Correlating Events with Tracked Movements in Time and Space: A GeoTime Case Study

Thomas Kapler, Robert Harper, and William Wright
Oculus Info Inc.

{tom.kapler, robert.harper, bill.wright}@oculusinfo.com

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Abstract

GeoTime is a new paradigm for visualizing events, connections and movement in a combined temporal and spatial visualization. This paper will show how this information visualization capability allows intelligence analysts to quickly reveal relationships between tracked movements and events of interest. Entity movement over time can be examined, without the need for animation, to reveal types and patterns of behavior, interactions, and deviations. A simple case study will be examined that effectively employs the GeoTime spatiotemporal visualization theory and analysis techniques. A hypothetical hit-and-run accident is used to show the movement of vehicles and their behaviors leading up to and after the event.

Keywords: Multi-INT/fusion, Geospatial Information Systems, Visualization, Temporal Analysis, All Source Intelligence.

1 Introduction

Effective mental tools that enhance an analyst's ability to perceive and understand information form an important part of any analysis technique. One very powerful tool for dealing with complex data is problem externalization through visualization. By putting ideas in a visual format, the likelihood these ideas will persist improves (Heuer, 1999). Moreover, when information is presented visually, efficient innate human capabilities can be used to process and understand orders of magnitude more information (Card et al, 1999).

The GeoTime visualization concept (Kapler et al, 2004) improves perception of entity movements, events, relationships, and interactions over time within a geospatial context. Events are represented within an X,Y,Z-T coordinate space, in which the X,Y plane shows geographic space and the Z-T axis represents time into the future and past as shown in Figure 1. In addition to providing the spatial context, the ground plane marks the *instant of focus* between before and after. Events along the timeline "occur" when they meet the surface. Events are arrayed in time along *time tracks,* which are located wherever events occur within the spatial plane. For analysts, GeoTime's single view representation of a combined temporal-spatial three-dimensional space amplifies concurrent cognition of entity relationships and behaviors in both space and time (Kapler et al, 2004).

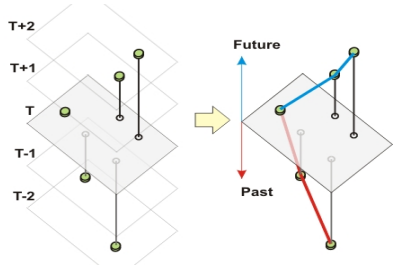

Figure 1: Individual views of movement in time are translated into a continuous spatiotemporal representation.

Previous work has focused on GeoTime theory, techniques, and tools without exploring the application thereof. Our goal here is to present the GeoTime concept as an effective tool for analysis through the use of a relevant, albeit fictional, case study. Although slightly contrived, the example presented is meant to show a specific example of GeoTime analysis and to trigger discussion of specific temporal-spatial visualization analysis techniques.

2 The Case Study

The case study presented here shows how GeoTime can be applied to real-world intelligence analysis problems involving combined spatial and temporal dimensions. This particular case involves determining the possible involvement of several moving entities in a significant event

within an urban setting. Although the situation under study was constructed for the benefit of this paper, the GeoTime analysis techniques presented here are believed to be widely applicable to many situations in which time and space are significant factors. Our case study can be set up as follows:

Oakland local police have reported that a "Hit-and-Run" involving a pedestrian occurred near Lafayette Square (longitude -122.274, latitude 37.805) at 10:30am this morning. Witness reports are vague, but generally consistent, stating that the offending vehicle was a taxi cab belonging to A1 Cabs, a local taxi company. A1 Cabs has given police their dispatcher's logs containing times and locations of passenger pickups and drop offs. Furthermore, all A1 Cabs have onboard GPS units that send intermittent position updates to the dispatch office. These position logs have also been given to the local police. It is hoped that this information will be sufficient to determine which, if any, A1 Cabs taxi was responsible for the incident.

In this study, three disparate information sources are available to analysts:

1. The original police report containing the time, location, and details of the incident;
2. The taxi dispatcher logs containing times and locations of passenger pickups and drop-offs, and
3. A log of periodic GPS position updates from each taxi, accurate to within two meters (NSTB/WAAS, 2004).

GeoTime will be used to amalgamate and analyze the available data and an attempt will be made to determine which taxi was the most likely culprit.

3 Analysis

Loosely based on Davidsonian semantics (Davidson, 1980), the most fundamental information construct in GeoTime is the concept of an "event." An event binds an action to a location, a time, and the parties involved. It links the what, the where, the when, and the who. Each information source in this case study provides a sequence of events that contain an event description or type, a location, and a temporal context. Furthermore, most events also involve a moving entity such as a taxi cab and, occasionally, a taxi passenger. By modeling all of the given information as GeoTime events, a perceptually persistent but dynamic representation of the movement of taxis and their passengers through space and time on the morning of the hit-and-run is revealed.

A bottom-up, data driven analysis workflow (Heuer, 1999) is applied to this scenario, using GeoTime as the source and presentation medium of all available data. Analysis will begin by reducing the amount of "noise" in the data set under consideration through a series of selection and filter activities. Following this, a standard procedure of hypothesis generation, collection of supporting or refuting evidence, refinement, conclusions, and re-evaluation (Heuer, 1999) will be followed.

3.1 Visualizing the Situation

As a first step, the entire data set can be visualized in GeoTime's 3-D combined temporal-spatial view. This fictional scenario takes place in Oakland, CA on the morning of September 1, 2004, and so this volume of space-time has been isolated for analysis. The region of interest containing a visualization of all available data can be seen in Figure 2. Each taxi has been given a unique color and has its movement shown by a solid line movement trail.

While GeoTime is designed to aid in a variety of analysis tasks, including visualizing entity relationships and interactions, this particular analysis application focuses only on tracking entity movements and correlating their observed behavior with the hit-and-run incident and geographical features.

Some general trends are immediately evident. Most of the recorded taxi movement is concentrated in the area indicated by the overlaid red arrow. This is also the area of the hit-and-run, as in this scenario we have only collected information for taxis that were in the same general area of Oakland on the morning of the incident. Outside of this concentrated area, one can see when and where taxis make frequent trips to outlying areas such as the airport.

Figure 2: Overview of entire data set, showing area of activity concentration.

For tracking taxi movement on the morning of the incident, GeoTime entity movement trails provide a visualization of movement in space during a given time span. In the simplest sense, trails allow the analyst to quickly identify an entity's approximate geo-referenced movement throughout a time period without the need for animation. The shape of trails also allow rapid visual identification of patterns or anomalies in behavior. The slope of entity trails show maximum possible average velocity of an entity during a segment of travel: a trail nearly parallel to the vertical time axis indicates little movement over a large amount of time (slow movement), whereas a trail closer to parallel with the horizontal ground

plane indicates significant movement over little time (rapid motion).

Before considering the hit-and-run incident itself, it is pedagogically interesting to examine the movement of one taxi throughout the morning. GeoTime allows the analyst to opt to display only a subset of the data that he or she finds interesting. Isolating Taxi 3234's movement and leaving the geographical and temporal bounds fixed, a telling picture reveals itself in Figure 3. In this image, the taxi's actions throughout the morning can be easily seen, including (as marked in the figure):

1. Routine passenger pickup, movement, and drop-off sequences showing when the taxi is on fare and when it is for hire,
2. Periods of no movement within the city, possibly indicating waiting at a taxi stand,
3. Slow rate of movement on a freeway indicating a possible traffic jam, and
4. Rapid motion along the same freeway after the area of traffic slow-down has been passed

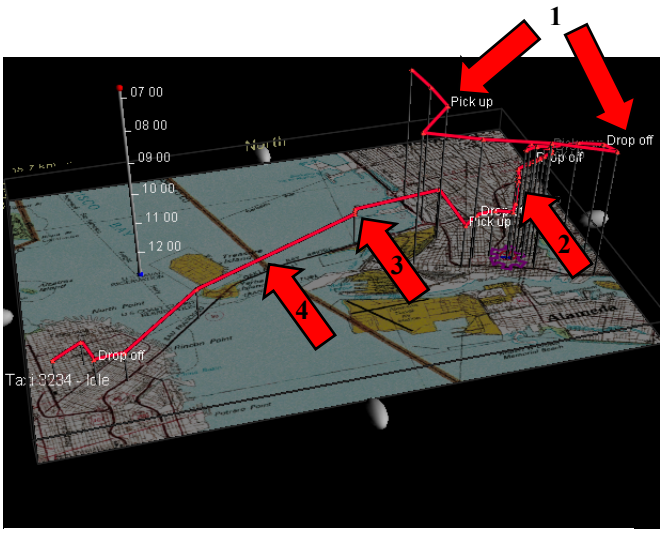

Figure 3: Overview of one taxi's movement over the entire morning. Shows passenger pickup-movement-drop off series (1), period of no movement within the city (2), slow movement on the freeway possibly due to traffic (3), and rapid movement on the same freeway past the location of the slowdown (4).

3.2 Focusing on the Area of Interest

To begin taxi movement analysis, as it pertains to the hit-and-run incident, the analyst needs to drill-down to the area of interest in both space and time. While data is available for many hours preceding and following the incident, it is only pertinent to this first stage of analysis to examine a temporal region extending to just before and just after the hit-and-run. To simplify the visualization and assessment of the data, a region with a 300 meter radius is created and all events within this region are aggregated to a single location. To accomplish this in GeoTime, an "aggregating area" is drawn on the landscape around the location of the hit-and-run event. This places all taxi position update-events, within this spatial and temporal region of interest, along a single time track and permits easy isolation of those taxis that were within 300 meters at the time of the incident.

Figure 4 shows the region of interest, a sketched purple annotation on the ground plane, aggregated to a single location with a red arrow highlighting the hit-and-run and the entity trails of nearby taxis. In this case, four taxis with red, blue, yellow, and green trails appear to be within close spatiotemporal proximity to the hit-and-run and can now be considered potential suspects. These suspect hypotheses can be grouped into a GeoTime layer for future reference.

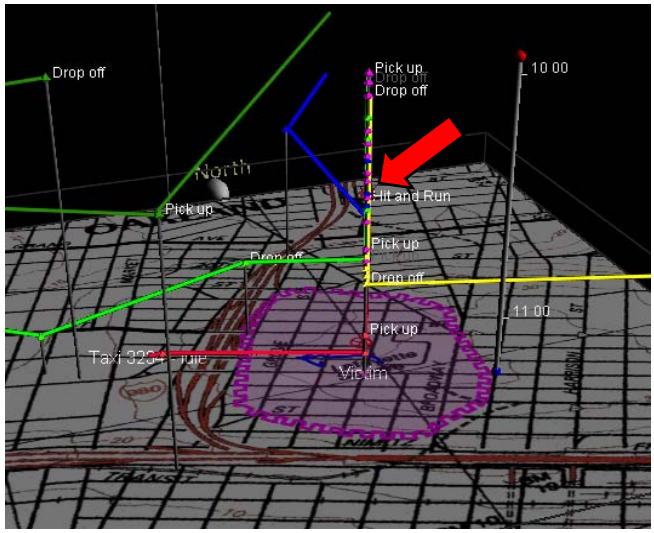

Figure 4: Region of interest around hit-and-run aggregated onto a single time track for rapid assessment of taxi-incident spatial and temporal correlation.

3.3 Examining Potential Suspect Behaviors

At this stage in the analysis, we have identified four different hypotheses for the identity of the perpetrator of the incident. Each suspect taxi was within 300 meters of the hit-and-run at 10:30 am, the time of the incident, and now must be individually assessed for potential involvement. Figure 5 shows the movement of the first two taxis around the time of the incident; taxi 3234's movement trail in red and taxi 6234's in blue. Figure 6 shows the behavior of the third and fourth suspects, taxi 5234 in yellow and taxi 4234 in green. The analysis of each taxi's behavior follows.

Analysis of Taxi 3234

The red trail in Figure 5 shows Taxi 3234 at the same position over a series of GPS update events (highlighted by the red overlay arrow #1) beginning 20 minutes before the incident. This series of events implies that the taxi was stopped without a passenger at the same position for a period of nearly one hour. At 11:05am, 35 minutes after the

incident, the taxi picks up a passenger at this same location and immediately departs. The most likely explanation is that the taxi was waiting at a taxi stand at the time of the incident and left when it was hired by a passenger in the area. Using the event's geographical context, the precise waiting location of the taxi can be found and checked against locations of known taxi stands in the area. While it is possible that the taxi could have left its position, hit a pedestrian, and returned to its starting location between GPS updates, it is extremely unlikely. Therefore, we may allege that taxi 3234 was not responsible for the hit-and-run.

Analysis of Taxi 6234

By examining the blue trail in Figure 5, we can see the approximate route taken by taxi 6234 over the one hour time period surrounding the time of the hit-and-run. The two most interesting events in this taxi's route occur two minutes before and one minute after the time of the incident. This segment is marked by red arrow #2 in Figure 5. GeoTime's use of accurate geographical context proves to be very useful in this situation. It is evident that since the events marking the end points of this segment occur along the same road, it is likely that the taxi followed the route shown by the blue annotation arrow on the ground plane (highlighted by the red overlay arrow #3). If this was the case, it would appear that this taxi cab was traveling on a steady course from east to west near the location of the hit-and-run but on a different road. Furthermore, the blue movement trail does not indicate any erratic or suspicious behavior such as sudden movements, deviations in course, or changes in speed. A preliminary hypothesis of the activities of this taxi is that it was not involved in the incident and was merely passing by one street south of the hit-and-run.

Analysis of Taxi 5234

The movement trail of taxi 5234 is shown in yellow in Figure 6. In this case, the trail shows that the suspect moved toward the location of the hit-and-run in the 30 minutes preceding the incident as annotated by red overlay arrow #1. The next position update available for this taxi is a significant distance away, twelve minutes after the hit-and-run, and this section of travel is denoted by red overlay arrow #2. It is interesting to note that the taxi's speed of travel significantly increased from the leg marked #1 to the leg marked #2 of its movement. In effect, the taxi cab drastically increased its speed around the time of the incident and rapidly moved away from the area. This is potentially suspicious behavior, possibly indicative of a suspect fleeing from the scene.

Looking more closely at the events shown, it appears that this taxi picks up a passenger at the end of this leg of rapid movement, shown at red overlay arrow #3. This additional information provides a new context in which to view the sudden speed change of taxi 5234. A likely explanation for the observed behavior is that taxi 5234 received a call around 10:30am regarding a passenger needing pickup. The taxi then proceeded to move quickly to the location of the passenger, possibly to prevent another taxi from securing the fare. While it is still possible that this taxi was involved in the hit-and-run, the given data is consistent with an overzealous move towards a passenger pickup and is therefore not overly suspicious.

Analysis of Taxi 4234

Taxi 4234's movement at the time of the incident is shown in green in Figure 6. In the half hour before the hit-and-run, this taxi moves towards the scene of the incident, coming

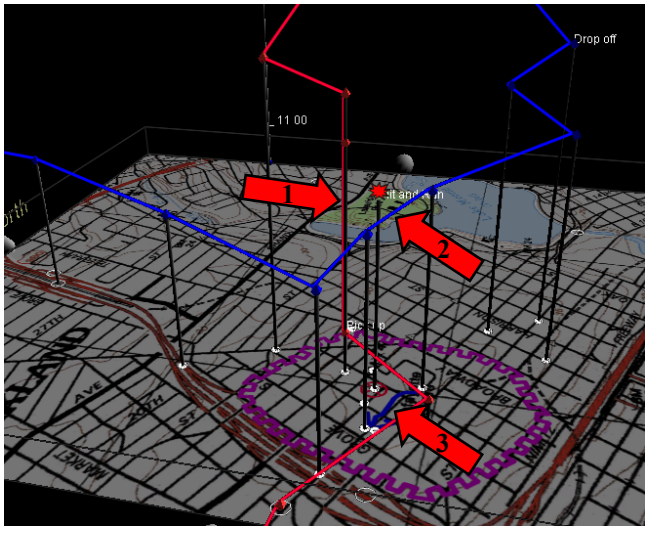

Figure 5: Movement trails for taxis 3234 (red trail, 1') and 6234 (blue trail, 2') showing their behavior in the region of nterest at the time of the hit-and-run. An ink annotation (3') shows a segment of the route most likely taken by taxi 6234.

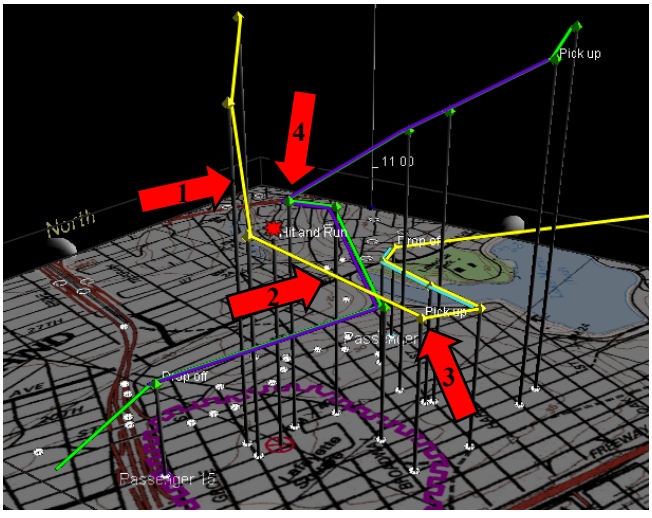

Figure 6: Movement trails for taxis 5234 (yellow trail, 1', 2', 3') and 4234 (green trail, 4') near the region of interest at the time of the hit-and-run.

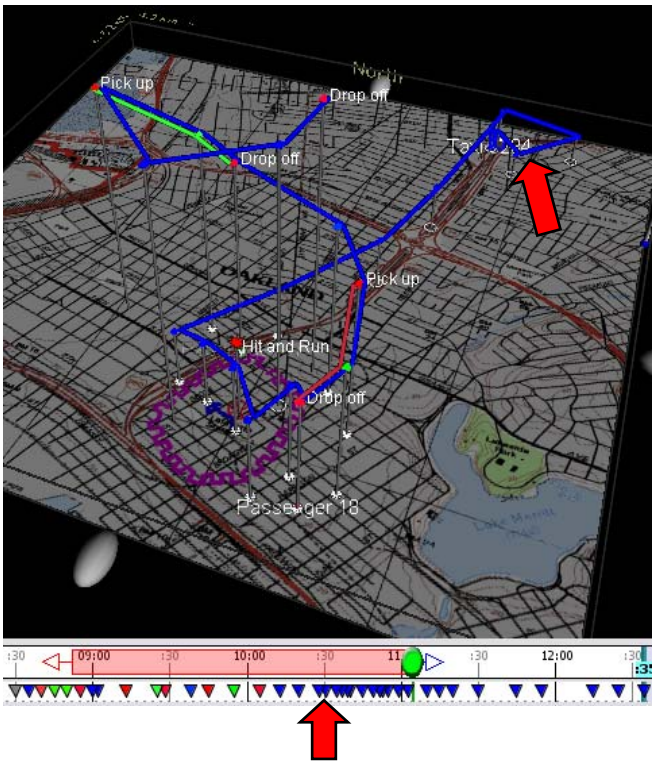

Figure 7: Movement trail for taxi 6234 with a wider spatial and temporal scope. Shows movement and passenger pickup-drop off behavior following the time of the incident.

within 100m just two minutes before it happened. The next position report, two minutes after the hit-and-run, shows the suspect has sharply reversed direction and is traveling away from the location of the incident. Initially, this pattern of movement appears to be suspicious, as if the taxi were involved in the hit-and-run, turned, and fled.

Once again, it is important to look beyond the simple first appearances of the taxi's movement in an effort to explain why the suspect would act in this manner. With a quick look at the events in taxi 4234's trail, GeoTime shows that the taxi picked up a passenger just before the incident and headed west. The passenger's movement trail, following that of taxi 4234's trail, is shown in pale-purple in Figure 6. After the hit-and-run, the taxi quickly reversed direction, proceeded around the area of the incident, and dropped the passenger off on the far west side of the area of interest. That the taxi was carrying a passenger at the time of the incident provides a possible alibi for this suspicious motion: The hit-and-run may have caused a traffic stoppage and with pressure from the passenger, the driver may have decided to turn around and find another route to the passenger's destination. While it is possible that this taxi was the culprit, it is unlikely due to the existence of a passenger witness.

3.4 Reassessment

Upon initial assessment of the evidence at hand, all four taxis that were in close spatial-temporal proximity to the incident were assumed to be innocent. At this time it is important to reassess the given evidence from a broader perspective. We will begin by reexamining taxi 6234's actions following the incident, as shown in Figure 7.

When first analyzed, taxi 6234's movement looked predictable and uninteresting. However, by expanding the visible time bounds and highlighting all pick up and drop off events, additional information is revealed. At the bottom of Figure 7, GeoTime's linear timeline shows all recorded events for taxi 6234. Using GeoTime, we have colored the events such that GPS updates are in blue if the taxi is for hire and green if hired, and passenger pickups and drop offs are in red. It is immediately apparent that after the time of the hit-and-run, taxi 6234 does not transport any more passengers. Examining the behavior of the other suspects shows that they all continue to pickup and drop off passengers following the incident. Furthermore, in the hour after the incident, without transporting any known passenger, the suspect moves away from his normal area of business to a completely different area of the city where he remains for well over an hour.

Upon initial assessment of taxi 6234's movement at the time of the hit-and-run we determined that the direct route shown by the blue annotation in Figure 5 (arrow 3') was the most likely. However, such a route would mean that 6234 was not on the road where the hit-and-run occurred. Figure 8 presents an alternate route for taxi 6234 that would take it to the time and place of the incident. We can use the geographical context imagery and annotation tools provided by GeoTime to explore, analyze, and report such hypotheses. In this case, further investigation is needed into reasons that may have caused taxi 6234 to avoid the section of road along the direct path between the events highlighted with the two red overlay arrows. Construction or traffic slowdowns on this segment of road are one possible explanation.

Given this additional information, it seems likely that this taxi was responsible for the hit-and-run. The suspect was not transporting a passenger at the time. Immediately after the incident, he drove to a distant area of the city for no apparent reason. Finally, he did not take on fares for several hours following the incident. The combination of these anomalous behaviors, with the suspect's very close spatial and temporal proximity to the hit-and-run, make taxi 6234 appear to be the most likely culprit responsible for the incident.

4 Conclusions

The purpose of this case study was to show how GeoTime's single integrated space-time view enables rapid and efficient analysis of intelligence data. In this case study, four hypothetical suspects were isolated and each one was examined using a number of criteria. GeoTime's entity

trails can clearly show behavior over time by visualizing taxi location, direction, and rate of movement without the need for animation. Moreover, the trails were useful in visualizing important patterns in taxi movement including general trends such as areas of high activity, repeated behavior (such normal areas of business), and deviations in normal behavior (such as anomalous trips to different areas of the city), as well as specific behaviors including idling at a taxi stand, and sudden changes in speed and direction of travel.

The addition of textually and chromatically annotated event types describing each taxi's actions and status, particularly passenger pickup and drop off, adds another important dimension to the displayed information. Passenger interaction data can be used to further explain taxi movement behavior, for example, faster movement when heading to pick up a new passenger. It can also be used to find deviations in normal activities, such as a sharp decrease in the number of passengers carried over a time period.

GeoTime's one-data-view system eliminates the typical analyst's dependence on multiple spreadsheets, tables, maps and other simultaneous cross-referenced views that can cause cognitive confusion. In this case study, our dataset was atypically small, comprised of only 300 records of event data. However, a standard spreadsheet-type analysis of this information would still require the analyst to work with more than seven full screens of numeric data at a screen resolution of 1024x768 with a standard font size.

Through the use of an interactive, new visualization paradigm, GeoTime provides an effective tool for rapid, high volume spatiotemporal information analysis and understanding. GeoTime provides an environment in which to visualize spatial-temporal situations and information, filter and focus to relevant data subsets, form hypotheses, and gather supporting or refuting evidence for these hypotheses.

5 Recommendations

We have shown that GeoTime provides a unique analysis environment for problems involving tracked movements surrounding significant incidents of interest. Additional research topics that should be explored include representation of data uncertainty, hypothesis generation, and new visualization techniques for very large data sets and "dirty" data. Ongoing research and experimentation, with real data against real problems, would help develop the full potential of the GeoTime visualization tool.

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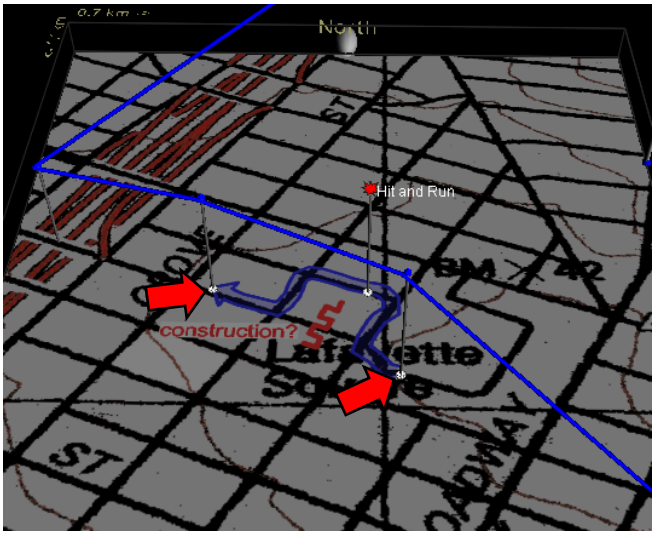

Figure 8: Geospatial reference provided by GeoTime allows exploration of possible alternate route taken by taxi 6234.

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