International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 6 Issue 5, July-August 2022 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Intelligent Traffic Management System using Shortest Path

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ABSTRACT

Due to current significant increases in population and consequently in traffic congestion in most metropolitan cities in the world, designing of an intelligent traffic management system (ITMS) in order to detect the path with the shortest travel time is critical for emergency, health, and courier services. The aim of this research study was to develop a theoretical traffic detection system and capable of estimating the travel time associated with each street segment based on the traffic data updated every 20 seconds, which successively finds the path with the shortest travel time in the network by using a dynamic programming technique. Furthermore, in this study we model the travel time associated with each street segment based on the historical and real time data considering that the traffic speed on each road segment is piecewise constant. It would be useful to implement such algorithms in GIS systems such as Google map in such a way that the service delivery drivers can avoid congested routes by receiving real time traffic information.

KEYWORDS: *IoT, GPS, GIS, ITMS*

How to cite this paper: Bharti Kumari | Vinod Mahor "Intelligent Traffic Management System using Shortest Path" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-6 | Issue-5, August 2022, pp.1126-1132, URL: www.ijtsrd.com/papers/ijtsrd50598.pdf

IJTSRD50598

I. INTRODUCTION

Congestion is particularly associated with motorization and the diffusion of the automobile, which has increased the demand for transportation infrastructure as population has increased. However, the supply of the transportation infrastructure has often not been able to keep up with the growth of mobility.

Problems which are generated by traffic congestion consist of incremental delay, vehicle operating costs such as fuel consumption, pollution emissions and stress that result from interference among vehicles in the traffic stream, particularly as traffic volumes approach a road's capacity. Across the India, more people are spending more time sitting in traffic jams than ever before [1].

Traffic congestion occurs when the demand is greater than the available road capacity. There are many reasons that cause congestion; most of them reduce the capacity of the road at a given point or over a certain length, for example people parking on the roads or increase in the number of vehicles. As shown in Table 1.1, below the Federal Highway Administration, [2] mentioned that about half of Indian traffic congestion is recurring,

Table 1.1 The causes of traffic jams

Bottlenecks	40% of total congestion
Traffic Incidents	25% of total congestion
Work zones	10% of total congestion
Bad weather	15% of total congestion
Poor signal timing	5% of total congestion
Special events/Other	5% of total congestion

and is attributed to sheer volume of traffic; most of the rest depends on crashes, road construction works and severe weather events. Consequently, all of these factors affect our communities both mentally as well as economically. The Ohio Department of Transportation (2009) reported that traffic congestion prevents Honda's employees from arriving on time which may threaten Honda's low-inventory strategy in Ohio. There are always concerns that traffic congestion may delay emergency vehicles during critical moments when they need to arrive at the scenes as quickly as possible [3].

A. Data Collection Techniques

According to the Federal Highway Administration [4], the travel time data collection techniques can be categorized into the following groups:

Test vehicle technique: in this technique an observer records cumulative travel time at predefined checkpoints along a travel route, then this information can be converted to travel time, speed for each segment along the proposed route. In this technique it is not possible to store a large amount of data. In addition, it requires quality control considering that it is associated with human or electric errors.

License plate matching technique: in this method the plate numbers and arrival times will be recorded at various checkpoints, and finally the travel times will be computed by matching the license plate numbers or from the difference in arrival times. This method allows us to obtain travel times from a large sample of motorists, and it is possible to find out the variability of travel times among vehicles within the traffic stream. Furthermore, it is possible to transport data collection equipment between observation sites. However the travel time data is only available to the area where video cameras are installed.

Emerging technique: this technique estimates travel times by using a variety of methods, such as inductance loops, weigh-in-motion stations or aerial video. Some of the methods used in this technique are still in testing stages.

B. Objectives of Study

Developing a new system such as an intelligent traffic management system in order to reduce traffic problems is essential. The objectives of this study are three-fold:

Developing traffic detection and estimation of traffic mean speeds and travel times associated with each street segment based on the data provided by traffic detectors; Identifying specific zones in which all possible (or reasonable) routes are located (classification method and defining a coordinate system); and Designing of a route-finding algorithm.

C. Organization of Research

The rest of this research is organized as follows. Chapter 2 gives overview about literature review on previous research studies concerning with shortest path finding problems. Chapter 3 provides a description of the timetable and speed table updating system and the mathematical formulation of the dynamic programming and travel time modeling. Chapter 4 gives details about the results analysis example. Finally, Chapter 5 conclusions.

II. LITERATURE REVIEW

Shortest path finding using dynamic method problems are a subset of dynamic transportation problems including dynamic traffic assignment and dynamic fleet management. “dynamic” here can be referred with “online” or “real-time,” which means the problem-related solutions are time-dependent and occurring in real time basis. A shortest path problem is a problem of finding the shortest path from one source point to every other node in a directed graph in which each link has a particular weight. Every node and link stands for street intersection and road segment respectively. split the shortest path algorithms into the following three groups[5].

1. In a network provided, finding the shortest path from a particular point to every other node.
2. In a network provided, Finding the shortest path between all pairs of the nodes.
3. Finding the short path between two particular nodes. This group is the most popular in the transportation area.

A. Shortest Path Problem

In the last few years, some research efforts have focused on developing different algorithms for Dynamic Vehicle Routing Problems (DVRPs); many of these applications can be found in practice, for example dial-a-ride systems for transportation-on-demand, courier services, emergency services, pick-up and delivery of goods, and many others.

As a pioneering work, [6]developed a model for stochastic and dynamic vehicle routing with a single vehicle, traveling at a constant velocity in its region of service, whose time of arrival, location and on-site service are stochastic. The objective was to find a policy to determine service demands over an infinite horizon that minimizes the expected system time, however a challenging problem in a different direction is to investigate dynamic routing in a network environment rather than under some Euclidean metric.

developed an algorithm for a pick-up and delivery problem in which vehicles travel at a constant velocity in regard to new request locations that uses heuristic and numerical calculations to minimize the expected system time[7]. Their numerical results show the benefits of such techniques in real-time situation [8].

Comprehensive planning strategy for dynamic routing of traffic in a city. They proposed a routing system, which uses a routing algorithm based on the ant colony optimization algorithm. This algorithm follows the behavior of living ants that lay pheromone trail on the ground in order to find shortest way from the nest toward the food location. In their proposed model pheromone is a time function related to the vehicles that travel across the networks. The time function can be affected by congestion. Each node has a probability table in which there are entries for each neighboring node that can be reached via one connecting link, therefore the probabilities influence the driver's selection of the next route. Each time the driver will be notified about next route (node) and this process is repeated until the driver reaches his destination [9].

[8] presented an adaptive fastest path algorithm based on the (1) hierarchy of roads, (2) path segments on which travelling monitored frequently, and (3) significant speed advantage. Major roads are more preferable than minor roads except if there are minor roads with significant speeds over the major ones. They defined different speed patterns for various conditions such as time of day, weather or vehicle type. They employed A* algorithm to find the shortest path. A* is a shortest path finding algorithm that uses a best-first search algorithm to find the least-cost path from a given initial node to one destination node.

III. PROBLEM FORMULATION

Traffic Detection

The ultimate objective of this research is to develop a comprehensive system to route the traffic in an urbanized area. The development of this system stems from the combination of two distinctive sections namely traffic detection and routing system [10]. The typical work flow is depicted in Figure 3.1.

In order to route the traffic within a city, it is required to access dynamic data that shows traffic flow condition using detectors located in all possible routes within a street network [11].

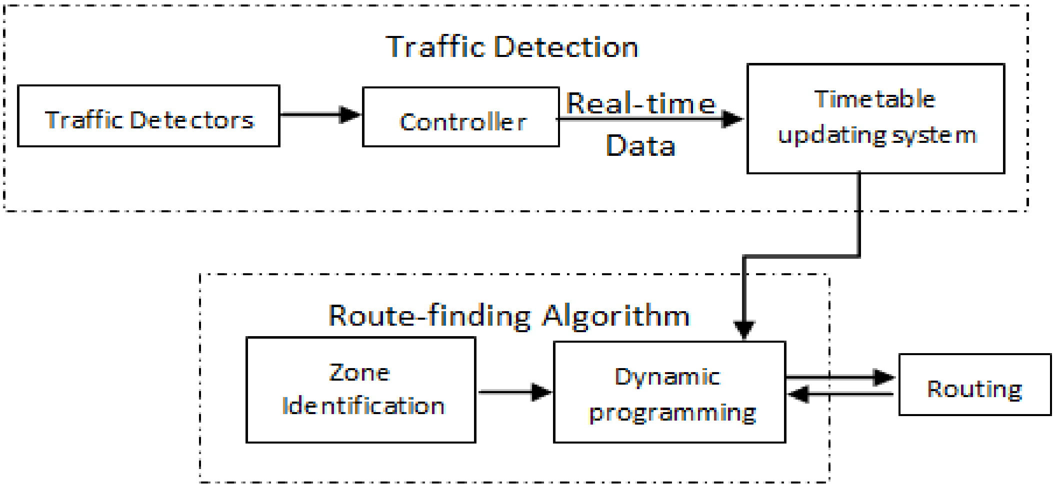

Figure 3.1 Work flow of a typical detection and routing system

According to the Federal Highway Administration there are different forms of traffic detectors that include:

- Inductive Loop Detection System: The loop detector forms a tuned electrical circuit of which the loop wire is the inductive element. When a vehicle passes over the loop, it results in a decrease in loop inductance. The detector senses the change in inductance and causes the electronics unit to send a pulse to the controller, indicating the presence or passage of a vehicle.
- Video Image Processing System: It allows the user to define a limited number of linear detection zones on the roadway in the field-of-view of the video camera. When a vehicle crosses one of these zones, it is identified by noting changes in the properties of the affected pixels relative to their state in the absence of a vehicle. it estimates vehicle speed and then measure the time that an identified vehicle needs to traverse a detection zone of known length.
- Microwave Radar Based Traffic Detection System: It transmits energy toward an area of a roadway and when a vehicle crosses the roadway, a portion of the transmitted energy is reflected back toward the receiver and consequently it calculates volume, speed, vehicle length and occupancy.
- GPS-Based Vehicle Tracking System: A GPS data logger can be used to collect a vehicle's position data periodically. Typically, a GPS data logger comprises of three parts: data storage media, GPS receivers, and power supply devices
- Acoustic Traffic Detection System: it measures vehicle passage, presence, and speed by detecting acoustic energy or audible sounds produced by vehicular traffic from a variety of sources within each vehicle and from the interaction of a vehicle tires with the road.
- Infrared Traffic Detection System: it detects the changes of temperature due to vehicle presence.

- Magnetic traffic detection system: magnetic sensors are passive devices that detect the changes in magnetic field due to presence of a metal object.

All of the above mentioned detector systems can provide both the number of vehicles (volume) and speed of each vehicle in order to calculate the time each vehicle needs to cover a particular route. Currently, loop detectors are still the dominant detectors in use, because they have been commodity-priced while the alternative detectors have not due to the short history of these detectors [12-14] Hence in this research study it is assumed that inductance loop detectors are installed on each street segment. The components of a loop detector shown in Figure 3.2 are as follows:

- One or more turns of insulated loop wire wound in a shallow slot sawed in the pavement.
- A lead-in cable from the curbside pull box to the controller cabinet.
- A detector electronic unit (DEU) housed in the controller[15].

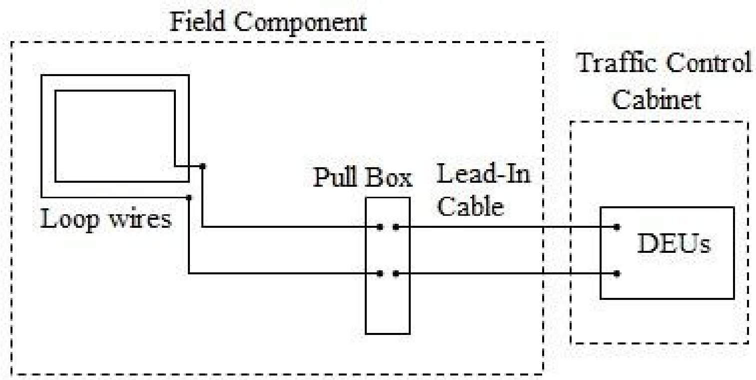

Figure 3.2 The components of a loop detector

An inductance loop detector will measure two important parameters for each 20 seconds time interval, namely:

- Occupancy; proportion of time during which the loop is occupied by a vehicle, (sec)
- Number of vehicles entering (I) or exiting (E) a street segment, (Veh/20 sec/ln)

Let's consider a model in which the average traffic speed associated with each street segment, $L(i,j)$ can be measured every 20 seconds and it is assumed that traffic detectors measure the number of vehicles every day for 24 hours continuously.

Let D(i,,j,tk) be density or the number of vehicles on street segment, L(i,j), also let I(i,,j,tk) and E(i,,j,tk) be the number of vehicles (observed volumes), entering and exiting the street segment during time slot Δtk=tk - tk-1 respectively[9]. Now if we assume that there is no vehicle on each street segment at t = t0, the number of vehicles during a defined time slot Δtk = 20 seconds can be given as follows:

$\Delta t_1 = (t_1 - t_0) = 20 \text{ sec. } ; D(i,j,t_1) = I(i,j,t_1) - E(i,j,t_1),\ I(i,j,t_1) \geq E(i,j,t_1)$

$\Delta t_2 = (t_2 - t_1) = 20 \text{ sec. } ; D(i,j,t_2) = D(i,j,t_1) + I(i,j,t_2) - E(i,j,t_2),\ D(i,j,t_2) + I(i,j,t_2) \geq E_2(i,j,t_2)$

$\Delta t_k = (t_k - t_{k-1}) = 20 \text{ sec. } ; D(i,j,t_k) = D(i,j,t_{k-1}) + I(i,j,t_k) - E(i,j,t_k),\ D(i,j,t_{k-1}) + I(i,j,t_k) \geq E(i,j,t_k)$

Hence the average traffic speed $S(i,j,t_k)$ on each street segment at time t_k can be expressed as shown in Equation 3.1:

$$S(i,j,t_k) = S_f(i,j) * \left(1 - \frac{D(i,j,t_k)}{J(i,j)}\right) \qquad (3.1)$$

Where:
J (i,j) = Jam density on street segment i, j, Veh/L(i,j)
S_f (i,j) = Speed limit on street segment i, j, mi/h
Consequently the needed time to cover the street segment $L(i,j)$ can be defined by Equations 3.2:

$$T(i,j,t_k) = \begin{cases} \dfrac{L(i,j)}{S(i,j,t_k)}, & D(i,j,t_k) \neq 0 \\[2ex] \dfrac{L(i,j)}{S_f(i,j)}, & D(i,j,t_k) = 0 \end{cases}$$

Where:
t_k= the time at which the latest time table has been created
T (i,j,t_k) = Average travel time on street segment i,j at time slot Δt_k
S (i,j,t_k) = Traffic mean speed on street segment i,j at time slot Δt_k, mi/h
L(i,j) = Length of street segment i,j, miles

IV. RESULTS ANALYSIS

A simulation process has been designed for the proposed route finding algorithm, which can represent the shortest path and estimated travel time [16-17]. Let's consider a shortest path problem for our proposed network shown in Figure 4.1, within this network the origin destination (OD) pair (1,5) is considered and it is assumed that a driver is at point 1 at time u1 =11:30:1

From the network it can be seen that 2 paths exist between nodes 1 and 5 if R = 0; these are listed in Table 4.1. The characteristics of the links are listed in Table 4.2.

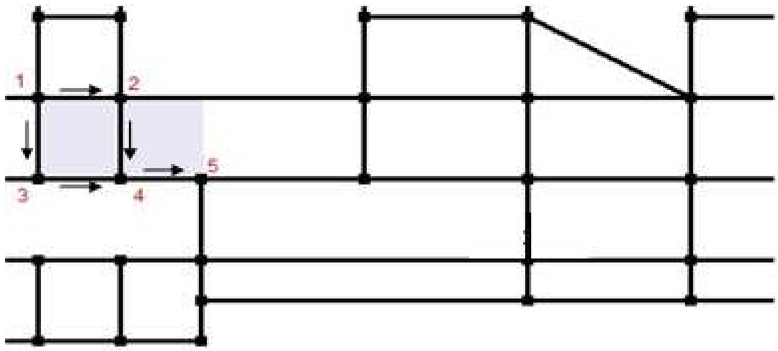

Figure 4.1 Proposed street network

Table 4.1 List of paths of OD pair (1,5)

Path	1	2
Node	1-2-4-5	1-3-4-5

Table 4.2 Network characteristics

Link	Length, *L (meters)*	Jam Density, *J (Veh/500 meters)*	Speed limit, S_f	Adjustment Factor, λ
1-2	500	20	35 *mi/hr* ≈16 *m/sec.*	0.9
1-3	500	20	35 *mi/hr* ≈16 *m/sec.*	0.5
2-4	500	20	35 *mi/hr* ≈16 *m/sec.*	0.8
3-4	500	20	35 *mi/hr* ≈16 *m/sec.*	1
4-5	500	20	35 *mi/hr* ≈16 *m/sec.*	1.3

Table 4.3 Observed data at different times

t_1 = 11:30:00
Observed Density at 11:30:00 Speedtable created at 11:30:00 Timetable created at 11:30:00

Node	1	2	3	4	5
1	-	5	3	-	-
2	-	-	-	6	-
3	-	-	-	4	-
4	-	-	-	-	7
5	-	-	-	-	-

Node	1	2	3	4	5
1	∞	11	13	0	0
2	0	∞	0	11	0
3	0	0	∞	12	0
4	0	0	0	∞	10
5	0	0	0	0	∞

Node	1	2	3	4	5
1	0	0.74	0.65	∞	∞
2	∞	0	∞	0.79	∞
3	∞	∞	0	0.69	∞
4	∞	∞	∞	0	0.85
5	∞	∞	∞	∞	0

t2 = 11:30:20
Observed Density at 11:30:20 Speedtable created at 11:30:20 Timetable created at 11:30:20

Node	1	2	3	4	5
1	-	3	4	-	-
2	-	-	-	2	-
3	-	-	-	7	-
4	-	-	-	-	5
5	-	-	-	-	-

Node	1	2	3	4	5
1	∞	13	12	0	0
2	0	∞	0	14	0
3	0	0	∞	10	0
4	0	0	0	∞	11
5	0	0	0	0	∞

Node	1	2	3	4	5
1	0	0.7	0.7	∞	∞
2	∞	0	∞	0.6	∞
3	∞	∞	0	0.9	∞
4	∞	∞	∞	0	0.7
5	∞	∞	∞	∞	0

V. CONCLUSIONS

This research presented a new method for dynamic vehicle routing in order to find the shortest path using real time data and historical data collected from traffic detectors installed in all street segments. The raw data provided by these detectors is transferred to the control unit, which converts them into traffic mean speeds and needed travel time to traverse each street segment. For this purpose speed tables and timetables are used to store traffic mean speeds and traffic mean travel times during each time slot. Furthermore, the position of each node is defined in a local and Cartesian coordinate system, which allows the zone identification and node selection algorithm to look for the desired nodes between the source and destination points which reduces the data size and speed up the process of finding the shortest path or extend the area that encompasses the source and destination points to take into account more nodes.

In this study the solving strategy is based on the dynamic programming, which takes care of the speedtable and timetable updating system to find the shortest path among possible alternatives, by considering each node toward the destination only once.

In this study two different models have been developed based on different decision criteria:

- Finding the shortest path based on the real time data collected from the street network.
- Finding the shortest path using travel time modeling method based on historical and real time data that incorporates both concepts of short-term travel time forecasting and shortest path finding. Therefore, this research effort opens many interesting and practical issues for future work.

Finally, such algorithms can be implemented in GIS systems such as Google map in order to help commercial sectors move goods and services quickly or to better and efficiently link health and human service providers with users/customers.

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