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ANT COLONY OPTIMIZATION AND RAILWAY ROUTES CONSTRUCTION

TAIWO JANET FOLASADE; ABUBAKAR AMINU MUA'ZU; HAMISU MUSA; ODOK MARSHAL; & MAMUDA BALA
Department of Computer Science, Faculty of Natural and Applied Sciences. Umaru Musa Yar'adua University Katsina, Katsina State, Nigeria

Abstract
Effective transportation system has an extensive role in shaping the development and environment of any country, as its impact on life and societal productivity cannot be underestimated nor overemphasized since it determines advancement of such country. For this reason, optimization of transportation system is essential for the successful progression of any nation state. This paper sought to assess if there is any relationship between Ant Colony Optimization (ACO) and railway routes system optimization. An enhanced ACO algorithm called Bio-inspired Railway Route Optimization System (BiRROS) was developed and simulated in a programming environment. The results obtained from the experiments conducted shows that relationship thus exists between ACO and railway system route optimization, as the performance of ACO was exceptional and is much faster in overcoming the delay encountered by passengers' train with travel time and distance covered by each train minimized on the selected axis. Hence, we conclude that the proposed BiRROS is capable of producing alternative paths.

Keywords: *Ant Colony Optimization, Railway Routes System Optimization, Bio-inspired routes optimization, ACO, Bio-inspired optimization techniques*

INTRODUCTION
Generally, optimization is required for effectiveness and productivity in every life situation, and is thus an important paradigm by itself with a wide range of applications. It is often performed in industries, engineering and other fields in order to minimize or maximize cost, maximize profit, energy consumption, improve performance output and also for efficiency purpose.

Transportation system is an example of an industry where continuous optimization is required, as an effective transportation system has an extensive role in shaping the development and environment of any country (Borndörfer et al., 2015). The objective of effective transportation is geared towards good network connectivity (that is, land and rail) amidst economic development. For this reason, persistent optimization in this industry is essential for the successful progression of any nation state. Rail system is an aspect of this sector that is steadily becoming the most desirable form of transit infrastructure around the world, partly because they are seemingly more environmentally friendly compared to airplanes and automobiles. Regardless of these recent attractions, continual optimization is necessitated in this system considering the issues peculiar to the sector like train timetabling problem, rolling stock scheduling, crew scheduling, train routing, routes definition and route optimization problem. In fact, the delay encountered by passengers' train during a trip stems from one of this problem (route optimization) which is often triggered by prominent barriers on railway routes like sharp bends, steep gradients, amongst others. These obstacles encountered have led to loss of patronage in some axis of the Nigeria Railway Corporation due to elongation of travel distance and delay in arrival time. Proffering solution to the identified challenge is what this work seeks to achieve by applying Ant Colony Optimization (ACO). ACO is swarm intelligence-based approach that is biologically inspired in nature and suitable for solving high level combinatorial problem that traditional methods cannot solve. ACO has been utilized evidently in several categories of problems such as vehicle routing, Travelling Salesman Problem (TSP), sequential ordering amongst others (Dorigo and Sturtzles, 2019). It is pertinent for decrypting problems that can be modelled and represented graphically. Given the testimonies of ACO in providing solution to Generalized Travelling Salesman Problem (GTSP) according to Hadjicharalambous *et al* (2007), Railway Travelling Salesman Problem is similar to GTSP only that not all cities (nodes) have to be visited. Hence, in this work we applied an enhanced algorithm to optimize railway routes on the North Eastern line of the NRC. This work is further guided by the following research objectives:

1) To establish the relationship between Ant Colony Optimization and railway routes construction.
2) To determine how Ant Colony Optimization can be used to enhance railway routes construction.

BACKGROUND

Railway Routes System in Nigeria

Rail transport is regard as the erstwhile overland means of transport in Nigeria (Agunloye & Ilechukwu, 2011), the most seemly and inexpensive style of transportation for intense traffic flows in the compactly inhabited urban areas. Rail transport has unrelenting played an imperative role in the socio-economic progression of many countries. Available history suggests that the railway system started in

Nigeria in 1898, following the laying of the first railway track from the South West (Lagos to Ibadan) by the colonial administrators (Muktar, 2011). The rail network in the country has two main rail lines: The Western line connects Lagos with Nguru in Yobe and the Eastern line that link up Port-Harcourt in the Niger Delta and Maiduguri in the North Eastern State of Borno. This rail network granted the only means of freight interchange between the Southern and Northern parts of the country for many years with little or no reconstruction. This brought about decadence in the sector. According to Oni and Okanlawon (2010) and Taiwo et al. (2019), travel times were elongated, with travel speed decelerated to a maximum of 65km/h owing to the steep curves, inadequate track equipment, sharp bends and the narrow gauge of the rail lines. While there is over 120,000km of national highways, however, there is an urgent requisite to extend the present railway system, creation of new lines serving certain industrial project areas and better integration of the country by providing a low-priced means of transportation.

Ant Colony Optimization

Ant Colony Optimization (ACO) is one of the most effective techniques in the broader field of swarm intelligence.

Hlaing and Khine (2011) said ACO inspired by the foraging behaviour of natural ant was first introduced by Dorigo, Maniezzo and Colorni, (1996) in the early 1990s and has become one of the most efficient algorithms for optimization related problems. ACO is established on the pheromone trail laying and observing behaviour of some ant species. This behaviour was shown to allow actual ant colonies to find the shortest paths between their colony and food sources. A pheromone is regarded as a chemical factor that activates a social reaction to other animals of the same species. In another publication, Neto and Godinho Filho (2013); Reed et al., (2014) said the concept behind ACO is built on the ‘‘natural’’ algorithm employed by real ants to produce a near-best path amid their nest and the food source. It is identified that ants are blind, deaf and almost dumb. At the same time, their behaviour is directed to the survival of the colony. During their food searching process, ants deposit chemical materials called pheromones on their way back to their nest that form a trail for other ants. Other ants perceive the chemical pheromone, and the paths become high likelihood to be visited following. The ants in the subsequent rounds become interested in the marked path; the more pheromone that is released on a path, the more attractive that pathway becomes. This noticeable trail fascinates other ants on the next seeking food process (Pedemonte et al., 2011; Cecilia et al., 2013). Benhala *et al* (2011), presented this food seeking process diagrammatically as shown in fig 1 below. Fig.1(a), depicted ants following a path between nest and food source. While in fig.1(b), an obstacle appears on the path: where ants choose, with equal probability, whether to turn left or right. In fig.1(c), higher amount of pheromone is deposited on the short path. And finally, in fig.1(d), majority of the ants chose the shortest path to the food.

The motive behind ACO is targeted at finding shortest most optimal path and this has made it gained popularity in providing solutions to problems that can be modelled graphically. It first area of application was travelling salesman problem (TSP) where several cities are to be covered. The major goal of TSP is discovering the shortest tour through a set of cities starting from a town and going through all other cities once (without revisiting previously assessed cities), and returning to the starting city (Pedemonte et al., 2011; Dorigo and Stützle, 2019).

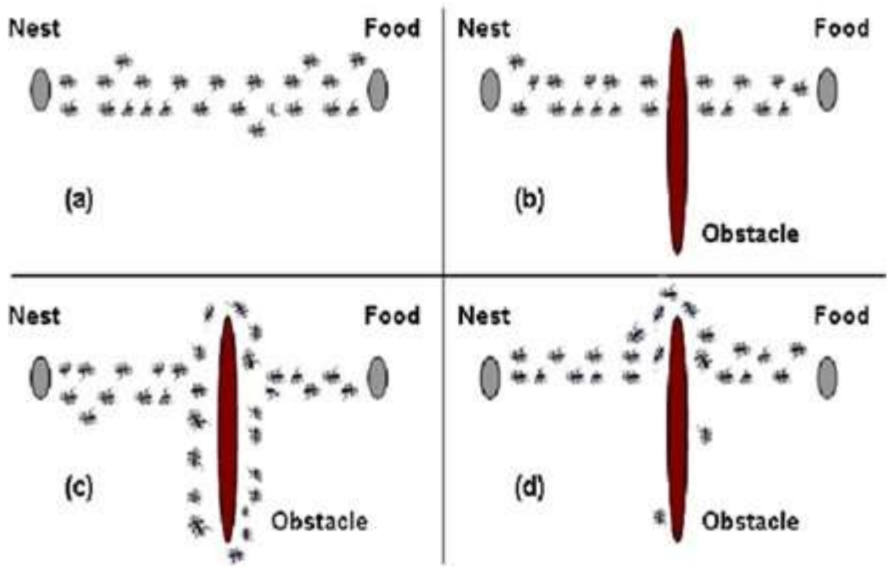

Fig.1: Ants food search via pheromone communication scheme (Benhala *et al,* 2011)

From TSP stems other areas of application of ACO as identified by Dorigo and Sturtzles (2019) shown in Table1 below.

Table 1: ACO Current Application Areas

S/N	Problem Type	Problem Name
1.	Routing	Travelling Salesman Problem (TSP), Vehicle routing Sequential Ordering
2.	Assignment	Quadratic Assignment Graph Colouring Generalized Assignment

		Frequency Assignment University Course Timetabling
3.	Scheduling	Job shop Open shop Flow shop Total tardiness Total weighted tardiness Project scheduling Group shop
4.	Subset	Multiple knapsack Maximum independent set Redundancy allocation Set covering Weighted constrained graph tree partition Arc-weighted l-cardinality tree Maximum clique
5.	Machine learning	Classification rules Bayesian networks Fuzzy systems
6.	Networking routing	Connection oriented network Connectionless network routing Optical network routing
7	Others	Bin packing Constraint's satisfaction Health sector related problem Bus stop allocation Facilities layout and Space planning

After studying the table above, it was observed that ACO application is trying to gain popularity in solving railway related problems as seen in the work of Tsuji *et al* (2012), that dealt with deadheads in railway due to random selection and increment in number of small train units; Eaton and Yang (2016), considered delay in train rescheduling; Ni (2018), tackled passenger transfer related issue amongst others. However, it was also noticed that none of these optimization algorithms is extended to railway system route optimization. Given the suggestions of Sahana et al., (2014) and Kuttner (2018) on ACO, a bio-inspired technique capable of solving highly combinational problems and its applicability to different sized problem where route/path optimality is prioritized, this research work seeks to propose an enhanced ACO algorithm that will reduce the delay experienced by passengers' train on the North-Eastern route of Nigeria Railway Corporation (NRC) by improving travel time and distance covered in a trip.

METHODOLOGY

The section is divided into two: algorithm design and program flowchart for the BiRROS simulator.

Algorithm design: The railway route optimization system problem is a real-life challenge peculiar to locations where passengers train is to be transported from one point to another. To proffer a solution to this challenge, the ACO algorithm of Dorigo & Sturtzles (2004); Chawda & Sureja (2012) in figure 3.6(a) were studied, and some constraints were slightly modified to produce an enhanced algorithm needed for our work.

Original Algorithm

```
1. procedure ACOMetaheuristic
2. Initialize pheromone trails and other parameters
3. While (termination criteria not met)
   {
      ConstructAntsSolutions
      DaemonActions % optional
      UpdatePheromones
   }
4. End ACO procedure
```

2(a)

Proposed Enhanced Algorithm

```
1. procedure ACO-BiRROS
2. Load map
3. Set source
4. Set destination
5. Set parameters, initialize pheromone
   trails
6. While (termination condition not met)
   Do {
   Construct Solutions
   Apply Local Search % optional
   Update Pheromones
   }
7. End do
8. End ACO- BiRROS
```

2(b)

Fig.2(a): Original Algorithm:(Dorigo & Sturtzles, 2004; Chawda & Sureja, 2012)
(b): Proposed Enhanced ACO-BiRROS

***Program flowchart for the BiRROS*:**

The flowchart for the BiRROS as portrayed in figure 3, is made up of thirteen steps. It begins with a start, after which the system files are checked for the software introduction screen and the main platform to be opened. After that, an input action is expected of the user to perform a click operation where the map is loaded so that the source and destination of the train can be selected.

Consequently, the ACO parameters will be initialized for the commencement of the simulation. At this point, the simulation is delayed as processing is being performed to ascertain the paths stemming from the selected source and destination.

Once the path is found, the result of the route is displayed. If the path detected has the shortest distance, the graph for such a path is created and presented as the most optimal path. Conversely, if the path is not optimal with the shortest distance, the simulation is repeated.

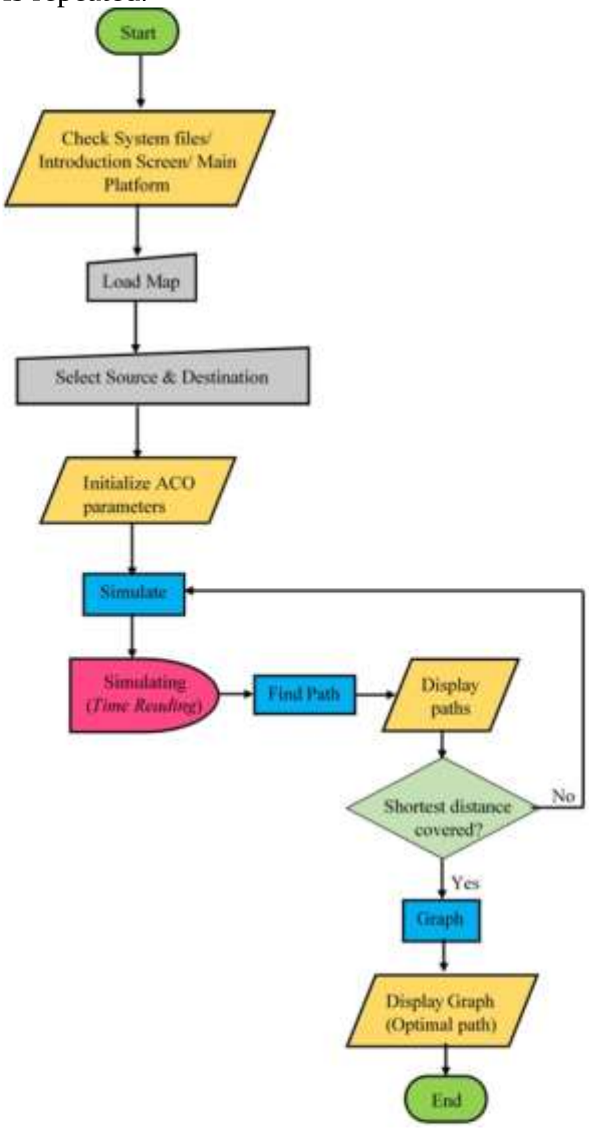

Fig.3: Program flowchart for the BiRROS

IMPLEMENTATION

The proposed enhanced ACO-BiRROS was implemented using C# programming language for coding, which was embedded in visual studio on Intel Core i7-2620M 2.70 GHz machine, whose operating system is Windows 8.1 Pro, 64-bit having 8.00 GB RAM size. The proposed algorithm was applied to real railway lines: Port Harcourt and Maiduguri route (North-Eastern line) on Nigeria Railway Corporation in order to evaluate its usefulness. Figure 4 shows the graph of railway map of this line.

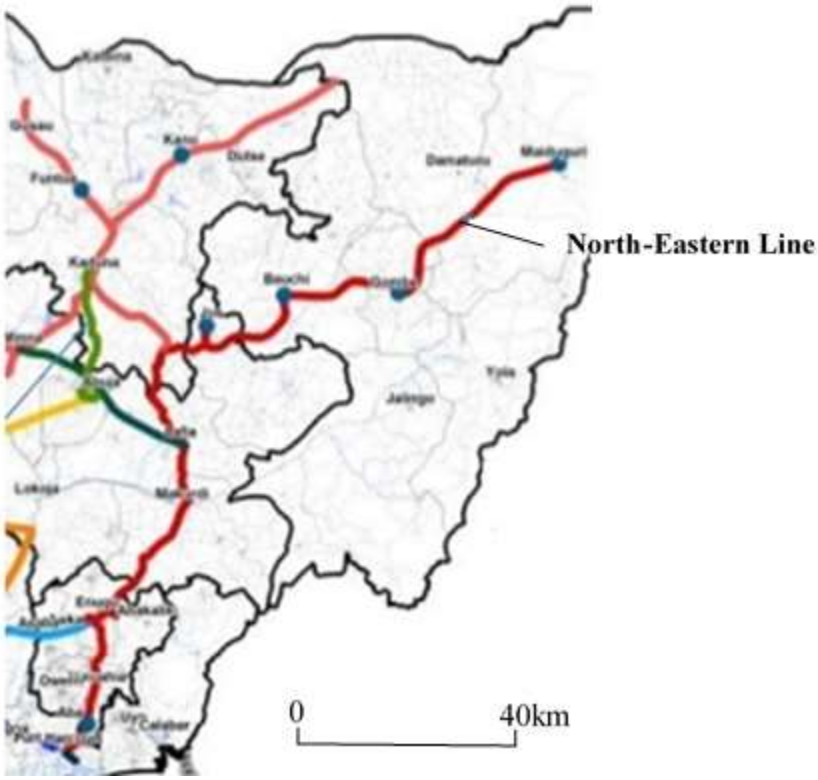

Fig.4: North-Eastern Line Railway Map.

The experiment was carried out using five different train stations labelled as 1 to 5 on the North-Eastern line railway routes. ACO parameters of alpha, beta, ant count and pheromone amount were set at varied intervals as indicated in table 2 for each train stations. Therefore, resulting in summation of two thousand, two hundred and fifty trials for the five train stations.

Table 2: ACO Parameters

Parameter		Train Station 1 (TS 1)	Train Station 2 (TS 2)	Train Station 3 (TS 3)	Train Station 4 (TS 4)	Train Station 5 (TS 5)
Number of iterations	1 to 10	450	450	450	450	450
Ant Count	10 to 100					
β value	2 to 6					
Ω value	0 ≠ pheromone 1= pheromone					

Pheromone evaporation rate	0.1 to 1.0

RESULTS

Research objective one for this paper was answered by Taiwo et al (2019), their result indicated that there is a positive significant relationship of 67.01% regression between ACO and railway system route optimization. Similarly, their correlation result represented as *Multiple R* shows 0.8186 signifying a positive relationship of 81.86% between ACO and its possibilities in optimizing railway routes.

This segment here on satisfies the research objective two for this paper. The results derived for each train station were summarized and concluded on β value, indicating five least travel time and distance for each train station. The results were compared for both proposed and existing route on β value as presented in figures 5 to 9, and we discovered that for all the five train stations, most optimal path with least travel time and distance was obtained where β value is 2.

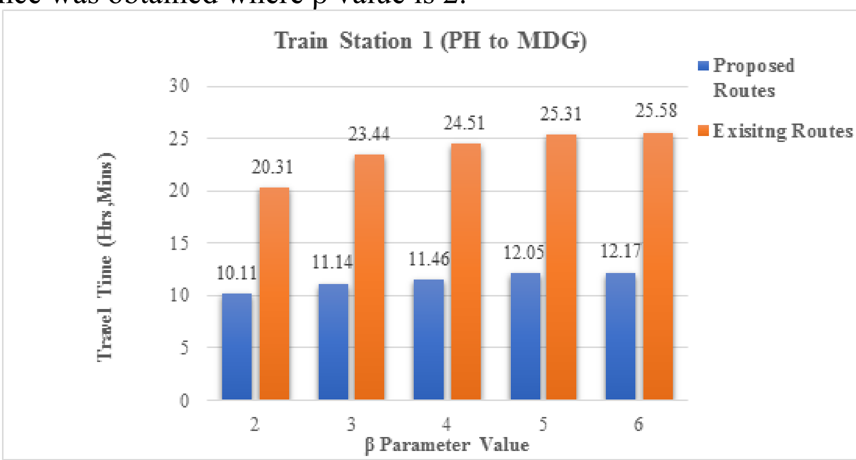

Fig.5: β value Travel Time Comparison for Train Station 1

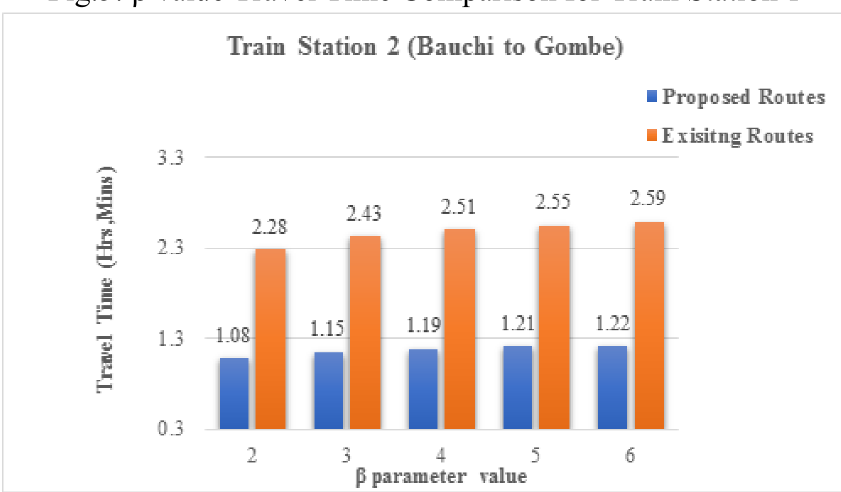

Fig.6: β value Travel Time Comparison for Train Station 2

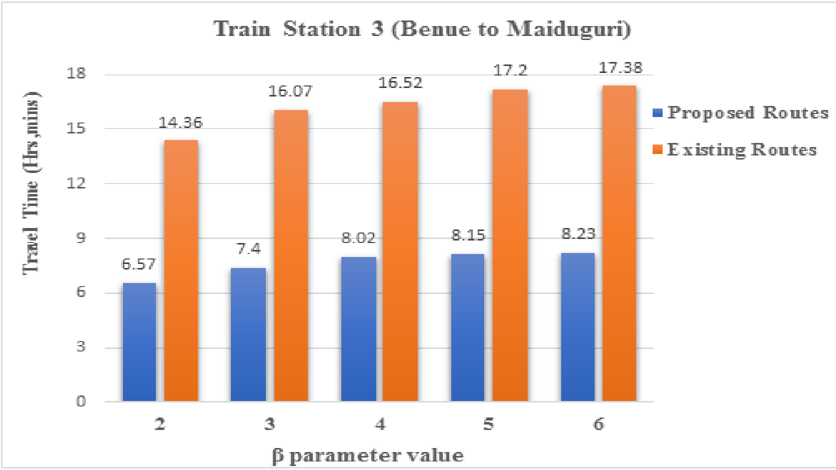

Fig.7: β value Travel Time Comparison for Train Station 3

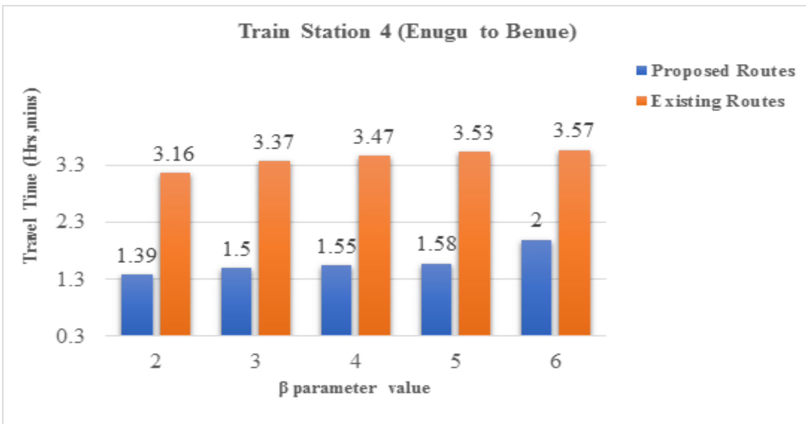

Fig.8: β value Travel Time Comparison for Train Station 4

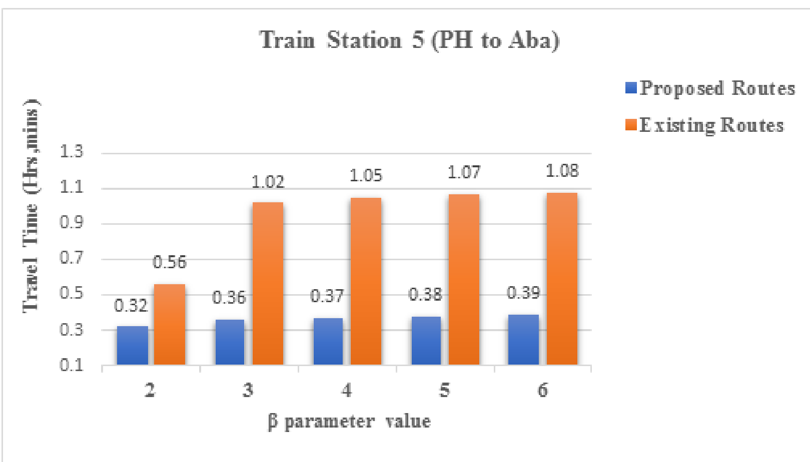

Fig.9: β value Travel Time Comparison for Train Station 5

The simulation results showed that our proposed Bio-inspired Railway Route Optimization System (BiRROS) is effective for discovering alternative routes for all the train stations with minimized travel time and distance when the result obtained was compared with that of the existing route.

CONCLUSION AND RECOMMENDATION

As observed from the conducted experiments, the performance of Ant Colony Optimization (ACO) was exceptional and is much faster in overcoming the delay encountered by passengers' train as it minimizes travel time and distance covered by each train on the selected axis. In our work, the cost (distance and travel time) decreases when β-value is smaller. This result shows that relationship thus exist between ACO and railway system route optimization. Hence, we conclude that the proposed BiRROS is capable of producing alternative paths, which may be helpful in case of sudden damage on existing paths (routes). Finally, even though the objectives of this paper were achieved, we suggest that more researches on the application of ACO in solving railway routes optimization problems should be conducted.

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