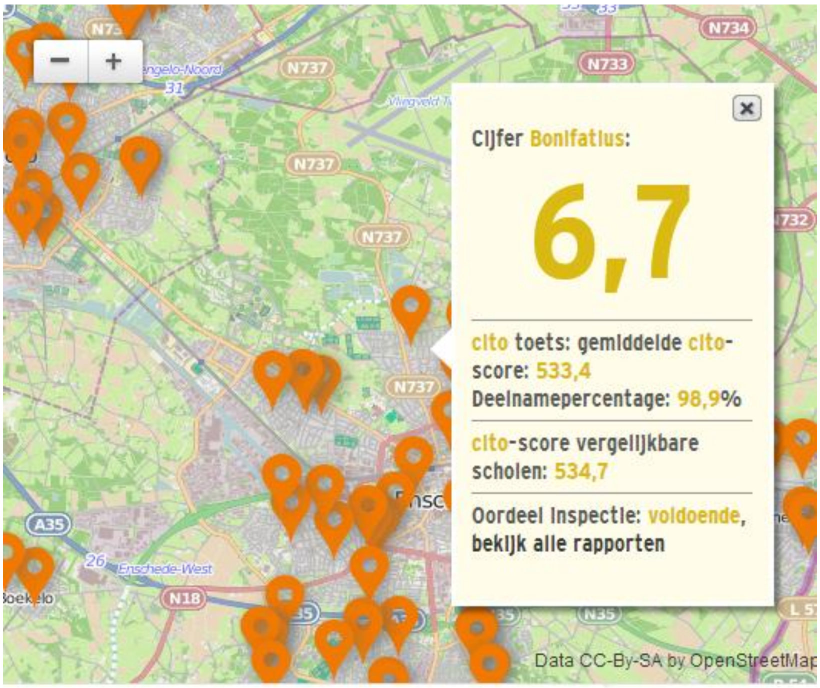

Figure 5.4: Cito scores of schools in enschede (rtlnieuws, 2013)

5.3. Methodology

The final goal of the project is to assign children between 5 and 12 years old to primary schools satisfying four criteria that seem to be important to parents when choosing schools for their children. These four criteria are:

1. Distance: we want to minimize total network distance between facilities and demands. This part of the problem is a P-median location-allocation problem.

2. Capacity: The facilities of our LA system are capacitated schools and the total capacity of primary schools almost equal to the population of children between 5 and 12, Therefore capacity of schools can be considered as one of our criteria. We have to take it as a criterion in order to have a harmony between schools' capacity and the number of assigned children.

3. Religion: It's assumed that every school has an official religion. Since there was no available data about schools' and population's religion in Enschede, the data achieved in Wikipedia® (2006) about Overijjssel province religion distribution in year 2006 was assigned to Enschede. Wikipedia® (2006) claims that 29% of the population of the overijjssel are Catholics, 26% are Protestants, 2% are Muslims, 6% are other religions and 37% are non-religious people. Therefore we assigned exactly the same percentage to children of Enschede. For schools, we assumed 30% of them are international schools that don't have any official religion and assigned the remained 70% the same achieved percentages.

4. Cito score: Every school is tested annually and a score is assigned to it. This score is between 0 and10. It can be one of criteria based on which parents choose their children school.

After collecting these datasets, The network distance between all demand points and all facilities was calculated using OD cost matrix in ArcGIS and a 64*400 matrix was made and it was the first input to be used in Matlab software. Figure 5.5 gives a general overview of the steps taken.

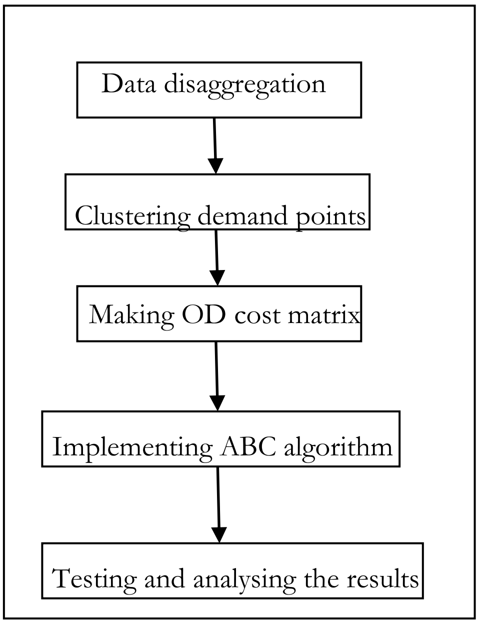

Figure 5.5: Flowchart of the project

5.3.1. Solution based on AHP and ABC

The next step is the implementation of ABC algorithm that was done in Matlab software. OD cost matrix results was the input and then we allocated the children to schools according to the following eight steps:

1. Making initial population of scout bees: every scout bee is a matrix that its rows includes all 64 schools and its columns includes the assigned clusters to each school Therefore the number of filled columns for each school is different according to the number of assigned clusters. For making the initial scout bees, we limited the distance between demand point and allocated facility to 5 kilometres. Therefore, facilities are chosen randomly but in a limited distance from clusters.

2. Making fitness function using AHP method and calculating fitness of initial scout bees: for evaluation of the bees (answers), we have to check them with our four criteria (distance, religion, capacity of schools and Cito score). We use function aggregation method for solving this multi-objective optimization. To have an understandable answer, we standardize all the objective functions. Standardizing means to convert their quantity to the range of [0, 1]using the following formula:

$$x' = \frac{x - x_{min}}{x_{max} - x_{min}}$$

The first objective function is distance. In distance function the aim is to minimize the distance. Therefore we take its inverse quantity to [0, 1]. As a result shorter distances will have higher quantities in distance function.

The second objective function is religion. Its quantity is made based on the number of clusters that are assigned to a school with the same religion, which is standardized.

The third function is capacity. To have its quantity, the difference between the population of clusters assigned to a school and the capacity of that school is calculated and then its inverse is standardized.

The fourth function is Cito score, which is between 0 and 10. We try to assign more students to schools that have higher Cito scores. Therefore its quantity is equal to standardized Cito score multiplied by the number of assigned students.

Now we have all objective functions yet to have the fitness function, we must know each objective function's weight calculated by AHP method.

Table 5.1 is the pairwise comparison matrix of objectives:

	Distance	Religion	Cito score	Capacity
Distance	1	2.667	4	2
Religion	0.375	1	1.5	0.75
Cito score	0.25	0.667	1	0.5
Capacity	0.5	1.333	2	1

Table 5.1: Pair wise comparison matrix of 4 criteria

The final weights of each criterion were achieved by applying least square method to this matrix. The final weights are:

$W_{Distance}$: 0.471 $W_{Religion}$: 0.176 $W_{Cito\ score}$: 0.118 $W_{Capacity}$: 0.235

Therefore the fitness function is:

$$f = 0.471 * Distance + 0.176 * Religion + 0.118 * Cito + 0.235 * Capacity$$

3. Choosing the best answers as the elite bees of the first generation: using fitness function to values of the scout bees, we can choose the elite bees in order to put them in the next repetition
4. Assigning one follower bee to each elite bee: followers go around the answers made by elite bees and by changing one factor they try to make new answers. Follower bees help the algorithm not to fall in local optima. In our case, for making follower bees; first we identify the schools which have more students than their capacity. Then we check the religion of the school and its assigned clusters. If there was any mismatch between the religion of school and one of its assigned clusters, follower bee finds the closest school that is not full to its capacity and its religion is the same as the taken cluster and assigns that cluster to the new school. This operation will be repeated for all the schools that have more students than their capacity.
5. Calculating the fitness function of follower bees.
6. Replacing elite bees by follower bees if followers' quality was higher according to fitness function.
7. Producing new generation of scout bees using elite answers of the last generation and new scout bees. Their total number will be the same as the first generation.
8. Repeating steps 2 to 7 till the termination condition is met: the termination condition in our case is the number of algorithm's repetition.

5.3.2. Solution based on ABC and Pareto optimal

For solving the problem using ABC and Pareto optimal, we don't need to make a cost (fitness) function. Therefore the obtained answers are just checked with our four criteria separately which are the objective functions that are not weighted. Then comparing the answers in all criteria separately and we can find the Pareto optimal answers. Pareto optimal answers are the ones that are not defeated in all objective functions by any other answer. To have Pareto Optimal answers, the process is as follows:

1. Making initial population of scout bees
2. Comparing scout bees based on our four objective functions: The comparison must be done pairwisely for all the bees in order to identify defeated and non-dominated answers. Defeated answers are the ones that their quantity is less than any other answer in all objective function.

Non-dominated answers are the ones that their quantity is not less than any other answer in all objective functions. It must be mentioned that unlike AHP method, in Pareto optimal the answers are compared weightlessly in all objective functions.

3. Choosing the Pareto front answers as elite bees: the number of the bees that are qualified as Pareto optimal is different in each run. But usually they make an appropriate percentage of scouts. Therefore it makes no problem for the algorithm.
4. Assigning one follower to each elite bee: The follower bees' function is the same as it was mentioned in AHP method. They make minor changes in elite bees answers in order to improve the quality. The number of followers can be determined based on the fitness value of elite bee. But here we just assigned one follower to each elite bee
5. Comparing followers' quality with elite bees: a comparison between the elite bee and its assigned follower must be done in all objective functions. If the elite bee was defeated by its follower, it will be replaced by that follower.
6. Producing a new generation of scout bees using Pareto optimal answers of the former generation plus new scout bees. Their total number has to be the same as the initial population of scout bees.
7. Repeat steps 2 to 6 till the termination condition is met. Here the termination condition is the number of repetitions.

5.4. Implementation

Following the above discussions on the methodology, the results and the implementation are presented in the followings. First we will see some answer using some initial random number of repetitions, scout bees and elite bees. Elite bees are the best allocations in each generation of scout bees. These are the variables of our problem and we can change them manually and run the program again and again to reach an optimum quantity for them. In the following we see initial quantities for variables, convergence graph for AHP method and six separate Pareto optimal graphs for pairwise comparison of criteria (distance, religion, Cito score and capacity).

Figure 5.6 shows the convergence graph for AHP method using 100 scout bees, 20 elite bees and100 repetitions.

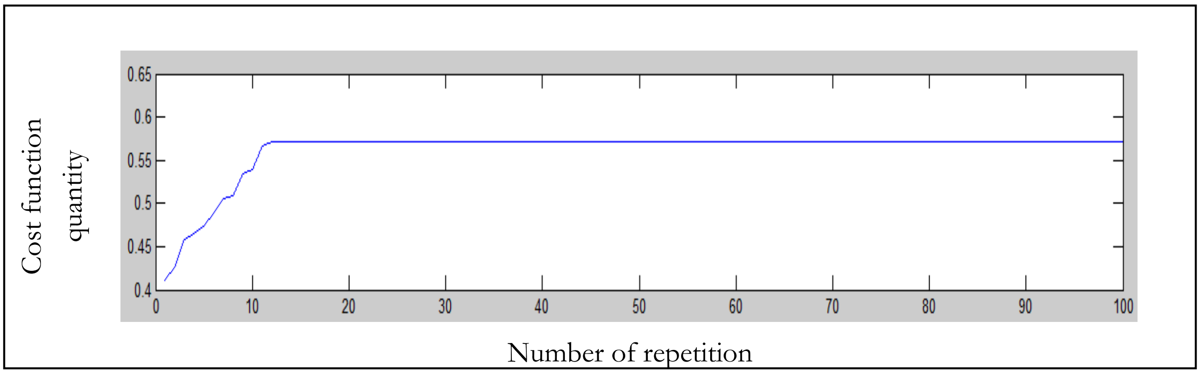

Figure 5.6: The Convergence graph for AHP and ABC method.

On the graph it seems that after 12 repetitions, the graph becomes convergent and the quantity of cost function is 0.5719 and the elapsed time is 945.44 secs. As the graph becomes convergent in eleventh repetition, we reduce the number of repetition to 30 times from now on.

For Pareto optimal solution, as we have four criteria we can't show its results on a single graph, because we cannot draw a 4-D graph, therefore we drew six graphs in order to compare those criteria pairwisely. In Figure 5.7 the blue points are the points that are in the final pareto optimal front. And the red ones are dominated answers.

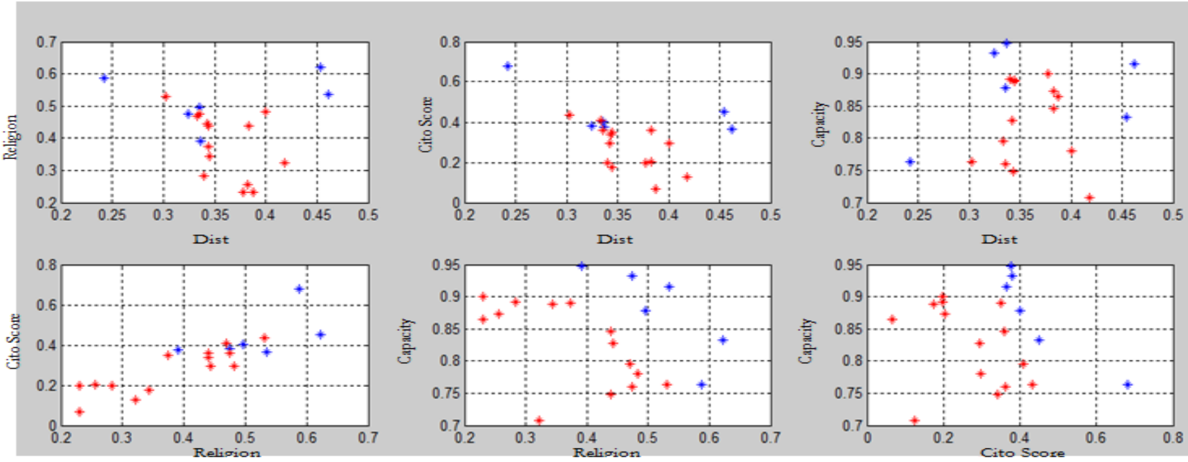

Figure 5.7: Four criteria comparison graph for 20 best answers.

Unlike AHP cost function quantity which is obtained using weighted criteria, Pareto optimal frontier which includes 6 of 20 answers in this run, is not weighted and we can check all these 6 graphs and their related matrices to choose the best allocation solution or we can have all the answers obtained by pareto as final solution for the allocation project. In different runs of the program, the number of elite bees obtained by Pareto optimal was between 7 and 15 and normally their number is about 10.

5.4.1. Tuning the variables for single-objective method

There are 3 variables that we can change them and check their effects on the convergence speed and convergence quantity. The table 5.2 can explain the obtained results.

Scout bees No	Elite bees No	Repetition No	Convergence quantity	Convergence time(s)	The repetition in which the function became convergent
100	20	100	0.5614	945.44	11
50	20	100	0.5418	346.78	18
30	20	100	0.5317	216.830	15
50	10	30	0.5162	104.029	12
50	5	30	0.4864	101.947	12
50	20	30	0.5339	111.090	9
50	30	30	0.5582	119.87	14
50	40	30	0.5253	128.830	18

Table 5.2: Tuning of ABC variables.

Checking the contents of this table step by step, we can conclude that the best quantities for our variables considering both convergence quantity and time are 50 scout bees for each generation, 30 elite bees for each generation and 30 repetitions or generations. The following graphs are obtained using the above mentioned quantities for variables and running the code another time. Since ABC algorithm is a random-based algorithm, the obtained quantities are not exactly the same as we saw in table 5.2 for the same values although it's quite close.

5.4.2. Final results analysis for tuned variables

As mentioned in the last section, the variables are tuned. Here we used those tuned variables in order to run the program again and have the final results with those quantities once again.

Scout bees: 50

Elite bees: 30

Repetition: 30

Elapsed time: 115.131 s

Converged repetition: 12

Convergence quantity: 0.5719

Average Distance: 4.67 km

The convergence graph of the algorithm using tuned variables is shown in Figure 5.8.

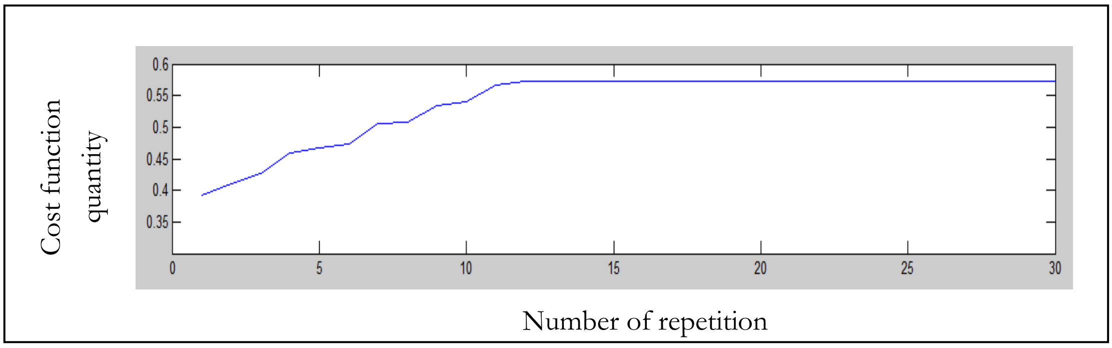

Figure 5.8: Convergence graph for tuned quantity of variables applying AHP method.

In the graphs of Figure 5.9 we can see the quantities of 30 final solutions for all objective functions (criteria). 21 of which are dominated solutions that are shown in red and 9 of them which are in blue are pareto optimal frontier solutions. If we could show it in a 4-D graph to have all the objective functions in a single graph, we would have these blue points as the first frontier of pareto optimal.

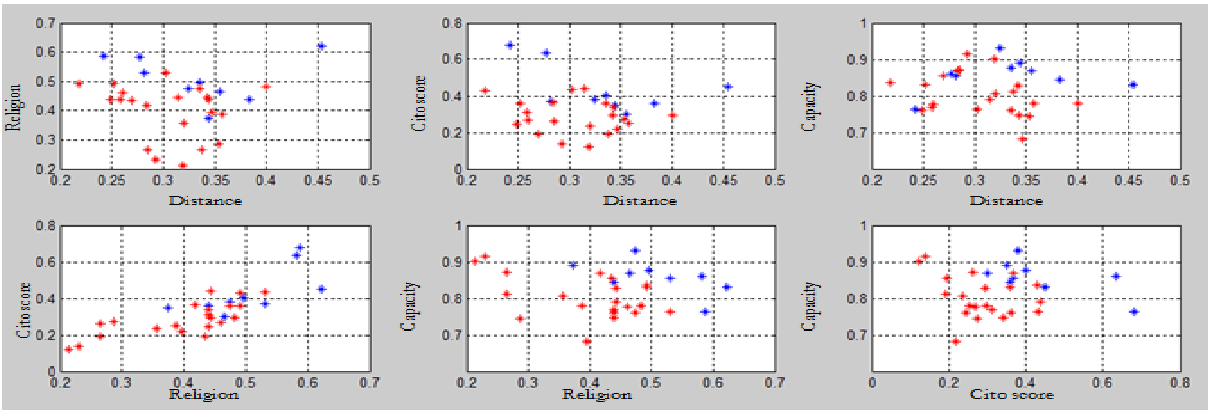

Figure 5.9: Criteria pairwise comparison for 30 final answers using Pareto optimal.

The following table can help us to estimate the precision of allocation according to capacity and religion criteria for 14 schools out of 64 existing primary schools. Looking at the table we can understand that a allocation is done successfully and these two criteria are acceptably met.

Assigned number of students	Capacity	Religion code of school	Number of assigned clusters	Number of assigned clusters that have the same religion as school
184	174	6	6	3
319	330	2	10	3
192	200	6	6	5
151	170	1	4	4
167	180	1	5	5
313	300	2	9	7
121	260	1	3	3
248	250	1	6	6
307	300	2	7	6
238	215	5	7	4
190	200	6	7	6
61	110	1	2	2
205	220	1	6	6
294	250	6	8	6

Table 5.3: A partial represent of Allocation for 14 schools.

5.4.4. Reproducibility test

We repeat the program using the tuned variables for 10 times in order to check the standard deviation of convergence number in optimization function. Table 5.4 includes these 10 results.

Run No	Convergence quantity of objective function
1	0.5541
2	0.5242
3	0.5372
4	0.5350
5	0.5370
6	0.5296
7	0.5251
8	0.5249
9	0.5518
10	0.5341

Table 5.4: Ten times running the code with tuned variables.

Standard deviation of these answers is calculated using the following formula:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i-\bar{x})^2}{n-1}} = 0.01054946$$

This quantity for standard deviation tells us that 68% of convergence quantities made by ABC algorithm using tuned variables is in a range between 0.5247 and 0.5458 which seems to be acceptable and shows that the implemented algorithm can be trusted.

5.4.4. Discussion

According to this case study, the children of Enschede were allocated to the existing primary schools based on four different criteria that generally seem to be important for choosing a school. For distance criterion, the network distance was applied and since the available road network of Enschede includes just main roads, the obtained average distance for each student may be higher than reality. The students can shorten their distance to the school using sideway roads and if we want to have a better estimation of the reality we need to have a more detailed road network of Enschede.

6. CONCLUSION AND RECOMMENDATION

6.1. Conclusion

The main objective of this research is to assign children of Enschede whose age are between 5 and 12 to the existing primary schools in town based on distance, religion, Cito score of schools and capacity of schools using ABC algorithm. For achieving this objective, some literatures about different classes of location-allocation and the previous usages of ABC algorithm were studied. Using this information, a method was proposed to solve this allocation problem. The research questions and their answers resulted from this research are presented in the following:

Question 1: How does Analytic hierarchy process (AHP) prepares the data for Bee Colony algorithm?

AHP method is used in this research for qualifying our multi-objective problem's solutions; it changes the multi-objective problem to a single-objective one using function aggregation method. In our case the hierarchy of AHP has two levels. The first level is the main goal that is assigning children to schools and the second level which includes important criteria for choosing school. A pairwise comparison matrix for comparing the importance of these criteria in our project based on expert knowledge and personal preference is made. Then, using least square approach on this matrix the weight for each criterion is achieved. Finally weighted objective function (cost function) is made using function aggregation method. This objective function is our general criteria to compare the quality of each allocation, done by ABC algorithm.

Question 2: How does Pareto front method work for Bee Colony algorithm?

Pareto front is an alternative way for AHP in solving multi-objective optimization problems. In this approach, instead of converting the multi-objective problem to a single-objective one, we try to check the quality of solutions in all criteria (objective function). The final acceptable solutions that go to Pareto frontier are the ones that are not dominated by any other answer. Instead of having a single best answer, we'll have a set of superior answers that make the Pareto frontier.

Question 3: What are the advantages and disadvantages of both AHP and Pareto front for this case-study?

Advantages of AHP: using AHP, our problem changes to a single-objective problem and all of the allocation solutions can be qualified using the obtained quantity of the objective (cost) function. Therefore it's simple to compare the quality of various answers since we use a single quantity as our qualification tool. Therefore it can be easily understood by everybody.

Disadvantages of AHP: Using AHP method, we have to determine the weight of each objective function (criterion). The weight of each objective function represents the importance of that objective function in our final function. Determining the pairwise weight of each objective function in pairwise comparison matrix must be done using expert knowledge. The main problem in implementing this approach is to give a proper weight to each objective function based on decision maker's priorities. It's practically impossible to weight the objective functions precisely and properly even if we completely know the priority of objectives in comparison with other objectives using expert knowledge may help us to have more realistic weights. Yet, there is no way to standardize this expert knowledge and as a result there is no way to standardize the assigned weights to each objective function. The only thing that helps us to qualify the expert knowledge partially is the consistency test of weights.

Advantages of Pareto Optimal: using Pareto optimal method, there is no need to weight the objective functions and therefore no mistake can happen in weighting process. Since instead of one single answer we have a set of answers as final best solutions that come to Pareto front, it's good for experts to observe these superior answers and choose the desired ones based on the conditions and requirements.

Disadvantages of Pareto Optimal: it cannot be easily understood by non-expert users since it gives back a set of solutions and their quality can't be compared easily without having expert knowledge. Also as its objective functions are not weighted, no criterion has more impact on the final best answers which come to Pareto frontier and the importance of all of the criteria is assumed to be the same.

Question 4: How does ABC algorithm work in this case study?

Any possible answer to the problem is a bee in ABC. Therefore, we generated some different allocations of the schools to house clusters as scout bees. Their fitness was calculated based on four objectives of distance, religion, Cito score and capacity. The ones with the higher objective values (fitness) were selected as elites. For each elite answer, a follower was created, which was the same allocation with minor changes in some parts of it. Again some random scouts were created for random allocation of schools. In the next repetition, among elites and followers of the former repetition and newly created scouts, the best ones are selected according to their fitness to become the elites of the new repetition. Repeating this procedure, the best answers of the schools allocation were calculated.

Question 5: What are the most important factors based on which people in Enschede decide about their children?

In this study the most important factors are 1.distance 2. Religion 3.Cito score of schools 4.capacity of schools.

6.2. Recommendation

This research tried to allocate children of Enschede whose age is between 5 and 12 to the existing primary schools and since the needed time for ABC algorithm to answer depends on how big the search space is, we can restrict the search space for initial scout bees using some constraints or factors that helps the initial scout bees to search the space more reasonably and not completely by random. Therefore it can decrease the size of search space and as a result the needed time for having the answers from ABC algorithm will decrease.

Also in this research we used ARcGIS software to calculate network distance using "OD cost matrix". Instead of that in future works a code can be written to calculate the network distance.

In this research we just did an allocation of students to the existing schools, another research can be done besides ours to locate new schools or combine some of the existing schools in order to better satisfy these four mentioned criteria..

Another thing that can be done to improve this research is to add some other important criteria to these existing one in order to have a more desirable allocation based on peoples' different priorities.

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