

Analysis of Fastest and Shortest Paths in an Urban City Using Live Vehicle Data from a Vehicle-to-Infrastructure Architecture

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Abstract – In this paper, I perform an analysis of the time to traverse different paths from a source to a destination in an urban city based on data gathered by a vehicle-to-infrastructure (V2I) intelligent transportation system (ITS) architecture. Vehicle tracking devices have been installed in 15 vehicles that frequent the University of Alaska, Anchorage on a daily basis. This data has been analyzed using FreeSim (<http://www.freewaysimulator.com>) to determine the fastest path from the university to a destination in downtown Anchorage, which is on the other side of the city. During the period of this research, two vehicles departed from the university to the destination along the fastest path and shortest path, respectively, each day of the week at 5:00p.m. to determine the actual amount of time to traverse each path. The fastest path traversed proved to be faster than the shortest path 67% of the time, and the calculated fastest path proved to be faster than the shortest path 84% of the time. I provide an analysis of these paths and give reasons as to why the fastest path was not always faster than the shortest path.

I. INTRODUCTION

Many intelligent transportation system (ITS) applications being developed assume that they will have access to individual vehicle location, speed, and direction data. Since this data is not widely available, many applications operate on generated data or attempt to convert discrete data (such as data gathered at loop detectors) to continuous-flow data. To gather data from individual vehicles, different architectures have been proposed, including vehicle-to-infrastructure (V2I), vehicle-to-vehicle (V2V), and vehicle-to-vehicle-to-infrastructure (V2V2I) [1]. In a V2I architecture, vehicles transmit their speed, location, and direction data through some roadway infrastructure to a central computing facility. From this data, a representation of the roadway network can be determined, and ITS applications can use this data for different purposes.

Many ITS applications have been proposed and are being tested, such as incident identification, collision avoidance, congestion improvement, driver alertness alarms, and fastest routing of individual vehicles, among other applications. Determining the fastest path from a vehicle's current location to its desired destination is one application that has been attempted using discrete data gathering technologies, such as loop detectors [2]. Using a continuous flow of data, such as that gathered by vehicle tracking devices that report speed, location, and direction for individual vehicles through a V2I architecture, the fastest paths for vehicles can be more

accurately determined. Fastest path algorithms have been developed by using speed as the weight of an edge, then adapting existing shortest path algorithms. Dynamic fastest path algorithms have also been created, which assume the weights of the edges are changing frequently, including adding or removing edges. Dynamic fastest path algorithms applied to intelligent transportation systems are covered in [3], as well as a description of other fastest path and dynamic fastest path algorithms.

Although these algorithms have been proposed and tested in a simulated environment, they have not yet been tested in a live environment with real data gathered through a pure V2I network. In [4], the data was gathered from loop detectors and smoothed to appear as continuous, though very little work has been conducted on live distributed data. The VATSIM traffic emulator [27] models a continuous flow of data since the vehicles in the application change speeds using algorithms based on the vehicles surrounding them, though live data is not currently used

In Anchorage, there are currently 15 vehicles containing tracking devices that transmit speed, location, and direction data to a central server. This data can be used to determine the fastest path from a vehicle's current location to its desired destination. Although 15 vehicles are not enough to determine the flow of traffic on all streets within the city of Anchorage, the vehicles that contain the devices frequent the University of Alaska, Anchorage, so the traffic conditions are relatively accurate around the university at the times the vehicles are commuting (generally between 7:30a.m.-8:30a.m. and 4:30p.m.-5:30p.m.). For this research, the afternoon rush hour was studied. Out of the 15 vehicles being tracked, 13 of them were able to travel along any path desired, and the remaining two vehicles were required to travel from the university to a predefined destination across the city. One of the vehicles took the shortest path each day and the other took the fastest path as determined by current traffic conditions and historical data from the same day of the week for the previous four weeks. The results are presented in this paper, organized as follows. Section II contains a brief description of related work. Section III explains the devices that were installed in vehicles and the vehicles into which they were installed. Section IV provides an analysis of the data that was gathered as related to fastest paths and the paths that were taken, and the conclusion is provided in section V.

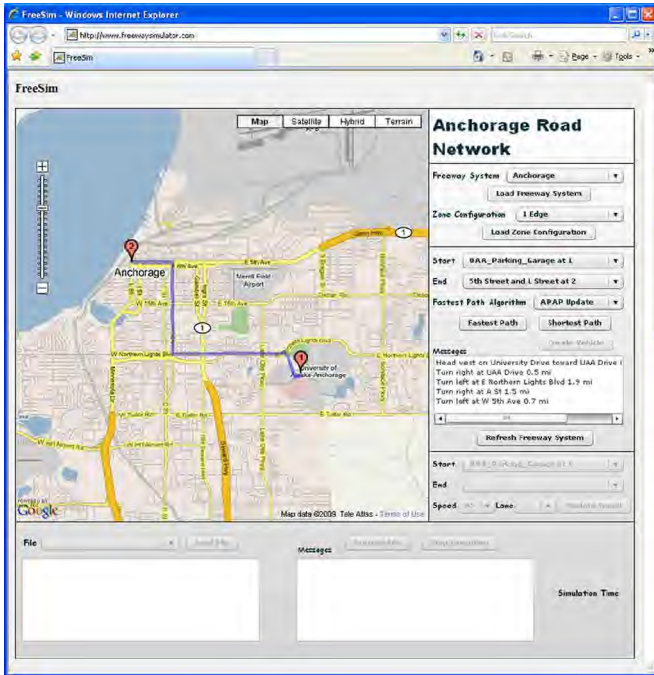
II. RELATED WORK

Vehicle-to-vehicle (V2V) [5] and vehicle-to-infrastructure (V2I) [6] intelligent transportation system

TABLE I. AVERAGE AMOUNT OF TIME TO TRAVERSE SHORTEST AND FASTEST PATHS ON EACH DAY OF THE WEEK BETWEEN OCTOBER AND DECEMBER 2008

Day of Week	Actual Time to Traverse Shortest Path	Calculated Time to Traverse Fastest Path	Actual Time to Traverse Fastest Path
Monday	17:32	15:06	15:32
Tuesday	17:16	15:05	15:39
Wednesday	17:37	16:18	17:05
Thursday	18:05	17:04	17:42
Friday	18:10	16:27	17:28

FIGURE I. FREESIM SCREENSHOT WITH SHORTEST PATH FROM SOURCE TO DESTINATION



architectures have been extensively studied recently. The two architectures were combined into the vehicle-to-vehicle-to-infrastructure (V2V2I) architecture in [1], and vehicular ad-hoc networks (VANETs) are beginning to be implemented in research groups [7]. In [8], the authors propose a way of determining speed from loop detector data by estimating the average length of a vehicle, and this technique is widely used by departments of transportation.

Using continuous vehicle data, incident identification, trip planning [9], characterization of traffic flows [10], and traffic prediction [11, 12] applications have been proposed. Many traffic simulators exist that attempt to allow researchers to test their algorithms and traffic planning applications on simulated data. FreeSim [13-15] is one simulator that does this, though the manner in which data is entered into FreeSim can be discrete or continuous, simulated or real, offline or real-time. An overview of simulators, including FreeSim, is provided in [15]. For the analysis performed in this paper, FreeSim was used.

Shortest path algorithms in graphs have been studied for many years, with popular algorithms from Dijkstra [16], Bellman-Ford [17, 18], and Johnson [19]. Dynamic shortest path algorithms (which are used for graphs that have constantly updating edge weights, including adding and removing edges) have been studied by Demetrescu and Italiano [20], as well as Miller and Horowitz [3], who took

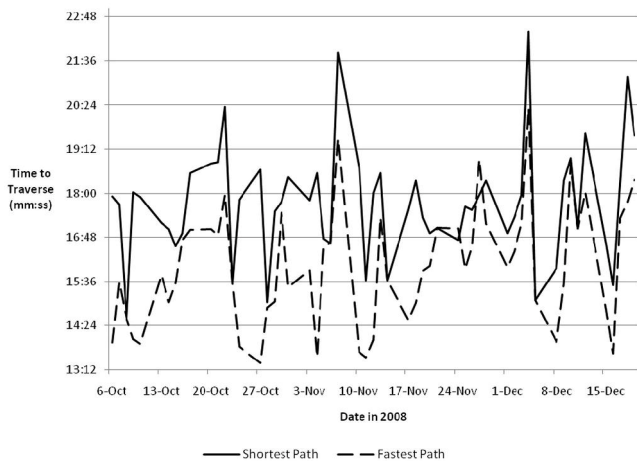
dynamic shortest path algorithms to the transportation sector. Changing the weights on the edges to represent speed will allow any of these algorithms to be used to calculate fastest paths instead of shortest paths.

With all of these algorithms and applications, the data used was either gathered at discrete locations (from devices such as loop detectors or video cameras) or the data was simulated to be continuous. More recent projects, such as MIT's CarTel [21] and UC Berkeley's Mobile Millennium [22] projects, are gathering data in a distributed manner from cellular phones, though no data has yet been published from these projects. Further, there is an additional challenge of trying to determine if the cellular device is actually located within a vehicle when it is transmitting the speed and location. A company called Airsage [23] has attempted a similar project in the Washington DC area. At the University of Alaska, Anchorage, the vehicles have dedicated vehicle-tracking devices installed, so there is no issue in determining which devices are communicating from vehicles. In addition, it is possible to strategically place the devices in vehicles that cover the city on a daily basis and minimize the amount of data necessary to be transmitted to a central infrastructure to maintain an accurate representation of the transportation network.

III. VEHICLE TRACKING OVERVIEW

To ensure the data received by the central server contained accurate speed, location, and direction data from a vehicle while the vehicle was moving, individual vehicle-tracking devices were installed in 15 vehicles. The RTV5 tracking devices from Live View GPS [24] are being used, which contain GPS receivers and cellular transmitting and receiving antennas. The device transmits a unique identifier, speed, location, direction, ignition status, and the number of GPS satellites that are in view. If there are fewer than four GPS satellites in view, the data is not transmitted as there is a high probability of inaccurate location data at that point. Over a cellular link, this data is transmitted every 10 seconds (though this can be configured to communicate every five seconds or one second) to a central server, where it is stored in a database. If the device is unable to communicate over the cellular link, the data will be buffered until it can be transmitted. The data is exposed via a web site offered by Live View GPS using Microsoft Virtual Earth [25], and for the purposes of this study, the data is also fed directly into FreeSim, which is used for the simulation and to determine fastest paths at different times using current and historical data. FreeSim's interface uses Google Maps [26] to show the paths and the locations of all of the vehicles that contain the

GRAPH I. ACTUAL TIME TO TRAVERSE SHORTEST AND FASTEST PATH



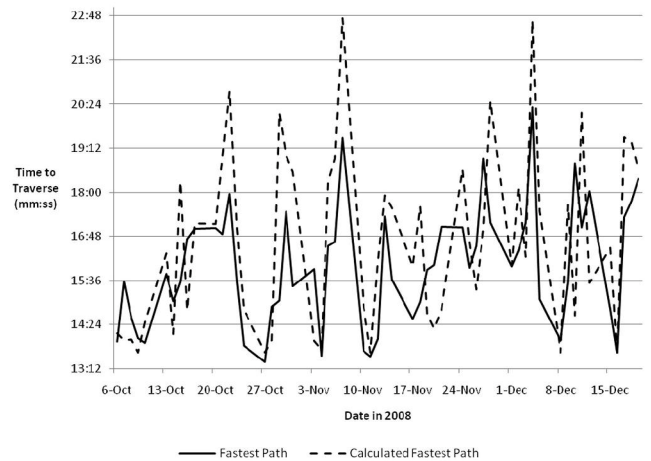
tracking devices. A screenshot of the FreeSim interface is provided in Figure I.

Since 15 vehicles are not enough to fully cover the city of Anchorage and provide speed data for the entire transportation network at all times of the day, the vehicles that contain the devices were strategically chosen as ones that frequent the University of Alaska, Anchorage and travel across the city around 5:00p.m. each weekday. The shortest path, including the source node and destination node, is provided in Figure I. The shortest path is 4.6 miles and takes 13 minutes and 39 seconds at speed limit with no traffic and average delays at traffic signals. Thirteen of the vehicles did not have any limitations on the directions they were required to drive. One of the remaining vehicles always had to traverse the shortest path from the source to destination, and the other remaining vehicle had to traverse the fastest path each day. The fastest path was calculated by taking the vehicle data from the past four weeks for that specific day of the week at 5:00p.m., as well as the data that was already reported for the current day by the other vehicles. For example, to determine the fastest path for Monday, December 22, 2008, the vehicle data from November 24, December 1, December 8, and December 15 were averaged together, then weighted with the current data for December 22. The fastest path was determined immediately before the vehicle left the university, which was at 5:00p.m. each weekday. The fastest path vehicle would then take that fastest path, with the actual amount of time to traverse the path tracked by the vehicle-tracking device and reported through the V2I architecture to the central server. The shortest path vehicle also contained a vehicle-tracking device that reported the actual amount of time to traverse the path it took through the V2I architecture to the central server. The following section contains an analysis of this data.

IV. FASTEST VERSUS SHORTEST PATH ANALYSIS

Figure I shows the source and destination points that are used in the fastest and shortest path computations for this study. With only 15 vehicles currently installed with vehicle-tracking devices, if there was no data for a specific section of

GRAPH II. ACTUAL TIME TO TRAVERSE CALCULATED FASTEST PATH VERSUS CALCULATED TIME TO TRAVERSE FASTEST PATH

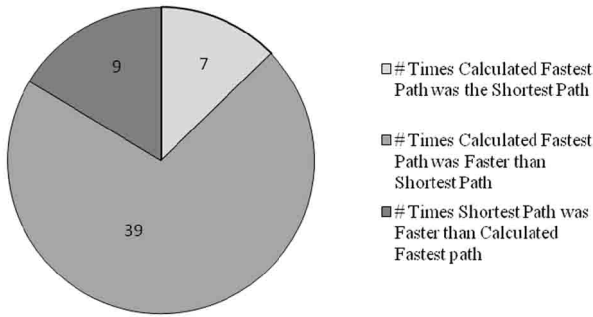


the roadway, the speed limit was used. Only roads with a speed limit of more than 35 miles per hour were included, since those are the main roads used by most vehicles, including those containing the tracking devices. Because of this, there were 10 reasonable paths that a vehicle could have taken to traverse from the source to the destination, which use a combination of the main arterial roads provided in Figure I. The data gathered was from October 2008 through December 2008. The average travel times for each day of the week at 5:00p.m. for the actual shortest path, actual fastest path, and calculated fastest path are provided in Table I. As can be seen, over time, the calculated average amount of time to traverse the fastest path is relatively close to the actual amount of time to traverse the fastest path, and the actual amount of time to traverse the fastest path is less than or equal to the actual amount of time to traverse the shortest path. At speed limit with average delays for traffic signals, the 4.6 mile shortest path would take 13 minutes 39 seconds.

Graph I shows, for each day, the actual amount of time to traverse the shortest path compared to the actual amount of time to traverse the fastest path. The fastest path was determined before the vehicle left the source, which could explain why the fastest path is not always faster than the shortest path. The actual driving conditions could have changed while the vehicle was traversing what was determined to be the fastest path before the vehicle left. As more vehicles are equipped with tracking devices, the transportation network will be more accurately represented as well. However, the computed fastest path is actually faster than the shortest path 84% of the time and faster or the same as the shortest path 96% of the time. These percentages show that even with a small number of vehicles being tracked, strategically placing the vehicle tracking devices can allow a significant savings in commute times to be experienced.

Graph II shows the amount of time that was calculated for the fastest path compared to the actual amount of time to traverse it. Although accurate on some days, other days show that the driving conditions changed substantially before the vehicle traversed the path. Incremental updates provided to the vehicles could further decrease the amount of time to traverse the fastest path, though the actual amount of time to traverse the path is still dependent on traffic conditions.

FIGURE II. COMPARISON OF CALCULATED FASTEST PATH TO SHORTEST PATH TIMES



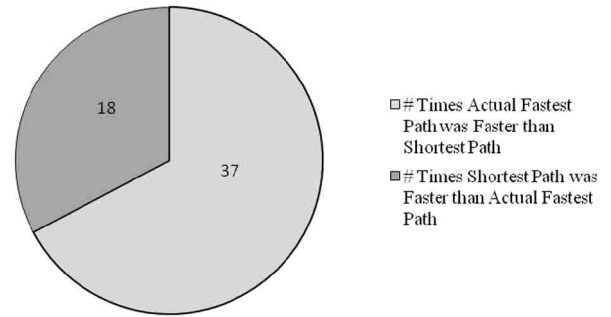
Out of the 55 days used in this study, Figures II and III relate the amount of time to traverse the fastest path, the calculated fastest path, and the shortest path to each other. Figure II compares the amount of time to traverse the calculated fastest path to the shortest path, showing that it was faster than the shortest path 39 times and the same as the shortest path 9 times. Only 7 out of the 55 days showed the shortest path as being faster than the calculated fastest path.

This can be explained by realizing that the traffic conditions along the paths could have changed after the fastest path was calculated. Figure III shows that the fastest path was faster than the shortest path 37 times, and the shortest path was faster than the fastest path 18 times. In both of these cases, having incremental updates sent to the drivers during their trips would aid in improving this inaccuracy.

V. CONCLUSION

This study is one of the first to use live distributed data as gathered through a V2I architecture to analyze traffic flow. The data was gathered from 15 vehicles in the Anchorage area that frequent the University of Alaska, Anchorage on a daily basis. Each weekday around 5:00p.m., the vehicles depart from the university. Thirteen of the vehicles had no restrictions on their paths. One of the remaining vehicles traveled along the shortest path from the university to a destination in downtown Anchorage. The other vehicle traveled along the fastest path from the university to the same location in downtown. The fastest path was calculated using current data and historical data for the same day of the week in the previous four weeks. With only 15 vehicles containing tracking devices, if there was no data for a specific section of the transportation network, the speed limit of the road was used. This may have provided inaccurate data since some of the roads each day did not contain any data from one of the 15 vehicles. Further, the vehicle traversing the calculated fastest path was not receiving incremental updates in the middle of the commute, so if the fastest path changed based on changing traffic conditions, the vehicle traversing the calculated fastest path was not alerted to the change. Even with these two potential problems in calculating the fastest path, the results of this study were quite positive. The calculated fastest path actually took less time or the same amount of time as the shortest path 96% of the time, and the

FIGURE III. COMPARISON OF FASTEST PATH TO SHORTEST PATH TIMES



fastest path took less time than the shortest path 84% of the time.

I am currently in the process of installing vehicle tracking devices in more vehicles in the Anchorage area. I am also communicating with vehicle fleet organizations that already have tracking devices installed, such as delivery companies, taxi fleets, buses, and emergency response organizations. With more vehicles reporting speed, location, and direction data, the fastest paths will be much more accurate. In addition, I am already working on an application to report fastest paths to vehicles while in transit based on their current locations, which will account for changing traffic conditions while vehicles are in route.

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