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TIME DEPENDENT ROUTE SELECTION FOR COURIER VEHICLE USING ANT COLONY OPTIMIZATION

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Abstract: The study delves to estimate the fastest route for courier vehicle routing in Dhaka city for different times of a day. It identifies the fastest route through Ant Colony Optimization (ACO) considering real time traffic scenarios. ACO mimics forging behavior of ant colonies to search for the route among various paths which requires minimum travel time. The study road network comprises with five locations, i.e. nodes which are interconnected with links i.e. roads. Travel time requires for each link are estimated and total travel time requires for different routes under four times of a day, such as, morning, afternoon, evening and night time are estimated. The result shows that optimized route obtained by ACO can decrease travel time by 6.12% to 18.37% and delay by 13.64% to 40.91% compare to those of actual route. Night time (7:00-10:00PM) trip requires the lowest travel time and less delay compare to other times of a day, and hence, courier vehicle routing should be scheduled accordingly. The proposed technique in this study can be incorporated with large scale transportation route planning and scheduling.

Keywords: *Courier vehicle, Vehicle routing, Ant Colony Optimization, Travel time, Road network.*

1. INTRODUCTION

Urban traffic condition varies frequently with time and days and traffic congestion suffers both public and freight transportation sector with huge loss of time. Freight transportation agencies always have to aware of congestion to avoid unnecessary delay while delivering goods within congestion-prone city roads. Hence, it is challenging for those agencies to deliver goods timely [1, 2]. Appropriate route selection can save travel time, cut transportation cost and reduce additional delivery time efficiently. One of the essential subset of freight transportation sector is courier service transportation, which delivers parcels, documents and goods to the door-to-door of customers. Our research investigated the existing route for courier vehicle of a courier service agency, which are travelling across some selected courier service point in Dhaka city. Later, we identified the appropriate routes for those vehicle using Ant Colony Optimization (ACO) under different real time traffic conditions.

Meta-heuristic algorithm such as, Ant colony optimization requires less computation time and can solve non-linear large scale complex problem. On contrary, traditional optimization algorithm may trap into local optima in the Non-deterministic polynomial solution space and cannot find global optima quicker. Ant Colony Optimization is a meta-heuristic approach where a set of software agents known as artificial ants are employed to search for suitable solution for a given optimization problem. It is first coined by Marco Dorigo in 1992 to find optimal path for a graphical network [3]. ACO has been widely adopted in travelling salesman problem [4, 5], optimizing vehicle routing time [6, 7], analysis of frame structure [8], bridge inspection routing [9], and reservoir operation [10] and so on. Our proposed problem used ACO to identify suitable route for courier vehicle considering shortest travel time, i.e. fastest route.

Studies on Freight transportation routing draws its own attention because of its significant role in a country's economic development. Some of the researches discussed on rail-road intermodal routing using fuzzy algorithm [11], truck routing using Markov decision method [12], bi-level decision making for freight routing using static equilibrium [13] and multi depot seafood vehicle routing using ACO [14]. Courier service carries letter, package, and messages— is distinguished from typical mailing service for its swift delivery, speed, and security and tracking advantages. Courier service offers expedite delivery of parcels, documents door-to-door, whereas, freight transportation moves goods in bulk. Various types of researches have been conducted for betterment of courier service. Lee and kim [15] investigated the feasibility of electric bicycle for courier in Seoul city. Gulc [16] performed questionnaire survey on service quality assessment of courier service. Syauqi and Zagloel [17] worked on vehicle routing of e-commerce courier service and used genetic algorithm approach to minimize delivery distance and time. Steever et al. [18] studied vehicle routing of food delivery courier service using mixed integer linear programming. Lopez-Santana et al. [19]

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performed scheduling and routing of courier service system using ant colony optimization. Barua [20] adopted support vector machine for alternative route selection.

To our best knowledge, no prior study has been performed on optimizing the courier vehicle routing in context of Dhaka city, Bangladesh. Since, Dhaka is a densely populated metropolitan city and travel time is much unpredictable due to gridlock recurrent traffic congestion. Identifying the fastest route and saving travel time is challenging task for the freight transportation agencies and courier services within the city. Though google map shows the fastest route between two locations (nodes), it fails to find the fastest route in case of trip chain where a route includes multiple locations (nodes). The study identified the fastest routes under different times of day dynamically. Besides, very few systematic researches have been conducted for the performance improvement of courier service of Bangladesh. Meta-heuristic approach, such as, ACO is a latest and promising tool for solving vehicle routing problem which has yet to be explored for the traffic scenarios of Dhaka city.

2. METHODOLOGY

A. Study of road network and data collection

We investigated an existing route of 'Continental Courier Service' covering five locations (nodes, N). N = {n_1, n_2 …n_5}. The locations and vehicle routes are selected for this study by interviewing the courier service personnel. Among the nodes, n_1 is the central depot (hub) and n_2, n_3… n_5 are different courier service points. The nodes represents different courier service point located in Dhaka city such as, Moghbazar (n_1), Farmgate (n_2), Kawran Bazar (n_3), Shegun Bagicha (n_4) and Motijheel(n_5). Each tour of a courier vehicle originated from hub (n_1) and visit each of the nodes once, collecting delivery products and returned to the hub (n_1). Each node is connected to each other with links (l: L| {l_1, l_2… l_n} ∈ L). The sequence of visiting nodes i.e. paths (p: P | {p_1, p_2… p_n} ∈ P) dependent upon the route selection preference of either the driver or courier service agency based on their judgment about existing traffic condition. The driver of the vehicle or the concerned courier service agency tries to select the route (r: R | {r_1, r_2… r_n} ∈ R) among the paths in such a way that the total travel time is minimized. We have collected vehicle travel time for each link under four different times of a day (T) on January 5, 2021 using google map, those are Morning (t_1) (8:00-11:00AM), Afternoon (t_2) (12:00-3:00PM), Evening (t_3) (4:00-7:00PM) and Night (t_4) (7:00-10:00PM), where t: T| {t_1, t_2… t_n} ∈ T. The google map of the nodes and routes are shown in Fig. 1.

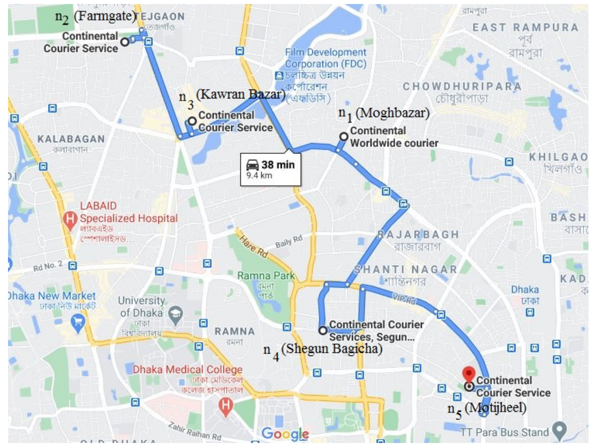

Fig. 1. Google map of study road network showing nodes and vehicle routes

There are number of paths (P), only the path through which vehicle visit the nodes are the route (R⊆ P). We used Ant Colony Optimization to determine fastest route (r_n) for each time of day (t_n).

B. Model formulation

Assume, T is the matrix of travel time of dimension n × n, where n is the node of the road network. In this network n = 5. The elements of T represents the travel time required to travel between pairs of nodes (i, j) where, i, j = 1, 2, … n= 5. The problem statement is formulated as binary traveling salesman problem and the objective is to minimize travel time (Equation 1). The variables are either 0 or 1, based on whether a trip is made from node i to node j (x_{ij} = 1) or not (x_{ij} = 0). Then nodes are assigned to number 1 to n = 5 with the extra variable u_i, so that the numbering correspond to the order of nodes in the entire trip. This will exclude sub-tours and considered only feasible trips, which visits all the nodes starting from hub n =1 node and return back to n = 1. The objective function and constrains of the problem are given as following:

Objective function,

$$z = \text{minimize } \left(\sum_{i=1}^{n} \sum_{j=1}^{n} t_{ij} x_{ij}\right) \qquad (1)$$

Subject to,

$\sum_{i=1}^{n=5} x_{ij} = 1$ j = 1, 2, …. n and i ≠ j

$\sum_{j=1}^{n=5} x_{ij} = 1$ i = 1, 2, ….n and i ≠ j

$u_i - u_j + n\, x_{ij} \leq n-1$ i, j = 2, ….n and i ≠ j

$x_{ij} \in \{0, 1\}$ i, j = 1, 2, ….n and i ≠ j

We solve the above equation (1) with its constrains using code developed [21], calibrated and modified in python v. 3.7. The detail optimization technique of ACO is described in the next section.

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C. Ant Colony Optimization

Ant Colony Optimization (ACO) is a bio-inspired algorithm which is based upon the foods forging behavior of ants. Individual ant has limited capability, weak vision, and limited audio-visual communication and cannot capable to achieve a complex task. However, ants can communicate to each other through laying down a chemical substance, called pheromone on their path as a marker and solve various problems through group work. Ants find the shortest path of food source through depositing pheromone on their path, other ants smell the pheromone and follow the path [4-6].

Similarly, Ants (k) are agents, they move along nodes randomly in the road network starting from hub node (n_0) in the proposed ACO. They choose where to go based on pheromone strength τ^k_{ij} (Equation 2). An ant's path represents a specific candidate solution. When an ant has finished a solution i.e. return back to hub node n_0, pheromone is laid on its path $\Delta\tau^k_{ij}$, according to quality of solution η_{ij}. Pheromone strength is decaying with rate ρ over time and decay rate is less than pheromone deposition rate. We consider ρ = 0.95 in our study. This pheromone trail affects the behavior of other ants. Pheromone trail accumulates with multiple ants using the path. t_k is the travel time required by ant k. Since our problem is a minimization of travel time—inverse of t_k is considered for pheromone deposition rate. If an ant does not follow a path $\Delta\tau^k_{ij} = 0$. Amount of pheromone τ^k_{ij} in a particular path is calculated by summing total pheromone rate $\Delta\tau^k_{ij}$ and considering decay rate using Equation (3). Probability of choosing a path connecting i to j node by ant is p_{ij}, which depends on pheromone deposition and quality of the link of the road network as shown in Equation (4), where α, β are weightage factor usually considered 1. The ants detect lead ant's path and inclined to follow, more pheromone on path increases probability of path being followed [5, 6]. The detail formulation of proposed ACO is presented in the following:

$$\Delta\tau^k_{ij} = \begin{cases} \frac{1}{t_k} \\ 0 \end{cases} \quad (2)$$

Where, $\Delta\tau^k_{ij}$ = amount of pheromone deposited by k-th ant on the link connecting node i and j.

t_k = travel time of the path required to travelled by ant k.

$$\tau^k_{ij} = (1-\rho)\, \tau^k_{ij} + \sum_{k=1}^{m} \Delta\tau^k_{ij} \quad (3)$$

ρ = decay rate

$$p_{ij} = \frac{(\tau_{ij})^{\alpha}(\eta_{ij})^{\beta}}{\sum[(\tau_{ij})^{\alpha}(\eta_{ij})^{\beta}]} \quad (4)$$

p_{ij} = probability of choosing link between i and j.

η_{ij} = quality of ij link on the road network.

3. ANALYSIS AND RESULTS

Travel time required to complete the entire trip of a courier vehicle is measured from google map. Actual route is collected from the interview of the courier service personnel. The optimized routes under different times of a day is calculated using ACO. TABLE I shows time required by a courier vehicle for actual and optimized route under different times of a day. Maximum travel time is at morning peak period during 8:00-11:00AM for both actual (138 minutes) and optimized (119 minutes) routes. Roads within the study road network become very congested due to office and school goers. Traffic in after noon (12:00-3:00PM) and evening (4:00-7:00PM) time are steady and still high. Evening rush hours are not as congested as morning hour because of variation of office and school closing time. Night time (7:00-10:00PM) traffic is little ease from congestion and routing time required for the vehicle is less for both actual (80 minutes) and optimized (70 minutes) routes.

TABLE I: Travel time required in actual and optimized route under different times of a day

Time of Day	Travel time (min), TT	
	Actual route	Optimized route
8:00-11:00AM	138	119
12:00-3:00PM	98	92
4:00-7:00PM	98	80
7:00-10:00PM	80	70
Free flow travel time (FFTT)	54	

Free flow travel time (FFTT) within the road network is collected from the google map. FFTT is the time when there is no congestion and traffic can move freely without any obstruction. If TT_i is the travel time for i-th observation and $FFTT_i$ is the free flow travel time for that i-th observation, then corresponding D_i is

$$D_i = TT_i - FFTT_i \quad (5)$$

Since, traffic in morning time suffer long delay for both actual (84 minutes) and optimized (65 minutes), it is preferred to avoid courier vehicle routing in this time (TABLE II). Most preferred time for courier vehicle routing within the road network is at night time (7:00-10:00PM), where delay is less for both actual (26 minutes) and optimized (16 minutes) routes.

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TABLE II: Delay measured in actual and optimized route under different times of a day

Time of Day	Delay (min), D	
	Actual route	Optimized route
8:00-11:00AM	84	65
12:00-3:00PM	44	38
4:00-7:00PM	44	26
7:00-10:00PM	26	16

Actual route of travel for the courier vehicle is fixed over time and it is $n_1 \rightarrow n_3 \rightarrow n_2 \rightarrow n_4 \rightarrow n_5 \rightarrow n_1$, Where n_1 = Moghbazar, n_2 = Farmgate, n_3 = Kawran Bazar, n_4 = Shegun Bagicha, n_5 = Motijheel. The optimized route obtained using Ant Colony Optimization (ACO) varies over times of day. The route for morning, afternoon and evening time are: $n_1 \rightarrow n_5 \rightarrow n_4 \rightarrow n_2 \rightarrow n_3 \rightarrow n_1$ and the route for night time is: $n_1 \rightarrow n_4 \rightarrow n_5 \rightarrow n_2 \rightarrow n_3 \rightarrow n_1$ (TABLE III).

TABLE III: Actual and Optimized route with respect to different times of a day

Actual Route

	$n_1 \rightarrow n_3 \rightarrow n_2 \rightarrow n_4 \rightarrow n_5 \rightarrow n_1$
Time of Day	**Optimized Route**
8:00-11:00 AM	$n_1 \rightarrow n_5 \rightarrow n_4 \rightarrow n_2 \rightarrow n_3 \rightarrow n_1$
12:00-3:00PM	$n_1 \rightarrow n_5 \rightarrow n_4 \rightarrow n_2 \rightarrow n_3 \rightarrow n_1$
4:00-7:00PM	$n_1 \rightarrow n_5 \rightarrow n_4 \rightarrow n_2 \rightarrow n_3 \rightarrow n_1$
7:00-10:00 PM	$n_1 \rightarrow n_4 \rightarrow n_5 \rightarrow n_2 \rightarrow n_3 \rightarrow n_1$

The study found that, optimized route decreased travel time by 13.77% (Morning time), 6.12% (Afternoon time), 18.57% (Evening time) and 12.50% (Night time) compare to those of actual route. Similarly, optimized route reduced delay by 22.62% (Morning time), 13.64% (Afternoon time), 40.91% (Evening time) and 38.46% (Night time) compare to those of actual route. Maximum %decrease in travel time and delay were found at Evening time, which were 18.57% and 40.91% respectively.

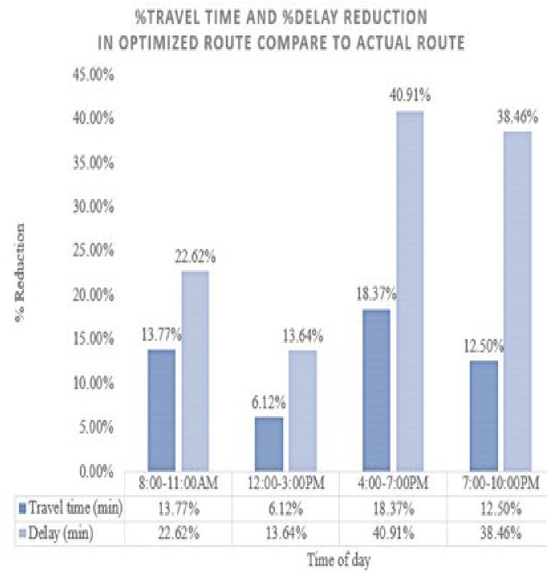

Fig. 2. %Reduction of Travel time and Delay in optimized route compare to those of actual route under different times of a day

4. CONCLUSION

Existing GPS apps and google map cannot optimize travel time in case of trip chain consist with numbers of origin (O)-destination (D) nodes, those can only identify fastest route in-between pair of origin-destination node. Meta-heuristic algorithm, such as, ACO can efficiently solve the problem of origin-destination (OD) matrix and identify the fastest route avoiding congestion. This approach can save valuable travel time of vehicle routing, increase productivity, efficiency for courier vehicle. Again, travel time is closely related with fuel consumption and vehicle operating cost (VOC). Therefore, our proposed technique can cut fuel consumption and VOC directly.

The proposed Ant Colony Optimization (ACO) technique can be implemented for large scale route optimization problem with large size of OD matrix. The study can be extended for different types of e-commerce delivery services, ride share and logistics of transportation agencies. Besides, it can also be tested for different cities considering various traffic scenarios and driving behavior so that the effectiveness of ACO can measured. Including traffic composition, density and speed limit with the future study will produce valuable information. In addition, the Actual travel time can be collected from interviews- which reflects a perceived average time by the drivers for each leg of the tour not the actual

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one. The study did not collect travel log of the courier vehicle directly, which again may not be available in the scenario of Bangladesh. Performance evaluation among other meta-heuristic approaches, such as, genetic algorithm, simulation annealing and particle swarm optimization can be performed for further study.

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