# Application of Ant Colony Optimizer (ACO) For Effective Path Planning in a Big-Box Store or Retail Facility

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## ABSTRACT

Real-life stochastic problems are better addressed by adopting metaheuristic techniques. One of the interesting metaheuristic techniques for defining the shortest path is the ant colony optimization (ACO) algorithm. A considerable number of maps for shortest path have been considered in time past using classical techniques which is appropriate for deterministic variables. For stochastic or nondeterministic decision variables, metaheuristic techniques are much more appropriate. This is possible by mimicking the path navigation and swarm propensities of natural entities to provide real-time quality geographical images representing diverse areas or terrain for easy access to routing and path planning for sustainability and economic benefits in systems. In this research, the solution power of ACO has been demonstrated to predict customers' behaviour in a popular retail outlet, using the travelling salesman problem (TSP) for stochastic shortest path during the purchase of items in a big-box facility with multiple products and sixteen (16) sections. Data obtained from the facility has been validated. The tour length was subjected to pheromone optimization to obtain a pheromone update of 0.00345 per metre as the maximum and 0.001725 as the best update at varying evaporation rate. In conclusion, out of the selected sections, two major paths in the big-box facility yielded optimal tour length and as such either of the paths can be followed by customers to spend the minimum required time in the facility.

## Keywords
Ant Colony Optimization (ACO), Fast-Moving Consumer Goods (FMCG), Travelling Salesman Problem (TSP)

## 1. Introduction
Over the years, a considerable number of maps have been developed by strategist and operational scientists in a bid of providing real and quality geographical images representing different areas of the earth for easy navigation, routing, transporting of goods for the economic benefit of man. With the recent advancement in technology globally, the development of more sophisticated maps with novel function like tracking of locations, description of routes between places and so on is no coincidence but an achievement that was merely time-dependent. In a bid of improving subsequent maps by discovering more routes which would serve as a linkage between cities and as well limit road hours, researchers have shifted their attention to swarm intelligence which is an aspect of computer technology. Swarm intelligence is a problem-solving technique that is inspired by observing the behavioural activities of a living organism with emphasis on insects and some other animals (Hlaing & Khine, 2011). The advancement in computer technology is geared towards developing algorithms which mimic the behaviour of insects in solving problems. An in-depth study of the swarm intelligence has shown that the ant colony algorithm is one of the most successful and effective

approaches for the optimization of the combinatorial problem (Soni, Jain, Chan, Niu, & Prakash, 2019). This is due to the existence of parallel processing, a favourable feedback mechanism and so on. This research study takes into consideration, the application of ACO.

The ant colony algorithm (ACO) is a meta-heuristic approach for optimizing computational problems based on probability. It makes use of artificial ants in simulating the real-life behaviour or movements of ants to obtain the necessary data required to provide a solution to a problem. Ants usually move in colonies and since they are blind, their choice of path is based on probability. Ants though the blind search for food and place of shelter (nest) like any other living organism with vision. When ant forage from one place to another, it secretes an enzyme called pheromones (communication medium) along the path taken to reach its destination i.e. nest to the food source and vice versa (Tewani, 2017). Consequently, when other foraging ants seek for food, a greater number of ants follow the path with a pheromone trail until eventually, the ant colony follow the shortest path between their nest and food source i.e. the shorter the path richer the pheromone trail. Ant colony algorithm is widely adopted for solving of various combinatorial problems such as vehicle routing**,** internet routing**,** travelling salesman**,** scheduling problem**,** image processing, knapsacks problem**,** pollution control etc. (Sapna, Abdul, & Ibraheem, 2015).

### Merit and Demerit of ACO

Considering the nature of available optimization techniques, it is quite conspicuous that irrespective of the benefits they present, they also have certain limitations and the ACO is not an exemption. Tewani (2017) thinks that there are certain merits of using the ACO in problem-solving. Some of the observable advantages include the following: the ability of the algorithm to address complex problems; the algorithm is quite easy to learn; it offers a wide range of applications; it has short search period for a solution to be obtained. The major demerit is the probabilistic tendency of the algorithm, as solutions are entirely dependent on ants' ability to identify the optimal path. According to Almaalei & Razali, (2019); Reshanwala and Vinchurkar, (2013) and Tewani, (2017)) the ACO finds its application in diverse areas, a few of the applications include Vehicle routing problem; travelling salesman problem; job scheduling problem; water pipeline network design; graph contouring problem; telecommunication network and many more. This paper is focused on the novel application of the ant colony optimization techniques using fast-moving consumer goods as a case study.

## 2. Literature Review

Considering the vast amount of knowledge base available for study, several pieces of literature on ant colony optimization were consulted and reviewed to be abreast with the concept. Reviews made span through the various application of ant colony optimization technique as will be observed in the paper.

Qui, et al. (2018) conducted research focused on relay routing algorithm for remote concentrated ammeter reading based on ant colony optimization. A survey was conducted on how remote concentrated ammeter reading can be improved using a relay routing algorithm. In a bid of obtaining an optimal relay route, ant colony optimization was used to propose a relay routing algorithm. The results generated from the application of the proposed algorithm after undergoing analysis and extensive simulation depicts that the ant colony optimization improves the reliability of an ammeter reading, has an anti- destruction of route search and high efficiency.

Shetty et al. (2018) developed an improved ant colony optimization algorithm by focusing on Minion ants (MANT) and its application on the travelling salesman problem". In the paper, the authors explored the challenges or roadblocks encountered in solving complex travelling salesman problem and concurrently modified the ant colony optimization by proposing a new ant colony optimization called the MAnt. The proposed algorithm was executed at a desired pheromone evaporation rate and the results obtained showed that there was a sharp decrease in the tour cost when it was applied to most travelling salesman problems. As such, the MAnt algorithm is seen as a novelty in solving combinatorial problems and not just restricted to the travelling salesman problem alone. Baranowski et al. (2014) explicitly analysed how an ant colony optimization technique can be used to solve the travelling salesman problem. Shuqeir and Qublan, (2014) focused their research on a hybrid algorithm based on ant and genetic algorithm for task allocation on a network of homogeneous processors". The ant colony optimization and the genetic algorithm were used by the author in this paper to solve a task allocation problem. To improve the results obtained, a TAP-ACO-GA was proposed through the combination of the ideas of the ACO and GA. The proposed algorithm was extensively tested and the follow-up results were found to be more favourable when compared with the ACO and GA for task allocation problems.

Chowdhury et al., (2019) proposed a modified ant colony optimization and the application for solving dynamic TSP using drones for surveillance as a case study. Oluwagbemiga et al., (2019) developed a hybrid ant colony tabu search algorithm for solving next release problems. In the research, the authors presented a hybrid solution which encompasses the usage of ant colony optimization and tabu search technique. Considering that next release problems are challenging tasks in software engineering, the paper reiterated the need to propose a model for requirements. In the paper, the authors adopted a cost-value model in maximizing value while minimizing the cost of the developed hybrid. This process of determining a new feature to be incorporated into software is key as the user's satisfaction is considered. Therefore, limiting the features added to each software helps minimize the cost as resources will be conserved. This buttresses the facts (Oluwagbemiga et al., 2019).

Tanzin, (2019) discussed the travelling salesman problem and made a comparison between ACO and other algorithms using time cost, scalability and memory usage as criteria. Jangra and Kait (2019) modified ant system solving TSP problem". The paper considered the entrapment problem faced by salesmen. The authors modified the pheromone update formula in a bid to mitigate or reduce the level of stagnation. With the modification of the equation, a better solution which offers better searchability was generated. Dahan et al. (2019) reiterated the need to mitigate the stagnation experienced in TSP problems by using a dynamic flying ant colony optimization technique in providing an optimal solution. Yang, et al. (2020) worked on a small-scale TSP problem by analysing and simulating parameters from an ant colony optimization experiment. Gao (2020) proposed a new ant colony optimization algorithm which can be used to generate optimal solutions for TSP. This research is focused on a novel application of ACO as a nature-inspired algorithm to study the navigation pattern of customers in a retail facility.

Florez et al. (2013) researched the ant colony optimization algorithm for the job shop scheduling problem". In the paper, the author discussed how the ant colony algorithm can be utilized in solving job shop scheduling problem (JSSP) to minimize the time taken by several machines to complete a finite number of operations. Habibeh, (2015). The Elitist ant system was used to optimize the JSSP and it was found that it proffers an optimal solution. Set covering problem optimization solution was disclosed in a paper titled "a hybrid ant algorithm for the set covering problem. Broderick, et al., (2011). The results were obtained by incorporating a feedback mechanism which checks constraints uniformity in ant simulation. Chhikara and Patel, (2013) studied how the ACO can be used to effectively enhance network security.

Kumar, (2015) hinted on how an optimal solution can be obtained for a tsp problem using the ant colony optimization technique. Madaan and Vashesht (2016) presented a solution to a travelling salesman problem using ant colony optimization technique. Hemalatha et al, (2018) Implemented the ant colony algorithm in RWA". RWA which is commonly known as routing and wavelength assignment which is equally a recurring problem in the optical mesh network. On this note, the authors put forward this paper to help mitigate the challenges faced in the system considering a fourteen (14) node network model which was used to remedy the task. From the results obtained from the research conducted, it is noteworthy to state that the ACO is the best approach in solving RWA problems when compared with other solution techniques.

Batista et al. (2019) proposed a new ant colony optimization technique which is quite effective in solving periodic capacitated arc routing problems with continuous moves. Sugumaran and Venkatesan (2019) optimized trust path for control of packet dropping and collision attack using ant colony in Manet". The paper emphasized the need for a secure communication network between a sender and a receiver. In proposing a secure network, a trust path ant colony optimization algorithm (TpAco) was developed. When TpAco is compared with other techniques, its result provides better performance in terms of end to end delays and packet delivery ratio. Gaur and Arif (2019) worked on a software test suite minimization using ant ACO. In a quest to maximize accuracy, three techniques; Naïve Bayes, 0/1 Knapsack problem and the ant colony optimization were combined to minimize a software test suite.

Le et al. (2020) demonstrated evolutionary algorithm-based complete coverage path planning for tetriamond tiling robots". The paper illustrated how a tiling robot's path can be planned by using a hybrid algorithm developed by combining the genetic and ant colony optimization algorithm. Gao et al., (2020) discussed how a mobile robot path can be planned by proposing an enhanced heuristic ant colony optimization (EH ACO). In a bid to buttress the concept the authors adopted four unique strategies which are; improvement of the heuristic distance in the local visibility equation, formulation of a novel pheromone diffusion gradient equation, the introduction of a backtracking strategy to mitigate stagnation, and merging of paths.
The first section of this research is focused on an introduction to ant colony algorithm, section two dwelt on review of literature, section three is the mathematical modelling and validation of dataset and finally the analysis and conclusion part of the research.

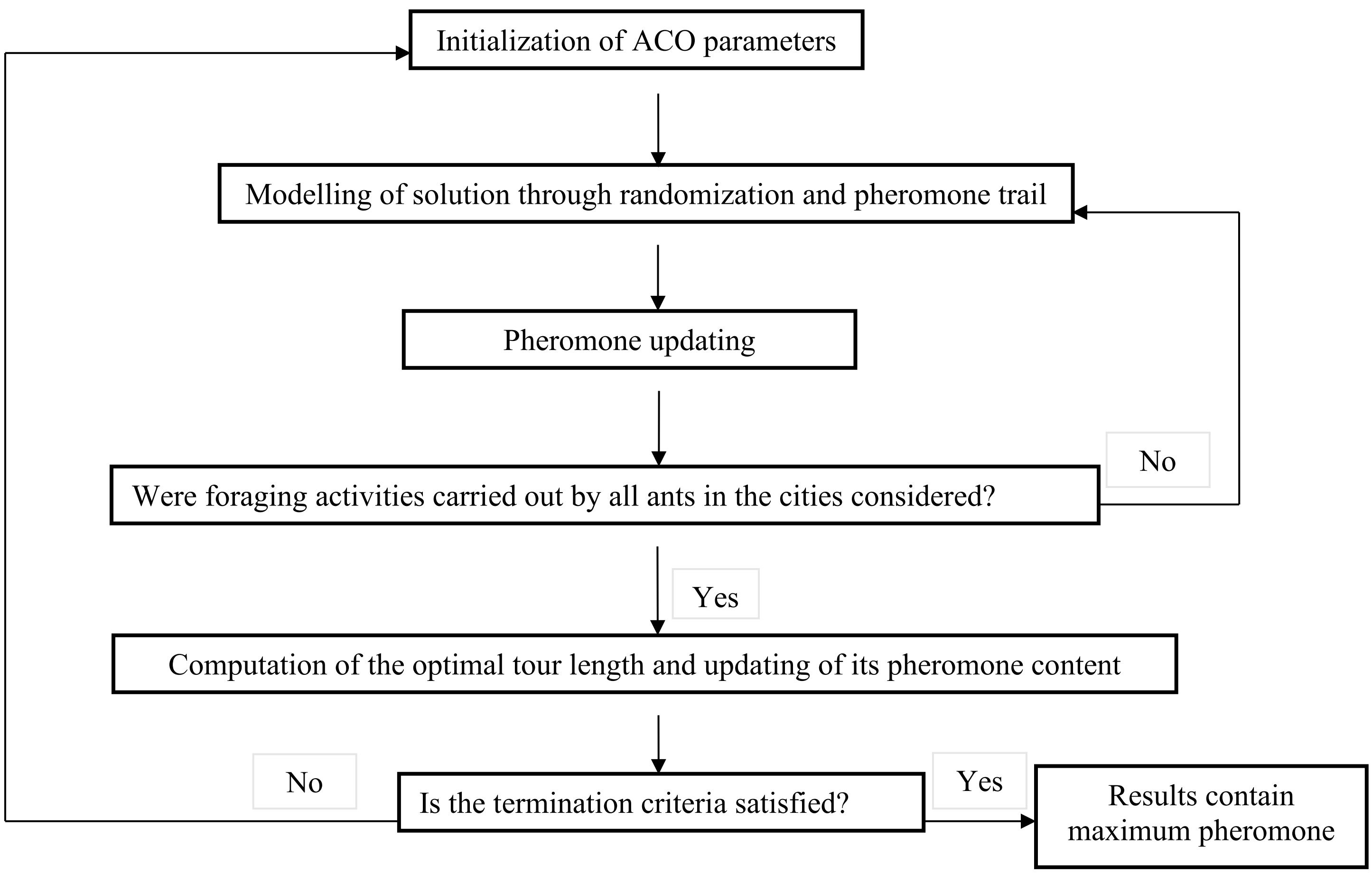


Figure 1. Flow chart showing the working procedure of ACO (Yun, Jeong, & Kim, 2013)

## 3. Methods

The mathematical modelling of ACO can be developed from the flowchart presented in Figure 1, through randomization and pheromone trail, pheromone updating and computation of the optimal tour length as well as updating the pheromone content. ACO as a meta-heuristic optimization process is stochastic. It models the real-life movement or behaviour of ants to solve the optimization problem. Since ants are blind, they move randomly from one place to another i.e. they choose a path based on probability.

### 3.1 Food Search Procedure

In the food search, the ant seeks the path with the shortest distance from their nest. The pattern of movement of ants while seeing the shortest path is presented in Figure 2 (Dreyfuss P. and Agostini, 2012). The foraging process is such that they deposit pheromones along the path taken while searching for food source until they arrive their terminus (food source). They equally return to their nest following the same path. During foraging process, these social agents consider the path with a high concentration of pheromone trail until they arrive at the shortest path to the food source. The pheromone secretion for iterations and the choice of next cities which is purely based on probability will be determined using the iterations carried out.

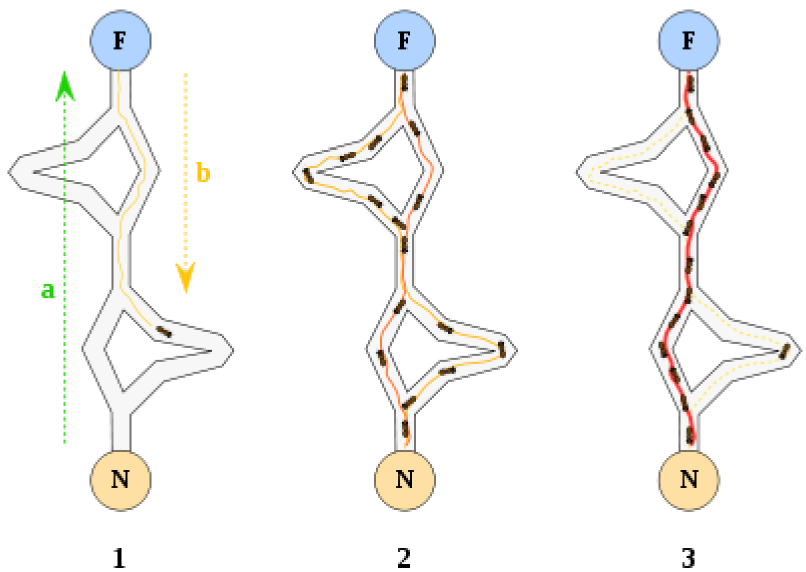


Figure 2: Ant movement seeking the shortest path

The path taken by ants can be analysed for optimality using Eq. 1 as presented.

$$P_{ij} = \frac{\tau_{ij}{}^{\alpha}\ \eta_{ij}{}^{\beta}}{\sum \tau_{ij}{}^{\alpha}\ \eta_{ij}{}^{\beta}} \qquad (1)$$

Where

$\boldsymbol{\eta_{ij}}$ represent the desirability of the edge or path or visibility of the path from a city.

$\boldsymbol{\beta}$ represent the parameter that controls the influence

$\boldsymbol{\tau_{ij}}$ is the amount of pheromone on the edge or path

$\boldsymbol{\alpha}$ is the parameter that controls the influence i.e.$\tau_{ij}$

Pheromone Update equation is presented in the system of Eq. 2.

$$\boldsymbol{\tau_{ij} = (1-\rho)\tau_{ij_{old}} + \sum_{k=1}^{m} \Delta\tau_{ij}} \qquad (2)$$

$\boldsymbol{\rho}$ is the rate of pheromone evaporation

$\boldsymbol{\Delta\tau_{ij}}$= the amount of pheromone deposited $= \boldsymbol{\frac{1}{L_k}}$

$\boldsymbol{L_k}$ represent the optimum tour length

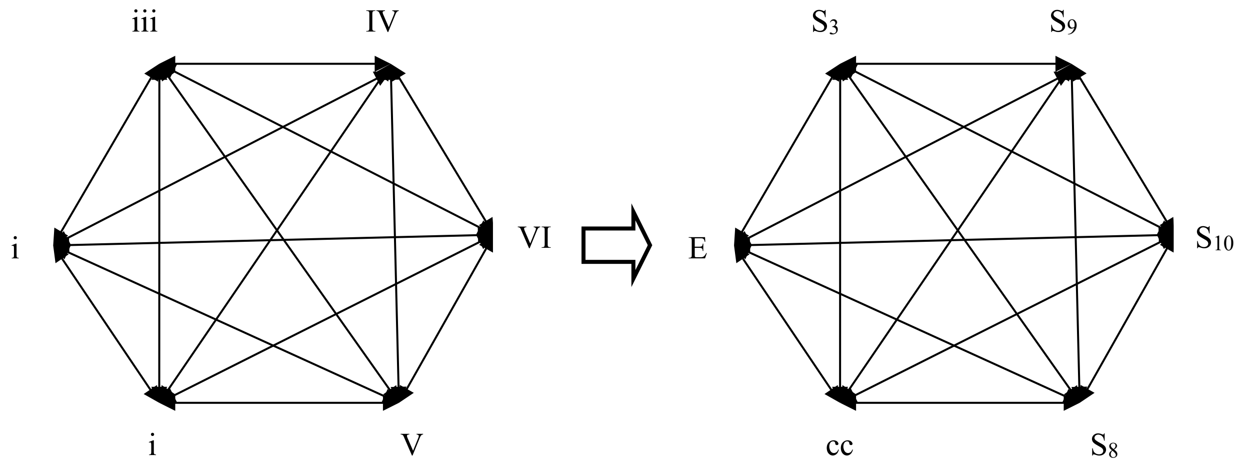


Figure 3. A representation of the tour points or locations of ants.

## 4. Data Collection

A big-box store or retail outlet with a location in Delta state has been used as a case study. The model of the case scenario was achieved by assuming six sections which are represented by nodes to be visited as shown in Figure 3. The arrow in the Figure is an indication of a possible transformation of the nodes into actual locations. By mimicking the pattern in which ant navigate in search for food, a demonstration of how customers behave while purchasing products in a big-box store as well as the possibility of locating the shortest route by adopting some of the basic phenomena governing the ant colony optimization. The big-box store considered in Delta state has sixteen (16) independent sections which offer the consumers quality products. The sections include: Detergents, air fresheners, brush wares etc; Toiletries, baby food and others; Deodorants, Soap; Pasta, baking accessories, canned fruits, eggs; Crockery, glassware, spices; Kitchen utensil, wares, cooking oil and vegetables; Small Appliance, Tea, Coffee; Yogurts, Cereal, Breakfast Bars; Juices, Biscuits, Fruit Juices; Sweets, Chocolates; Chips, Snack, Outdoors toys, Puzzles; Girls Toys, Boys Toys; Stationery, Schoolbag, School Stationery, Party Accessories; Luggage, Electric Ware, Motor Accessories, Bathroom; Pet Food, Pool Care, Pet Accessories; Outdoor Living, Gardening Tool.

To properly define the paths followed by customers during the purchase of items, the test scope was limited to specific sections which are section three, section eight, section nine and section ten. To obtain an accurate result, the TSP principle where a salesman visits one city once before returning to his origin was adopted. As estimated based on the information acquired from some workers, Table 1 shows the distances between the entry point, cash-out counter and the four sections under observation.

Table 1: Sections and distance between entry point to cash out counter in a Big-box Store

| Location | E | CC | $S_3$ | $S_8$ | $S_9$ | $S_{10}$ |
|---|---|---|---|---|---|---|
| E | | 50 | 100 | 140 | 160 | 200 |
| CC | 50 | | 20 | 60 | 120 | 30 |
| $S_3$ | 100 | 20 | | 50 | 150 | 70 |
| $S_8$ | 140 | 60 | 50 | | 80 | 80 |
| $S_9$ | 160 | 120 | 150 | 20 | | 40 |
| $S_{10}$ | 200 | 30 | 70 | 80 | 40 | |

 

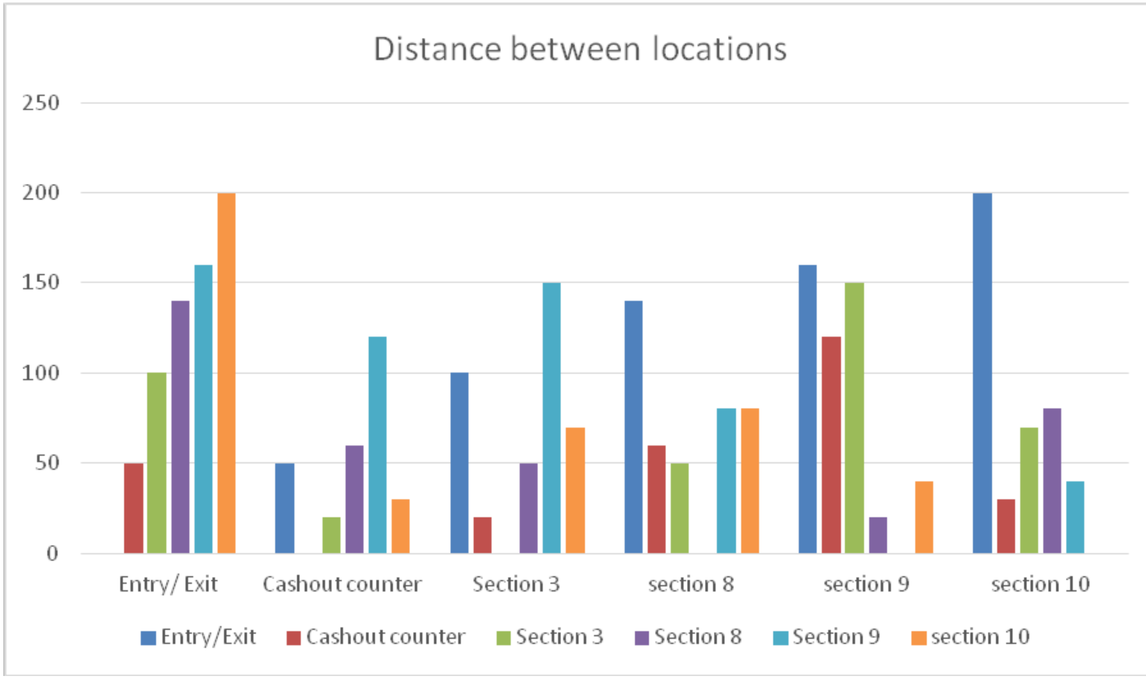


Figure 4: Selected Sections in the Big-box store and distance in meter between locations

A group of eight (8) individuals was formed and the experiment was conducted using the metaheuristic technique. Selected customers are expected to visit each of the sections before visiting the counter for payment and heading for the exit. The experiment aims to seek the shortest possible route for exiting the mall after visiting all the locations as depicted in the chart shown in Figure 4. The eight individuals can be presumed to be ants moving from their nest to a food source along an undefined path to achieve the shortest possible route from nest to the food source.

## 5. Results and Discussion

### 5.1 Numerical Results

**Iterations**

**First iteration**

Ant 1 moves along E-$S_3$-$S_8$-$S_9$-$S_{10}$-CC-E
Ant 2 moves along E-$S_8$-$S_9$-$S_{10}$-$S_3$-CC-E
Ant 3 moves along E-$S_9$-$S_{10}$-$S_3$-$S_8$-CC-E
Ant 4 moves along E-$S_{10}$-$S_8$-$S_3$-$S_9$-CC-E
The ant movement was patterned such that at entry, each section is visited first along a path and heading to the cash-out counter all sections are represented.

**Second iteration**

Ant 5 moves along E-$S_3$-$S_8$-$S_9$-$S_{10}$-CC-E
Ant 6 moves along E-$S_3$-$S_8$-S10-$S_9$-CC-E
Ant 7 moves along E-$S_3$-$S_{10}$-$S_9$-$S_8$-CC-E
Ant 8 moves along E-$S_3$-$S_{10}$-$S_8$-$S_9$-CC-E

For the first iteration, ant 1, 2, 3 and 4 covered 290m, 340m, 430m and 650m respectively.
For the second iteration ant 5, 6, 7 and 8 covered 290m, 440m, 340m and 440m respectively.

As shown from the results obtained from the trial, distance CC-E will have a high amount of pheromone deposited since all ants passed through that route. Route E-$S_3$ also possess a high amount of pheromone since it was chosen as the starting route for all for travels in the second iteration as a result of being the shortest route from entry. Route $S_9$-$S_{10}$ and $S_3$-$S_8$ will also have a high pheromone concentration as they are taken six and five times respectively in both iterations.

### 5.2. Optimization of results

To determine the optimality of the path taken by the ants, the following formula in the system of Eq.1 is used. The optimality of any path is determined probabilistically and the path with the highest chance of been taken is the optimal path.

$$P = \frac{\tau_{ij}^{\alpha}\ \eta_{ij}^{\beta}}{\sum \tau_{ij}^{\alpha}\ \eta_{ij}^{\beta}}$$

**Data Parameterization**

$\eta_{ij}$Is the desirability of the edge or path or visibility of the path from an edge?
$\boldsymbol{\beta}$ Is the parameter that controls the influence
$\tau_{ij}$Is the amount of pheromone on the edge
$\boldsymbol{\alpha}$ is the parameter that controls the influence i.e. $\tau_{ij}$

**Pheromone Update**

The system of Eq. 2 is useful to determine the pheromone update for a definite evaporation rate. The pheromone update chart is presented in Figure 5.

$\tau_{ij} = (1-\rho)\tau_{ij_{old}} + \sum_{k=1}^{m} \Delta\tau_{ij}$
Where
$(1-\rho)\tau_{ij_{old}}$ is the volatile pheromone remaining in the path
$\rho$ Is the rate of pheromone evaporation rate
$\tau_{ij}$ Is the current pheromone update to be determined at a specific pheromone evaporation rate
$\Delta\tau_{ij}$ Is the amount of pheromone deposited at time t= $\frac{1}{L_k} = \frac{1}{290}$=0.00345 per meter
Where$L_k$ is the optimum tour length
Constraint
$\tau_{ij_{min}} < \tau_{ij_{best}} \leq \tau_{ij_{max}}$ (3)
The equation above shows that the minimum amount of pheromone update is always less than the best pheromone update amount which is less than or equal to the maximum amount of pheromone update.

From the iterations, the optimum tour length is 290m
Hence assuming pheromone evaporation rates of 0, 0.5 and 1 the amount of pheromone deposited on the routes or edge is determined.
At $\rho = 0$ the pheromone deposited do not evaporate hence

$\tau_{ij_{new}} = (1-0)\tau_{ij_{old}} + (0 * \sum_{k=1}^{m} \Delta\tau_{ij})$ (4)
$\tau_{ij_{new}} = \tau_{ij_{old}} = 0$ (5)

At $\rho = 0.5$ the pheromone deposited along the path evaporates at a steady rate hence
$\tau_{ij_{new}} = (1-0)0 + (0.5 * 0.00345)$ (6)
$\tau_{ij_{new}} = 0.001725$ per metre

At $\rho = 1$ the pheromone deposited along the path evaporates immediately and makes it difficult for ants to sense it.

$$\tau_{ij_{new}} = (1-1)0.001725 + (1 * 0.00345) \quad (7)$$

$$\tau_{ij_{new}} = 0.00345 \text{ per metre}$$

$$\tau_{ij_{min}} = 0 < \tau_{ij_{best}} = 0.001725 \leq \tau_{ij_{max}} = 0.00345 \quad (8)$$

### 5.3. Graphical Results

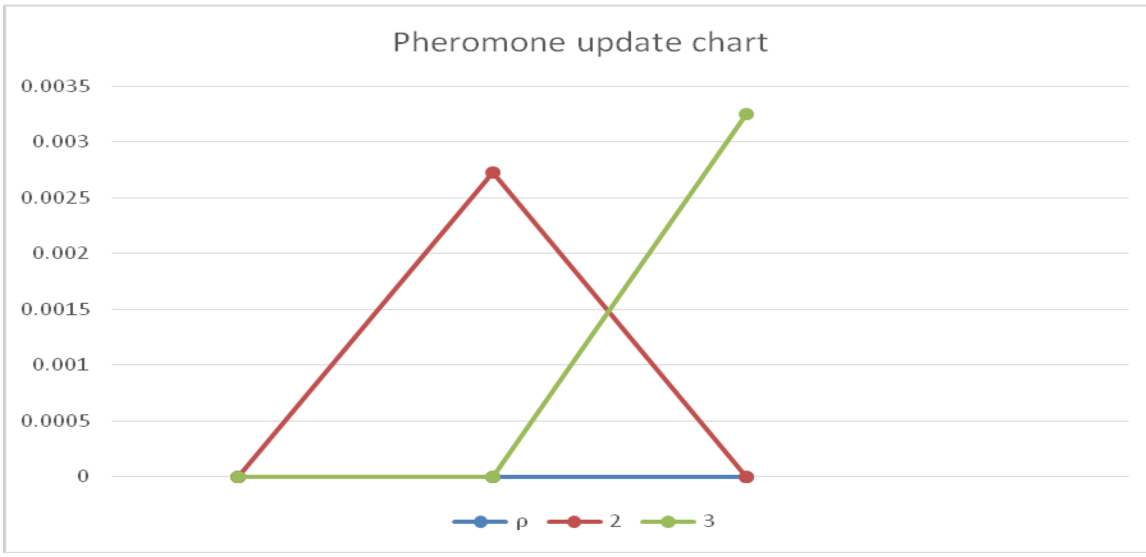


Figure 5: Pheromone Update Chart

The probability of choosing the path can be determined from the updated chart

### 5.4. Discussion

To effectively solve a TSP, the distance between locations is invaluable and this is shown with a distance between locations chart. Considering that ACO is probabilistic, the foraging processes of ants were simulated repeatedly. This is indicated by the number of iterations made. From the experiment carried out, certain routes were chosen repeatedly by the ants due to the high concentration of pheromone in that path. Per iteration carried out, the paths taken by ant 1 and 5 gives the minimum tour length and as such possessing the highest pheromone trail or concentration. This tour length was further subjected to pheromone optimization to get a pheromone update of 0.00345 per metre as the maximum and 0.001725 as the best update at varying evaporation rate. Looking at the pheromone update chart, it is conspicuous that the evaporation rate that produces the optimal solution.

## 6. Conclusion

This paper proposed a novel application of the ant colony optimization algorithm by utilizing the traveling salesman problem approach for the shortest path in a big-box store of fast-moving consumer goods (FMCGs). Since FMCGs are goods that attract numerous buyers to a specific facility, the congestion problem is to be mitigated. The paper effectively addressed this problem by using a big-box store with sixteen (16) sections and multiple products, considering four major sections of the selected facility. As shown in the iterative aspect of the paper, it was observed that two paths yield the optimal tour length and as such either of the paths can be followed by an individual to spend the minimum time in the facility. The utilization of a low pheromone evaporation rate ensures the availability of pheromone trail for a longer period. This is the secret towards achieving the best possible solution in ant colony optimization problem. Conclusively, this paper has shown the effectiveness of the ant colony optimization technique in defining the optimal path for customers to follow in a big box facility. In future research, other problems like data mining, knapsack problem, job-shop scheduling, set partition problems would be solved using the ant colony optimizer.

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## Biographies

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