AIRCRAFT EMERGENCY EVACUATION SIMULATION USING ANT COLONY OPTIMIZATION

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Abstract

The main objective of this work is to optimize the emergency evacuation of a 32 passengers airplane (short-range class). To make it possible, a research on optimization algorithms based on Ant Colony Optimization [ACO] – and Genetic Algorithms [GA] – was carried out, allowing the development of an in house optimization algorithm.

1 General Introduction

To certify a passengers aircraft, it is necessary that to submit the airplane to the emergency evacuation certification test. It must be demonstrated that the model and the configuration of the aircraft allow a full capacity evacuation of passengers and crew in 90 seconds or less, using its emergency exits with the flight attendants help.

The costs of these tests are very high and expose the test participating occupants to a risk of injury since the occupants are volunteers and have no prior knowledge of the aircraft.

Due to these risks, with the objective of improving safety and making it possible to optimize the passengers distribution along the seats before every flight, it is intended to develop a software to simulate formal aircraft emergency evacuation procedure, in order to find optimized solutions that fit the requisites established by the aeronautical authorities needed for certification.

1.1 Objectives

This study intends to determine the best distribution of passengers in aircraft interior, based on physical/motor characteristics of each one in order to make the emergency evacuation more efficient. A short list of objectives is punctuated below.

1. To develop an optimization algorithm aiming to achieve the main objective cited previously;
2. To simulate diferent emergency situations varying the passengers characteristics combinations, involving healthy men and women, as well as obese, elderly, children, physically handicapped, athlets, based on response to stimuli health studies, average run velocity, among others;
3. To develop a flight passengers behaviour analisys methodology, distributing them by usage of GA, improving a possible evacuation procedure without extrapolating flight requisites such as Maximum Take-Off Weigth and Centre of Gravity limits;
4. To develop a Visual Basic programming language program which calculates all evacuation parameters and allow the user to visualize the simulation running.

Thus, it is suggested the usage of a global methodology which consists of design, research, development and final analisys, culminating in the final software operation, simulating all possible occurrences, such as passengers collisions, obstacles in corridors (e.g. luggage on floor) and the crew itself.

2 Bibliographic review

In order to make it possible to develop and design the software here proposed, some theoretical studies are needed. Among them are the Travelling Salesman Problem [TSP] based on the Ant Colony Optimization [ACO] and the Genetic Algorithms [GA] to solve the problem of emergency evacuation. Also, the Fuzzy Logic is included in the list above to determine the decisions taken by the passengers during their running way, e. g. which side should each passenger take after standing up from his seat considering the distribution of other passengers and the crew along the airplane.

2.1 Ant Colony Optimization [ACO]

"Ant colony" algorithms were inspired by the behavior of ants in search of food regarding to work organization and cooperation among themselves. The communication of ants is performed by means of pheromones, chemicals produced by animals that allow mutual recognition of individuals. Some species of ants use pheromones to mark trails and just walk around. The ants use these trails to move from the nest to a particular food source.

In this sense, it is proposed to use the Ant Colony Algorithm [ACO] for simulation and optimization tests on aircraft emergency evacuation. So the description of this methodology is presented next.

Deneuboug, Aron, Goss, and Pasteels [1] performed an experiment with ants searching for food. They put two double bridges between the colony and the food and observed the behavior of these insects, as it is shown in Fig.1.

Initially, the ants were moving randomly in search of food, exploring possible solutions. When they found food, they return to the colony depositing pheromone on the path. A larger quantity of this pheromone should mean that more ants have found this path, increasing the likelihood that this should be the best route. Thus, this path would become an optimized solution based on the level of pheromone found.

The results showed that ants moved in the path with larger amount of pheromone. The deposit of the substance stimulated more ants to choose the more pheromone concentrated path. This means that the solution converged to that solution. Little-used paths lose pheromone by evaporation, reducing the likelihood over time of an ant using it.

The ant colony algorithm was created in 1992 by Marco Dorigo [2] using artificial ants to mark and track trails.

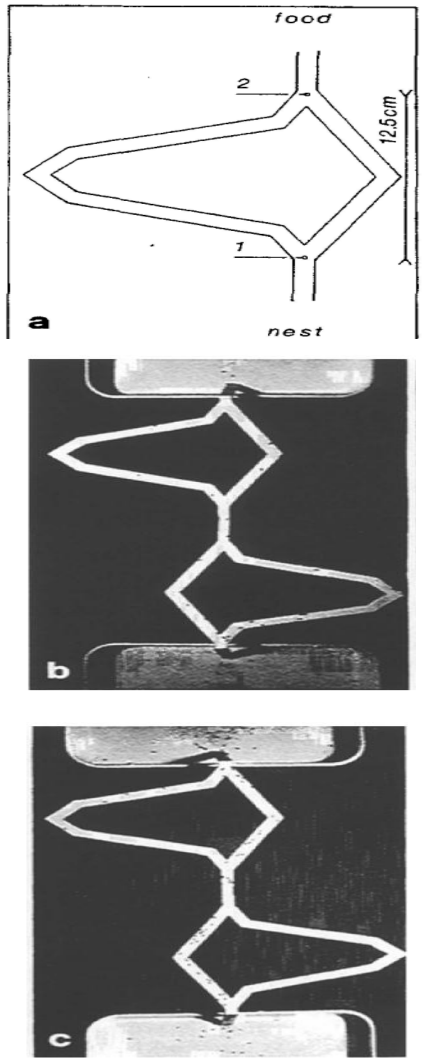

Fig. 1. Experiment Goss[1]. A Colony of Ants Selecting the Best Route Between the Colony and Food, (A) Schematic of the Bridge, (B) and (C) Pictures Taken 4min and 8min After the Beginning of the Experiment.

The basic algorithm characteristics are:

1. Positive feedback in function of the pheromone trail, meaning increase of the level of pheromone, producing a solution of better quality;
2. Virtual pheromone, which quantity is added to good solutions and decreased to bad solutions, avoiding the estagnation;

3. Cooperative behaviour of ants during exploration for food.

The algorithm to obtain the solution using may adopt the representation by graphs. A graph may be designated by G(N,A), where N is a group of nodes and A are the lines between two nodes. The artificial ants build up the solution by selecting probabilistically nodes and storing partially pathways. The construction of the solution has the following characteristics:

- The construction of the probabilist solution for the pheromone trail, without update during the going way;
- The return circuit is deterministic with pheromone updating. The update corresponds simultaniously to the rate of adition and evaporation of pheromone;
- The generated solutions are evaluated by their quality, and this evaluation is used to determine the amount of pheromone to be deposed and evaporated.

The Simple-ACO was the first created algorithm based on ant behaviour. Dorigo **[2]** adapted the ants behavior to obtain the solution for the Traveling Salesman Problem [TSP]. Its objective is to determine the best path to go through all the already chosen cities (coordinates i,j). He related each edge (*i,j*) from the graph G(N,A) to a variable τ_{ij}, called pheromone trail. The construction of the solution initiates with each ant leaving a certain city chosen randomly and choosing the next city probabilistically. The initial amount of pheromone is constant at all edges.

The likelihood p_{ij}^k of the ant k going from the city i to the city j is given by:

$$p_{ij}^k = \begin{cases} \dfrac{(\tau_{ij})^\alpha (\eta_{ij})^\beta}{\sum_{l \in \mathcal{N}_l^k} (\tau_{ij})^\alpha (\eta_{ij})^\beta}, & j \in \mathcal{N}_l^k \\ 0, & j \notin \mathcal{N}_l^k \end{cases} \quad (1)$$

Where τ_{ij} is the amount of pheromone at the edge *i,j* , α is the parameter that controls the influence of the pheromone, η_{ij} is the heuristic information which is defined in function of the problem characteristics, β is the parameter that controls the influence of the heuristic information, l is the element of the solution space and $\mathcal{N}_l^k$ is the feasible neighborhood of the city *i* associated to an ant k, in other words, it is the group of cities not visited yet by the ant k.

The choice of next city after all likelihood calculi is done by roulette method. It is generated a random number between 0 and the sum of all likelihoods. After that, all cities are travelled one-by-one summing its likelihoods. When a city gets a higher sum than the number generated randomically, indicates that the city is the chosen one. The pheromone τ_{ij} associated to the edge (*i,j*) is updated by the following equation:

$$\tau_{ij} = (1-\rho)\tau_{ij} + \sum_{k=1}^{m} \Delta\tau_{ij}^{(k)} \quad (2)$$

The first part of the equation represents the pheromone evaporation at the edge (*i,j*), the second is the pheromone deposit of all ants that pass through the edge (*i,j*), *m* is the number of ants, ρ is pheromone evaporation rate ($0 < \rho \leq 1$) and $\Delta\tau_{ij}^{(k)}$ is the amount of pheromone that the ant k deposits on the edge (*i,j*), given by:

$$\Delta\tau_{ij}^{(k)} = \begin{cases} \dfrac{Q}{L_k}, if\ (i,j)\ belongs\ to\ S_k \\ 0, instead\ of\ previous \end{cases} \quad (3)$$

Q is a constant, L_k is the total distance walked by ant k during its path and S_k is the group of cities visited by the ant k.

The ACO has already shown itself as great solver for the TSP, and is a promise for paths and geometry optimization. Due to its simple and efficient model, the ACO may be applied for emergency evacuation proposed for this software.

2.2 Genetic Algorithm

The Genetic Algorithm [GA] is an optimization heuristic method based on Darwin's Evolutionary Theory. It is an stochastic robust method which shows a good sweep of the solution universe of the proposed problem, obtaining global minimum and maximum.

The GA initiates by aleatory generation of an initial population (parents), usually codificated in chromosomes (the variable representation is a binary number sequence).

After that, the population is evaluated using mathematical models related to the proposed problem. Taking into account the results, aptitude values are attributed to the individuals in such a way that the likelihood of the best chromosomes being chosen for the next generation is higher. The reproduction process is repeated, the better chromosomes are transferred for the next generation until it converges to a generation with the best chromosomes only.

Besides it, there is an analysis of crossing and mutation of genes. As a result, it is found an optimized parameter that is proposed as the best genetically individual.

By this method, an aleatory chosen group of passengers, in other words, 32 randomly chosen physical/motor characteristics, will be distributed through the seats in different ways to obtain the best distribution that allows the fastest emergency airplane evacuation.

2.3 Quality Function Deployment [QFD]

According to Chan [3] the improvement in the fabrication performance in Europe is due to the implementation success of a number of action programs. By a large scale research, it has been identified 10 action programs with more attention as well 10 programs with more efficiency.

The Quality Function Deployment [QFD] is at the top of both lists. QFD is a method to deploy the client voice by characteristics in terms of quality, function, cost and reliability of the product or service. Also, according to Chan [3], it is a quality management system directed to the client with the objective of achieving his highest satisfaction. The typical QFD is composed of four steps, that were adapted to this work:

- **Step 1 – Passenger's needs:** to determine the real needs of the passenger during the emergency evacuation. e.g. – the passenger's need is to leave the aircraft, so it is necessary to decide which way is the best: go back or forward, turn to side or wait for a better opportunity of movement.
- **Step 2 – Relative importance Evaluation:** the decision of the passenger is classified in grades between 1 to 10, or another type of scale. e.g. – the possibilities of going ahead, backward, to the side or stay stopped is evaluated by the passenger based on the distribution of obstacles along the corridor (other people or luggage).
- **Step 3 – Competitive analysis:** the passenger evaluates the aircraft configuration and the passengers distribution. The knowledge about the emergency doors and vacancy along the corridor are very important for the effective evacuation from the airplane.
- **Step 4 – Final evaluation:** By combining the relative importance perceived by the passenger in Step 2 and the priorities in Step 3, the final evaluation is done by the classification of the items of greater grades that indicate high potential of success in the emergency evacuation.

2.4 Evaluation of the relative importance and Fuzzy Method

Assuming that "n" customers needs have been collected and identified, as showed on Step 1, values are assigned to each need with low values indicating low importance, and high values indicating great importance, according to the scale shown in Fig. 2.

NI________LI________medium________I________VI

1____2____3____4____5____6____7____8____9

Fig. 2. Importance Fuzzy Scale

Where,

NI – Not important

LI – Low importance

I – Important

VI – Very important

The reason of the usage of a nine points scale is justified by tests performed by SAATY [5]. It is simple and easy to use, and includes the information given by people about the measured attributes. However, it is known that the evaluations are always subjective, thus they are imprecise, and the language used to express feelings or judgments is vague. The use of precise and defined numbers to represent the linguistics evaluations, although widely used, it is not much accepted. A more rational approximation is to define a range for a indeterminate term in way to capture the indefinite characteristic. For example, the interval between 7 and 9 is defined as "important" and "very important". In mathematics, this idea may be expressed in terms of fuzzy logic and Triangular Fuzzy Numbers [TFN] may be used to represent subjective evaluations. TFN is a series represented by an interval which arithmetic is very intuitive and similar to the real numbers.

The Fuzzy Theory was developed to solve problems in which the activities descriptions, observations and judgments are subjective, vague and imprecise. The word "*fuzzy*" is usually used to make reference to a situation where the edge between the action and the judgment is indefinite.

3 The algorithm/methodology of evacuation

The simulation of the passengers evacuation from the airplane follows the flowchart below:

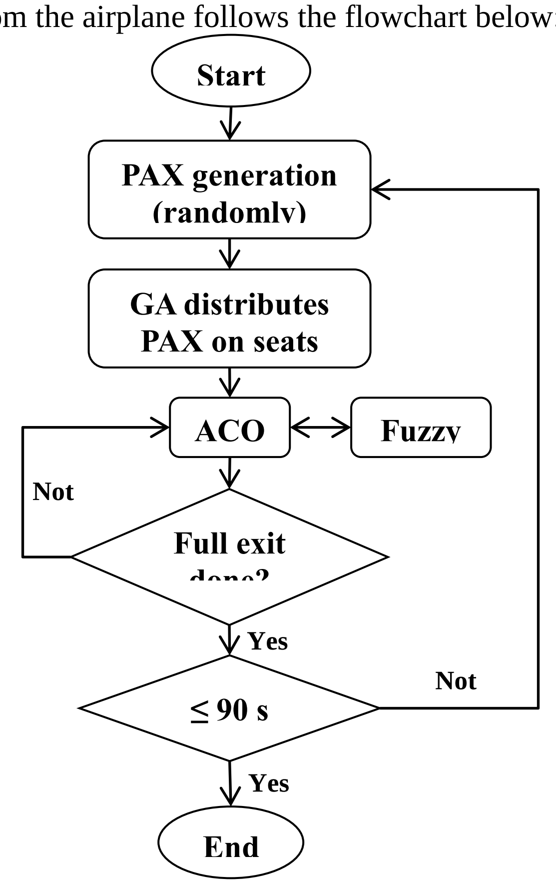

Fig. 3. Emergency Evacuation Simulation Flowchart

The steps are described below:

1. **<u>First Step: The boarding:</u>** Randomly, a crew is generated which is composed by one pilot, one co-pilot and a flight attendant, and the passengers (32). All occupants (passengers and crew) have physical and psychological characteristics generated aleatorialy such as:

   <u>Physical :</u>
   Weight (slim, medium size and obese);
   Age (young, teenager, adult and elderly);
   Physical capacities (capable or handicapped).

   <u>Psychological:</u>
   Nervous and calm;
   Fearful and courageous.

   These characteristics are represented by coefficients inside the software, and the relations among them determine the number of time steps executed. For example, the coefficient of velocity of a obese person is too low (e.g.: 0.1) in comparison to an athlete (e.g. 0.9). So, the ant that represents the athlete will do 9 steps while the obese ant will do just one. It simulates the differences among people during the evacuation. The same idea is applied to the psychological characteristics.
2. **<u>Second Step - The distribution of the passengers:</u>** The Genetic Algorithm will generate a lot of distribution of the passengers (characteristics) generated previously, in other words, each ant will be placed in different seats at each distribution in order to discover which position (combination) is the best.
3. **<u>Third Step - The Alert:</u>** The emergency landing procedure is started and a sign lights to alert about the emergency evacuation. The flight attendant will indicate which exit doors will open for the evacuation.
4. **<u>Fourth Step - The evacuation:</u>** The evacuation from the airplane and the chronometer count (limit time = 90

seconds) starts. The passengers stand up from their seats and start moving and taking decisions based on QFD/Fuzzy.

5. **Fifth step – Results:** An analysis and a classification of the results considered satisfactory (those which evacuation is 90 seconds or less) is performed. Thus, the fastest distribution of passengers for evacuation is selected. If no satisfactory values are obtained, the Genetic Algorithm will generate new distributions until a configuration that follows the requisites is found.

6 Final considerations

This work focuses on commercial airplanes manufacturers, service companies specialized in certification, companies of airplane interior design and aeronautical authorities.

The algorithm would solve the problem in an innovative way, allowing the user to know previously, through computer simulations using the ACO approach, unprecedented in the area, which are the solutions that meet the requirements for emergency evacuation.

The simulations are inexpensive and simple, aiming finding satisfactory solutions and optimize them in procedures and escape routes depending on the configuration of each aircraft.

The aim is to ensure success and reduce the costs and risks required in an actual testing.

This project seeks an improvement in the distribution of passengers of an aircraft, increasing the chances of an exit with no lives losses in aircraft emergency evacuation, which are very dangerous.

By distributing the passengers better, there are more possibilities of following all safety requirements stipulated and thus achieve its main goal: to save lives.

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