# Analysis of Vehicle Lane Changes for Determining Fastest Paths in the V2V2I ITS Architecture

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*Abstract* – **In this paper I perform an analysis of vehicle lane changes and how they relate to fastest path determination. I converted live discrete loop detector data from the California Department of Transportation into continuous data to be utilized by vehicles in a vehicle-to-vehicle-to-infrastructure (V2V2I) intelligent transportation system (ITS) architecture. The continuous data was then used by FreeSim (http://www.freewaysimulator.com) to simulate live traffic conditions. As the time to traverse the edges in the transportation network were being constantly updated, additional vehicles were inserted into the network to determine travel times and fastest paths from a source node to a destination node. The output shows that faster and more accurate paths can be found if lane data is obtained rather than just summary data of loop detectors. Further, if vehicles can be routed along paths with optimal lane changes to decrease the total travel time, a savings of approximately 33% of the travel time can be experienced. It is also shown that the number of lane changes needed in the fastest path with regards to lanes is lower than the number of lane changes needed for other candidate fastest paths, and highways with less congestion require fewer lane changes.**

## I. INTRODUCTION

While sitting in traffic, many drivers have questioned whether another lane of the highway is traveling faster than the lane in which they are traveling. Inevitably, if the driver does change lanes, it then appears as if the original lane may be moving faster than the new lane. Regardless of the local decision of lane choice, the ultimate goal is to reach the desired destination in the minimum amount of time. The purpose of this paper is to determine whether local lane changing decisions will affect the overall travel time of a driver. Further, if a vehicle-to-vehicle-to-infrastructure (V2V2I) architecture [1] is used, can vehicles be routed at lane granularity to reach their destinations faster?

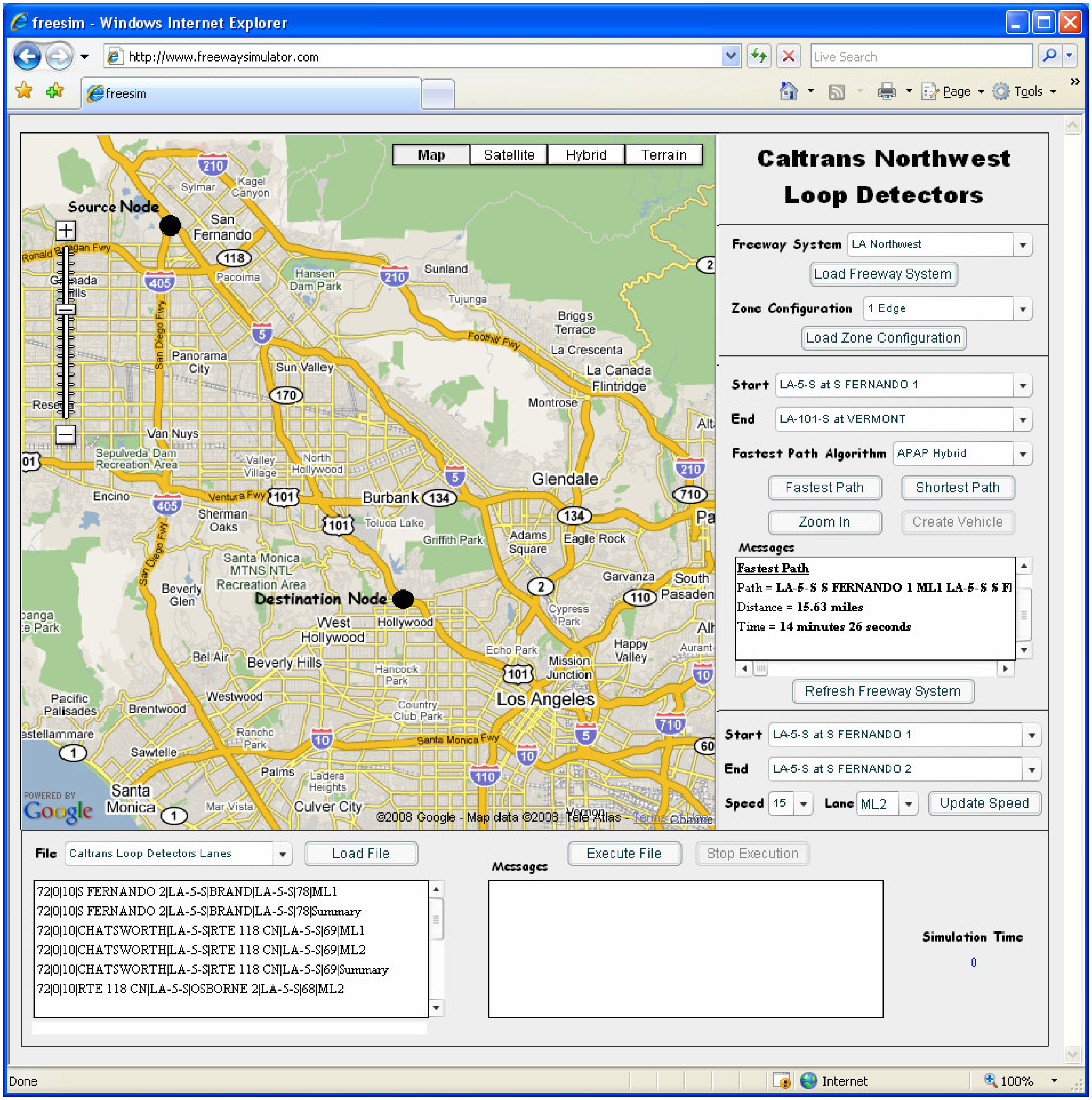
Drivers make lane changes for a variety of reasons, such as road conditions, traffic conditions, avoiding an incident, attempting to get to their destinations faster, or no apparent reason whatsoever. Regardless of the reason, an analysis has never been performed to determine the effect of vehicle lane changes on traffic in different ITS architectures. In addition, if drivers are making many lane changes, are they doing so unnecessarily and providing for a greater delay or are they actually decreasing their travel times?

Using the V2V2I architecture, the amount of bandwidth required by the central infrastructure can be significantly reduced while still maintaining comparable accuracy to the V2I architecture. I performed an analysis using the V2V2I architecture based on live loop detector data from 2006 gathered by the California Department of Transportation. The discrete data was converted to continuous data and provided to individual vehicles to transmit as they traverse different paths. Additional vehicles were inserted to perform the evaluation and to determine if there was an optimal route to traverse from one source to a destination based on the speeds of different lanes. The V2V2I architecture requires the highway network to be broken into zones that consist of one or more edges. In my case, each zone consisted of an individual lane of a section of a highway, with the sections being separated by the locations of the loop detectors. The loop detectors are 1/4 to 1 mile apart from each other. Each vehicle communicates with another vehicle in the same zone known as the Super Vehicle, which transmits the speed and location of the zone to the transportation infrastructure. As long as there is no failure in the central infrastructure, the Super Vehicles will perform queries against a database that knows the speed of traffic along all edges in the transportation network, behaving similarly to a pure V2I architecture. If there is a failure, the Super Vehicles will behave as a V2V architecture.

The data provided by the California Department of Transportation was fed into a simulator known as FreeSim, which can be downloaded for free from http://www.freewaysimulator.com [2-5]. FreeSim has V2I, V2V, and V2V2I architectures built into the framework and many helper programs to perform analyses on the resulting data. FreeSim has a graphical user interface that can be used to follow specific vehicles along their paths from source to destination, including monitoring any lane changes that may be made. Vehicles are able to update their fastest paths while in the middle of their routes, which allows them to determine in which lane to travel to provide them with the shortest travel time. Since FreeSim is operating on live loop detector traffic data gathered by a transportation department, no invented data was used in the simulation.

The remainder of this paper is arranged as follows. Section II provides an overview of the related work on intelligent transportation system (ITS) architectures and

FIGURE I. FREESIM SCREENSHOT SHOWING SOURCE AND DESTINATION VERTICES



Freeway System: LA Northwest

Zone Configuration: 1 Edge

Start: LA-5-S at S FERNANDO 1

End: LA-101-S at VERMONT

Fastest Path Algorithm: APAP Hybrid

Messages

**Fastest Path**

Path = **LA-5-S S FERNANDO 1 ML1 LA-5-S S FI**

Distance = **15.63 miles**

Time = **14 minutes 26 seconds**

Start: LA-5-S at S FERNANDO 1

End: LA-5-S at S FERNANDO 2

Speed: 15 Lane: ML2

File: Caltrans Loop Detectors Lanes

```
72|0|10|S FERNANDO 2|LA-5-S|BRAND|LA-5-S|78|ML1
72|0|10|S FERNANDO 2|LA-5-S|BRAND|LA-5-S|78|Summary
72|0|10|CHATSWORTH|LA-5-S|RTE 118 CN|LA-5-S|69|ML1
72|0|10|CHATSWORTH|LA-5-S|RTE 118 CN|LA-5-S|69|ML2
72|0|10|CHATSWORTH|LA-5-S|RTE 118 CN|LA-5-S|69|Summary
72|0|10|RTE 118 CN|LA-5-S|OSBORNE 2|LA-5-S|68|ML2
```

Messages

Simulation Time

0

fastest path determination. Section III explains the differences observed between using lane data and using summary data for determining fastest paths, as well as analyzing fastest paths of vehicles allowing lane changes, and the conclusion is in Section IV.

## II. RELATED WORK

Vehicle-to-vehicle [7] and vehicle-to-infrastructure [6, 8, 9] communication have been studied for a number of years. With V2V communication, vehicle ad-hoc networks (VANETs) were proposed and analyzed in [10], as well as secure mobile computing. V2I communication research is generally conducted utilizing inductor loops as a means of data gathering and estimating the speeds based on the occupancy, number of vehicles, and average length of a vehicle [8]. Further, using this data to attempt routing of vehicles along fastest paths has been done in [9].

Many applications based on speed and location data from vehicles have also been proposed, such as incident identification, characterization of traffic flows [11], fastest path retrieval [12], and trip planning [13]. Many papers

TABLE I. POSSIBLE PATHS FROM THE SOURCE NODE TO THE DESTINATION NODE IN FIGURE I

| # | Distance (miles) | Time to Traverse at 65mph (mm:ss) | Path |
|---|---|---|---|
| 1 | 15.63 | 14:26 | 5S–170S–101S |
| 2 | 18.40 | 16:59 | 405S–118E–5S–170S–101S |
| 3 | 21.65 | 19:59 | 405S–101S |
| 4 | 22.16 | 20:27 | 5S–118W–405S–101S |
| 5 | 24.63 | 22:44 | 5S–134W–101S |
| 6 | 27.40 | 25:18 | 405S–118E–5S–134W–101S |

have been written on traffic prediction [14, 15], and many simulators exist that attempt to implement these and other ITS applications. A good overview of traffic simulators is presented in [2], and the work discussed in this paper utilized FreeSim [2-5] due to the fact that V2V, V2I, and V2V2I communication [1] are built into the framework, and it is open source, free, and easily extensible for other applications.

Representing a transportation network as a graph and determining fastest paths from one node to another was discussed in [2]. Static graph algorithms, such as Dijkstra's [16], Bellman-Ford's [17, 18], and Johnson's [19] algorithms were extended to enable dynamic edge updates and constant queries by Demetrescu and Italiano in [20]. Miller and Horowitz added to the dynamic nature of the graph algorithms and customized the algorithms for ITS applications utilizing a pre-processing step in [2].

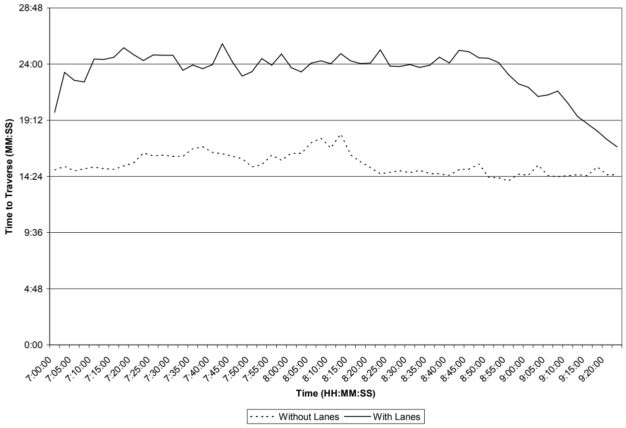
Analyzing fastest path determination using lanes has not been widely researched because of the inaccuracy of Global Positioning Systems for determining vehicle location in a lane. However, with differential GPS [21], as well as loop detectors providing lane data, this has now become feasible, and analysis of ITS applications using lane-granular data from vehicles is now possible. Combining the V2V and V2I architectures and considering lane-based data provides a new paradigm for ITS applications using the V2V2I architecture.

## III. LANE ANALYSIS OF FASTEST PATHS

The data I used in my analyses was gathered every 30 seconds from 7:00a.m. to 10:00a.m. on Friday, November 3, 2006, from 99 loop detectors owned by the California Department of Transportation. The loop detectors are located in an area of Los Angeles north of downtown, as shown in Figure I. Based on the data, I determined that there are six reasonable paths that a driver can take from the location denoted as "Source Node" to the location denoted as "Destination Node" in the figure. These paths are provided in Table I.

Using these paths, an analysis of determining the fastest path based on live loop detector data for a V2I architecture is provided in [2]. Comparing the V2I architecture to the V2V architecture for determining fastest paths is provided in [3] and [4]. Looking at fastest paths with lanes in the V2V2I architecture was preliminarily analyzed in [22]. Graph I shows the result of that work, proving that approximately 33% of a driver's commute time can be saved if ITS architectures are able to route vehicles along fastest paths that include lane changes rather than along paths that summarize the speeds of all the lanes. Of the 360 30-second periods between 7:00a.m. and 10:00a.m., the actual path changed 80 times for the fastest path without lanes. For the fastest path with lanes, the path did not change at all – path 1 (which is conveniently the shortest path as well) was always the fastest path, though between three and 16 lane changes were required, as shown in Graph III. This shows that the path chosen by a driver may not be as important as the lanes in which he travels if the optimal lane changes are made.

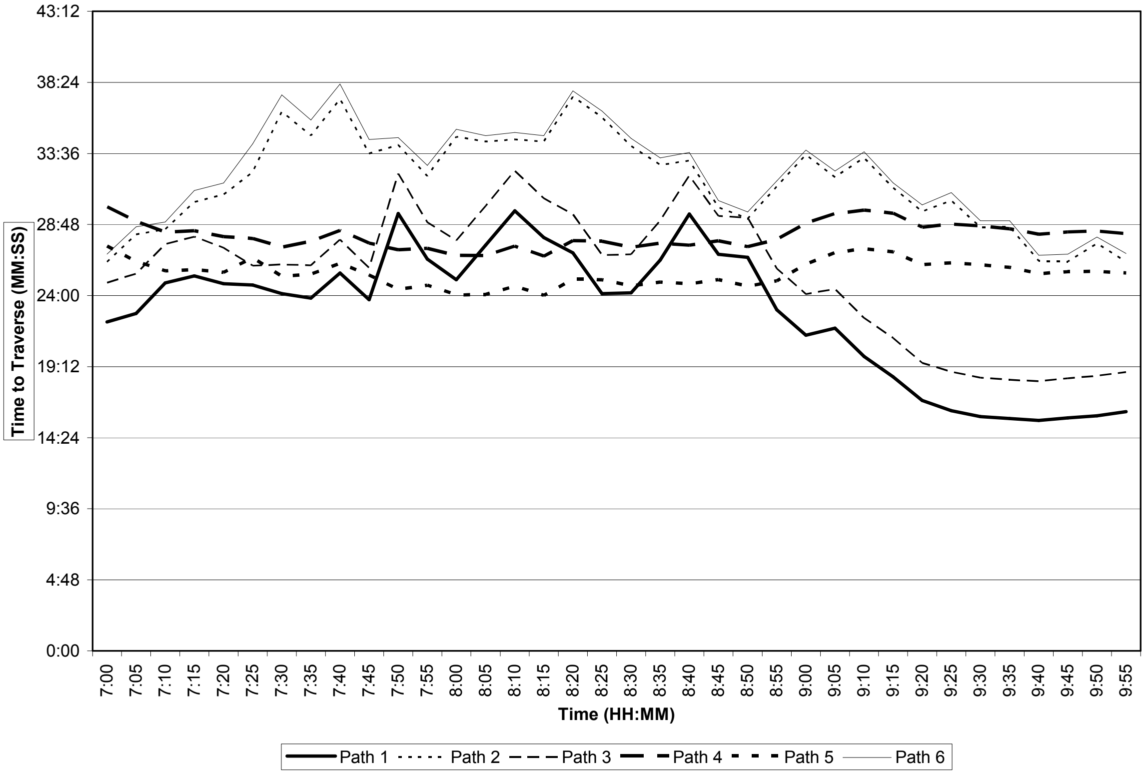
GRAPH I. TIME TO TRAVERSE FASTEST PATH WITH AND WITHOUT LANES



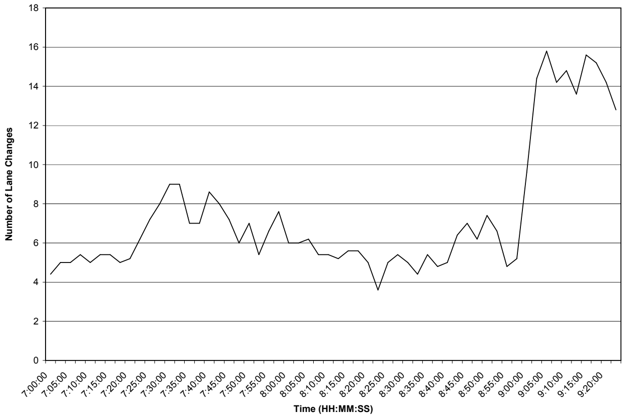
Graph II provides the amount of time to traverse each of the six paths with the summary data for each section of the highway being used. This data was determined based on averaging the valid speed data at each loop detector. The algorithm used to convert from discrete loop detector data to continuous vehicle data determined the constant acceleration or deceleration rate required by a vehicle to achieve the speed at the second loop detector based on the speed of the vehicle at the first loop detector. As can be seen, the fastest path changes between path 1 and path 5, with path 1 (which is the shortest path) becoming the fastest path when there is less congestion.

Graph IV, on the other hand, provides the amount of time to traverse each of the six paths using optimal lane changes to allow for the minimum amount of time from the source to the destination based on the current speeds. As was described earlier in this section, path 1 dominates as the fastest path during the entire duration. Further, the amount of time to traverse each path does not change nearly as significantly as the time to traverse each path using the summary data. For example, path 1 ranges from about 14 minutes to almost 18 minutes when lanes are used, but from about 14 minutes to almost 30 minutes when summary data is used.

GRAPH II. TIME TO TRAVERSE EACH PATH WITH CURRENT SPEEDS WITHOUT LANES



GRAPH III. NUMBER OF LANE CHANGES IN FASTEST PATH FROM SOURCE TO DESTINATION



Graph V shows the number of lane changes that were required along the fastest route within each path. The number of lane changes is proportional to the number of possible lane changes along each path, with at most 28 lane changes for path 1, 26 for path 2, 33 for path 3, 38 for path 4, 41 for path 5, and 39 for path 6. Graph V can be used to show that the number of lane changes is directly related to the amount of congestion on the highway and the length of the path, with more congestion (indicated by lower speeds) and longer paths leading to a higher number of lane changes along the fastest route within each path. The large jump in the number of lane changes along all of the paths at around 9:00a.m. is due to increased congestion on the 101 south of the 134, which is a section shared by all of the paths.

Looking at both Graph IV and Graph V together produces some interesting observations. At 9:00a.m., as the number of lane changes increases drastically for all of the paths, as well as the density of traffic decreasing for all of the paths, the amount of time to traverse each path begins to approach the minimum amount of time to traverse the path. With optimal lane changes, even during congestion, the amount of time to traverse a path can improve and approach the time to traverse a path under optimal conditions.

## IV. CONCLUSION

In this paper, I have analyzed how lane changes can affect the fastest paths provided by an ITS architecture. I used the V2V2I architecture, which provides a V2V architecture if any of the components in the V2I architecture fail, as well as providing a lower bandwidth requirement for the central server while maintaining a high degree of accuracy, as shown in [1]. I obtained live loop detector data from the California Department of Transportation, and converted the discrete data into continuous data, which was then fed into FreeSim [2-5]. Optimal lane changes allow drivers to experience approximately a 33% decrease in estimated travel time as compared to merely using loop detector summary data [22]. Further, using lane data, the fastest path and the shortest path remained the same, although there were between three and 16 lane changes required out of a possible 28 lane changes. The amount of time to traverse each path with optimal lane changes also began to approach the amount of time to traverse the path at optimal speeds, which shows that optimal lane changes can greatly decrease the amount of time to traverse a given path as well. In addition, paths that contained more congestion also contained more lane changes to traverse the path in the fastest manner. Paths with less congestion did not require nearly as many lane changes. As lane changes have been documented as a source of many collisions on highways, if congestion can be reduced, fewer lane changes will be required to traverse a path in the fastest manner. With the popularity of differential GPS [21], it is no longer sufficient to look solely at summary data, but it has now become necessary to look at lane granularity for ITS architectures.

## V. REFERENCES

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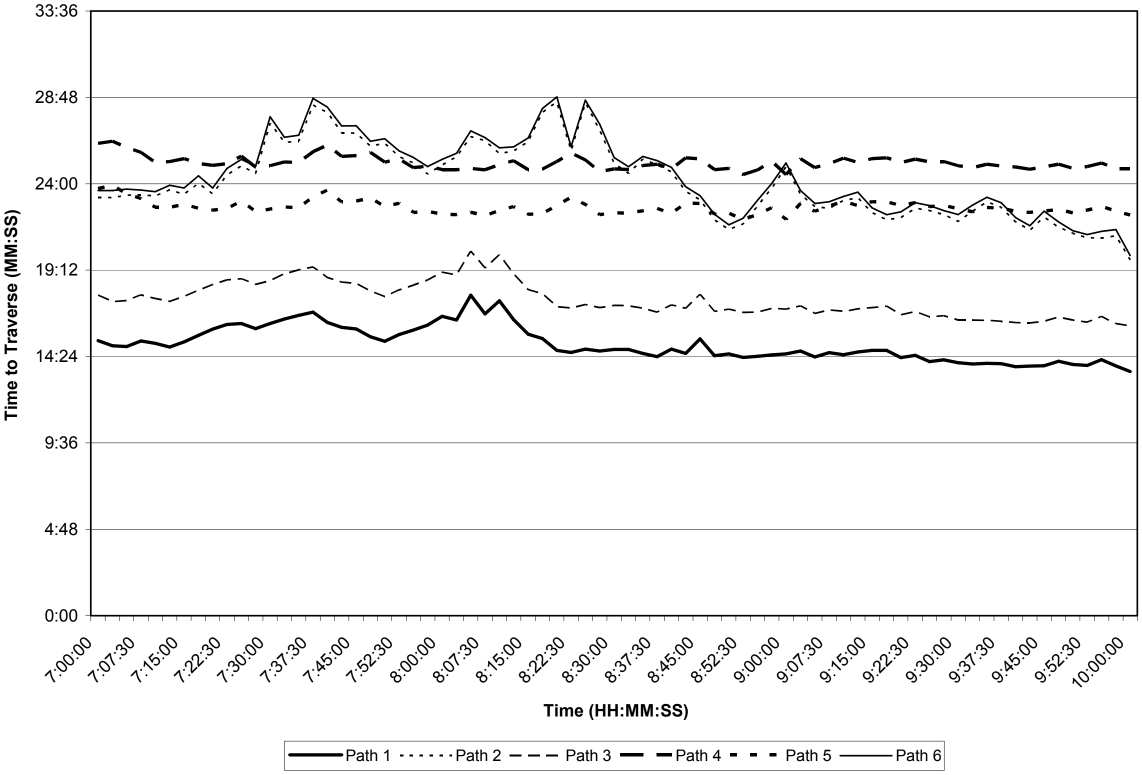
## GRAPH IV. TIME TO TRAVERSE EACH PATH WITH CURRENT SPEEDS USING OPTIMAL LANE CHANGES WITHIN EACH PATH



## GRAPH V. TOTAL NUMBER OF LANE CHANGES IN EACH PATH WITH CURRENT SPEEDS WHEN USING OPTIMAL LANE CHANGES