Visualizing Vehicle Acceleration and Braking Energy at Intersections along a Major Traffic Corridor

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ABSTRACT

Automobiles approaching a controlled intersection need to brake and come to a full stop when the signal transitions from green to red, and the vehicle must later accelerate to normal speeds after the signal changes back to green. These stops and starts associated with normal signal changes lead to unnecessary energy consumption and vehicle emissions. Previous studies have revealed that the optimization of traffic intersections' signal controls and coordination facilitates smoother traffic flows with reduced stop-and-go driving, which can significantly reduce traffic congestion and unnecessary fuel waste. This paper presents an interactive visual analytics dashboard that allows transportation planners to explore and analyze energy consumption patterns resulting from temporally varying traffic signal phases at multiple intersections along a major transportation corridor using traffic simulation outputs. The visual dashboard is implemented as an accessible and responsive web application and employs a combination of visualization techniques to cover multiple aspects of vehicle acceleration and braking at multiple adjacent intersections along a corridor. The paper presents a case study of a simulated traffic scenario on the Shallowford Road traffic corridor located in Chattanooga, Tennessee to demonstrate the capability of the visual dashboard.

CCS CONCEPTS

• **Human-centered computing** → **Visual analytics**; **Geographic visualization**; *Visualization toolkits.*

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KEYWORDS

traffic visualization, energy visualization, traffic energy use

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1 INTRODUCTION

The rapid pace of urbanization has led to the widespread and increased use of automobiles, which have become a significant source of energy consumption and greenhouse gas emissions across the world. In urban areas, stop-and-go driving patterns result in additional energy consumption due to unnecessary vehicle braking, idling, and accelerations back to free flow speed [6, 8]. This problem is particularly prevalent at city intersections, where stop-and-go traffic consumes near 50% of the vehicle energy for acceleration. Reducing the braking and accelerations associated with congested traffic conditions could lower vehicle energy consumption by up to 40% in urban areas [5, 14]. Several past studies focused on minimizing each vehicle's acceleration/deceleration and its associated transient engine operation to reduce energy waste and fuel consumption through the optimization of signal controls at individual signalized intersections [4, 7, 10, 17].

While these studies are significant and useful, coordinating traffic lights along city corridors remains a challenge in real-world traffic control operations, and optimizing the coordination of multiple traffic signals along a corridor remains a sophisticated task that has to take into account each individual intersection's demand, time of day, individual driving behaviors, and other factors to develop an appropriate prioritization strategy [9, 16, 18]. To foster an in-depth understanding of the signal control systems' influence on vehicle energy consumption patterns for evaluating or optimizing the effectiveness of traffic signal timing at multiple adjacent intersections, an intuitive method to explore and analyze the variability of vehicle braking and acceleration and the associated energy consumption patterns in relation to changes in the traffic signal timing between multiple connected intersections is often required.

However, developing such a method involves several challenges are due to the complex nature of vehicle energy data, which entails multi-scale, multivariate, and spatial-temporal patterns. These

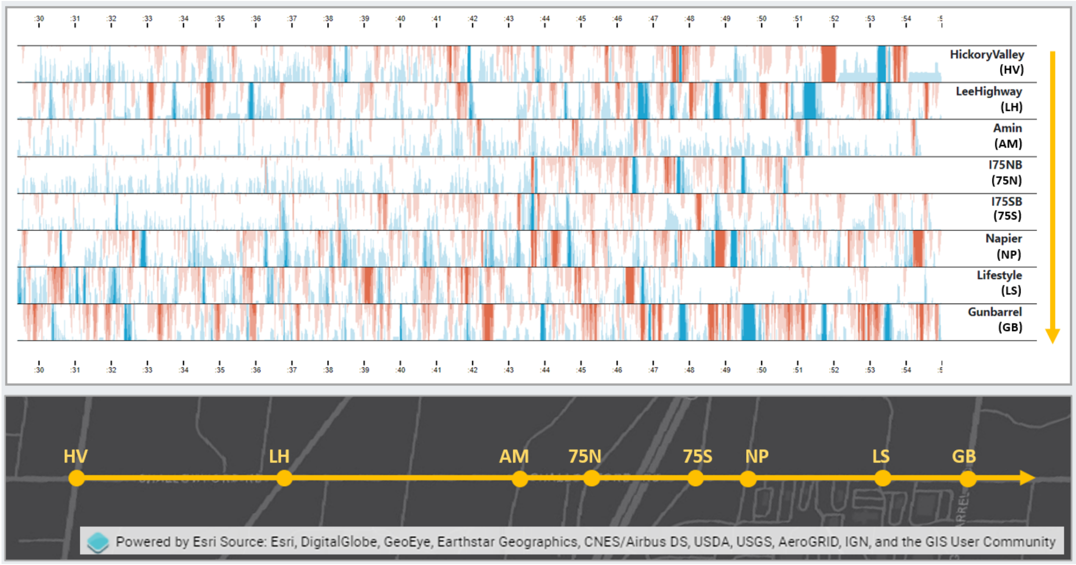

Figure 1: Horizon chart for all intersections (top) and a visual overview of the corridor's intersections (bottom).

challenges prevent comprehensive understanding of the multi-faceted energy consumption patterns within a transportation corridor from a holistic perspective, and can be addressed through the application of visual analytics. This approach has recently emerged as an applied research discipline from computer graphics and design and cognitive science to maximize the analytical reasoning on data that entails complex dynamics and patterns by integrating the strength of both computational techniques and human reasoning capabilities through interactive visual interfaces and dashboards [2, 15].

In this paper, we present the design and implementation of a web-based visual dashboard to enable the exploration and analysis of vehicle energy consumption patterns in response to the spatial and temporal varying traffic signal phases at multiple intersections along a major transportation corridor. We utilize simulated traffic scenarios to develop a methodology to monitor and analyze the driving patterns of vehicles, as well as estimate their associated energy consumption for acceleration and braking. In this setting, we can seamlessly incorporate the energy consumption aspects into traffic simulation efforts, which are critical for transportation planning in urban areas. This same methodology can also be applied to measured traffic data from Connected and Autonomous Vehicles (CAVs) and intersection-level sensors, once it becomes available. The visual dashboard aims to enable systematic procedures for estimating the vehicle acceleration and braking energy consumption from user-uploaded VISSIM traffic simulation outputs. It visualizes the spatial-temporal variability of the energy consumption associated with individual vehicle movements, multiple driving directions at an intersection, and signal phase changes at multiple intersections.

2 METHODOLOGY

In this section, we first give a short overview of the traffic scenario we visualize in this work. Next, we describe the data that we are using, as well as all required data transformations and derivatives. Finally, we describe each component of the vehicle energy use dashboard we have created, and we provide an interpretation of the results provided.

2.1 Shallowford Road Corridor

Shallowford Road is a busy corridor in Chattanooga, Tennessee located Northeast of downtown. It connects Lee Highway and Interstate 75 (I-75) with a major shopping district that stretches North and South between I-75 and Gunbarrel Road. Along this corridor, we evaluate traffic at eight intersections, as shown at the bottom of Figure 1 — from West to East: Hickory Valley Road (HV), Lee Highway (LH), Amin Drive (AM), I-75 Southbound (75S), I-75 Northbound (75N), Napier Road, Lifestyle Way, and Gunbarrel Road. The two I-75 ramps and Lee Highway are the main ingress and egress points into this area, while most of the other crossroads lead to businesses in the vicinity.

2.2 Traffic Data

For the purpose of this work, we use PTV VISSIM [12], a widely used traffic microsimulation tool, to produce simulated traffic data. We set up a simulation scenario with traffic that travels along the corridor with origins and destinations in the vicinity.

The resulting dataset contains simulated vehicle traces. For each vehicle data point, it stores the timestamp at $\frac{1}{10}$-second resolution, vehicle coordinates, vehicle position on the road segment (or "link"), lane number, speed, acceleration, and vehicle weight.

The vehicle coordinates are provided in a VISSIM-specific custom geographic projection. In a first step, we re-project the vehicle positions into a standard latitude/longitude format to enable display on a map.

For energy analysis, we define approach zones for each approach direction at each intersection. These zones stretch from a varying

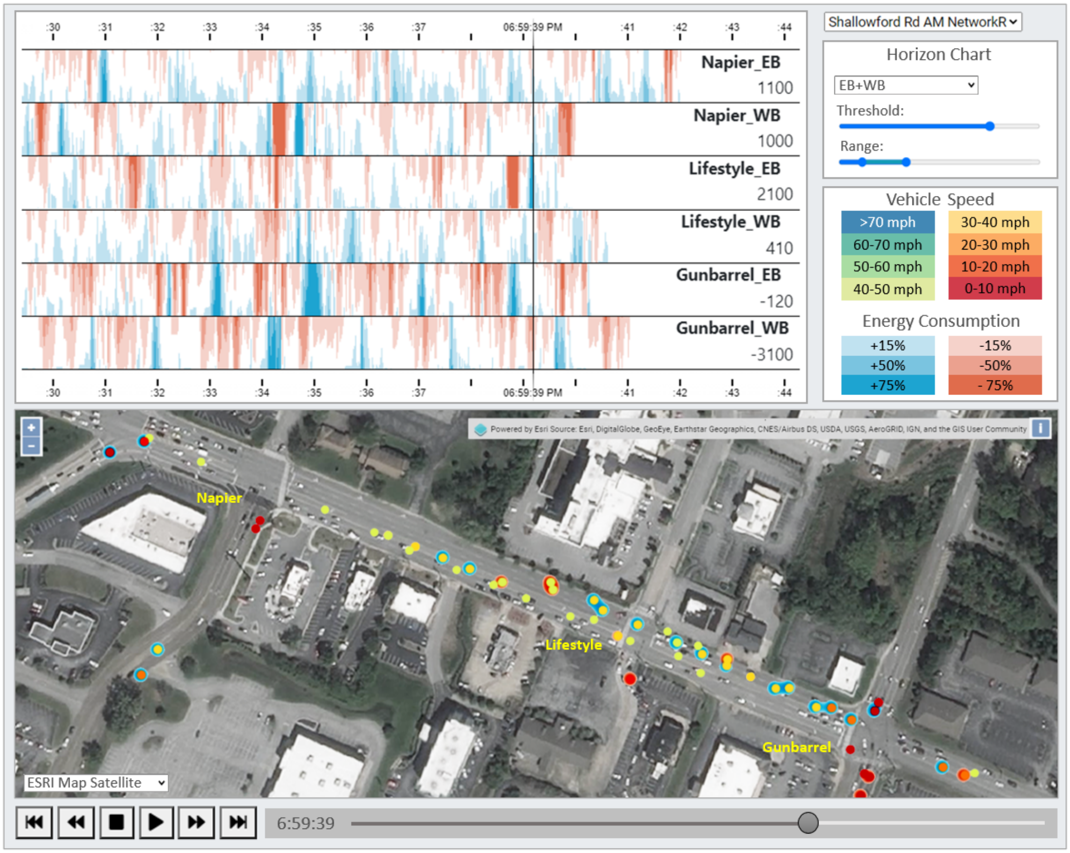

Figure 2: The visual interface combines halo representation with horizon charts..

distance behind the intersection to the intersection entrance. The length of the approach zone depends on various factors, including the distance from the nearest intersection in that direction.

2.3 Energy Use Data

To supplement the vehicle traces and speeds with energy use information, we approximate the kinetic energy from acceleration and braking, similar to the approach described by Rios-Torres and Malikopoulos [13]. We augment their calculation to factor in vehicle weights. We compute the energy as $\frac{1}{2}\int_{t_i^0}^{t_i^N} m_i \cdot a_i dt$, where t_i^0 is the time at which vehicle i enters the approach zone, t_i^N is the time when it exits the approach zone (to enter the intersection), m_i is the vehicle mass, and a_i is the vehicle acceleration as provided by the simulation results (the original approach derived this quantity from speed). Positive energy values indicate acceleration whereas negative values indicate braking.

2.4 Horizon Chart

The first visualization on our dashboard is a so-called Horizon Chart [11]. This type of chart is well-suited to comparing different time-series data [3] with positive and negative values in parallel, and we implemented the chart using a combination of Cubism.js and D3.js libraries. As shown in Figure 1, we have stacked up energy use time-series data (acceleration and braking) for all eight intersections in topological order from West to East, with the west-most intersection (Hickory Valley) in the top row and the east-most intersection (Gunbarrel) in the bottom row. The x-axis represents timestamps in the traffic data.

Within each row, we visualize acceleration energy in blue, starting at the bottom of the row and reaching up to the top of the row for maximum acceleration energy use. We visualize braking energy in red, starting at the top of the row and reaching down to the bottom for maximum braking energy use. This produces striped patterns in the horizon chart which give a high-level overview of acceleration and braking behavior on the corridor over the course of the chosen time frame.

Three interactive components (demonstrated in Figure 2) support further exploration of the data: a drop-down provides a number of filters by traffic direction, evaluating either one heading, two opposing directions (e.g., travel along the corridor and travel crossing the corridor), and all directions. A threshold slider is included to allow users to change the threshold of the horizon chart’s colormap (maximum value up to which the color changes), which can be used to emphasize energy variability of specific ranges. Finally, the range slider allows the user to choose the size of the time interval they are analyzing. This facilitates further exploration as one can choose between a high-level view, a very detailed view, or anywhere in between.

2.5 Animated Trails with Halos

The second visualization in our dashboard is a map-based visualization, which provides a more geospatial view of the vehicles in the system. Each vehicle is represented by a circle-shaped marker, which moves across the simulated vehicle trace. The circle is colored by vehicle speed, but could also represent other variables.

Around each circle, a halo is rendered to visualize energy use. It is colored by acceleration (blue) and braking (red) energy. Depending on the amount of acceleration and braking, the size and color of the halo will change. At maximum braking energy, the vehicle has a large, vibrant red halo. With less braking, the halo shrinks to a smaller, pale red halo. When coasting (i.e., neutral energy state), the halo is the same size as the vehicle marker, and at a neutral pale yellow tone. When the vehicle accelerates, its halo grows again, with colors ranging from pale blue for a small amount of acceleration to a vibrant blue at maximum acceleration.

On the road, we also indicate traffic light status by rendering small squares on the intersection. The squares are colored by traffic light state (red, amber, green), and they are placed for each approach direction to indicate the current traffic light conditions. This helps in interpreting acceleration and braking behavior. Alternatively to this type of display, we have considered adding colored stop bars or other more detailed displays, but we found that it interfered with the visualization of vehicle speeds and energy use.

The bottom of Figure 2 shows a screenshot of the animation. One can see westbound traffic accelerate between Gunbarrel Road and Lifestyle Way, starting at a lower speed (orange marker) and speeding up towards the speed limit. Our visual dashboard enables coordinated views between the web map-based animated trails with halos and the horizon chart. The horizon chart can dynamically filter and visualize the energy consumption of intersections within the web map's viewport extent. the web map-based animated trails with halos are developed using OpenLayers web map engine and WebGL libraries.

2.6 Sunburst

Sunburst diagrams are powerful tools for exploring and visualizing multivariate categorical data [1]. We present a sunburst diagram that visualizes the relationship between the individual intersections, approach directions, different types of energy consumption, and signal phases. Each variable is represented by a ring on this diagram. The innermost ring is divided by phase (traffic light color). Each phase is sectioned off further by the type of energy use. Finally, each energy use is sectioned off by intersection and travel direction. We added a user-interaction feature to allow the change of ring orders, which can be useful for revealing associations between different variables. The Sunburst chart is created using the D3.js.

Figure 3 provides an example for the order described above. The phase ring indicates that 77.9% of vehicle energy use happened during green phases. One can see immediately that the proportion of braking energy (red) is much higher during red lights (27.8% of energy use is braking) than during green lights (8.5% of energy use),

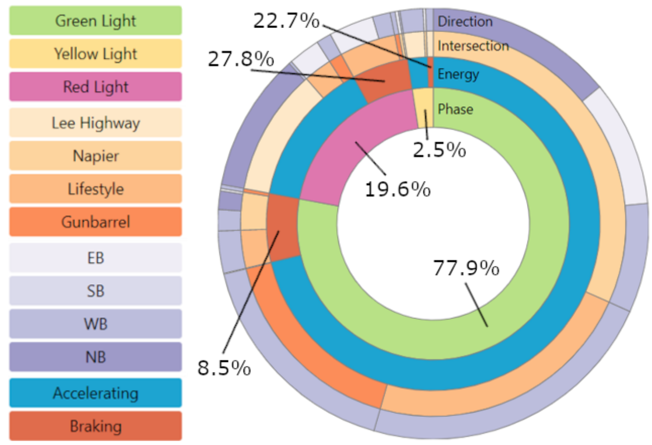

Figure 3: Sunburst chart for summarizing total vehicle energy consumption of stop-and-go traffic flows in relation to signal phases at multiple intersections.

with yellow lights falling in-between (22.7% of energy use). The intersection ring indicates that the highest acceleration energy during green lights happens at Napier (44.4%). The percentages have been annotated for the benefit of easier readability of the paper, however, the interactive version of the chart displays these percentages during hover-over.

3 CONCLUSION

Overall, the dashboard and visualizations have already enabled us to identify potential bottlenecks. We believe that it will be tremendously useful for optimizations of traffic signal schedules and vehicle speed control once measured vehicle data is available. The horizon chart provides a side-by-side view of traffic energy during a given time frame, and the provided filters let users have a detailed look at energy use between different intersections or for different travel directions within a single intersection. The animated vehicle traces provide a better view of individual vehicles and their acceleration and braking as the animation plays out, whereas the northbound traffic is braking at all three intersections visible in the screenshot. The visual dashboard is developed using lightweight and open-source web technologies, rendering it adaptive and flexible for visualizing vehicle energy consumption estimated using other methods or in other traffic corridors.

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REFERENCES

[1] Anne S. Berres, Haowen Xu, Sarah A Tennille, Joseph Severino, Srinath Ravulaparthy, and Jibonananda Sanyal. 2021. Explorative Visualization for Traffic Safety using Adaptive Study Areas. *Transportation Research*

Record (2021), 0361198120981065. https://doi.org/10.1177/0361198120981065 arXiv:https://doi.org/10.1177/0361198120981065

[2] Stephen Few and Perceptual Edge. 2007. Data visualization: past, present, and future. *IBM Cognos Innovation Center* (2007).

[3] Sarah Goodwin, Jason Dykes, Sara Jones, Iain Dillingham, Graham Dove, Alison Duffy, Alexander Kachkaev, Aidan Slingsby, and Jo Wood. 2013. Creative user-centered visualization design for energy analysts and modelers. *IEEE transactions on visualization and computer graphics* 19, 12 (2013), 2516–2525.

[4] Shauna L Hallmark, Ignatius Fomunung, Randall Guensler, and William Bachman. 2000. Assessing impacts of improved signal timing as a transportation control measure using an activity-specific modeling approach. *Transportation Research Record* 1738, 1 (2000), 49–55.

[5] Shean Huff. 2017. Sensible driving saves more gas than drivers think. https://www.ornl.gov/news/sensible-driving-saves-more-gas-drivers-think/.

[6] Orkun Karabasoglu and Jeremy Michalek. 2013. Influence of driving patterns on life cycle cost and emissions of hybrid and plug-in electric vehicle powertrains. *Energy Policy* 60 (09 2013), 445–461. https://doi.org/10.1016/j.enpol.2013.03.047

[7] Tim LaClair, Zhiming Gao, Ross Wang, Jackeline Rios Torres, Jibonananda Sanyal, Rajasekar Karthik, Phil Nugent, Srinath Ravulaparthy, and Anne Berres. 2019. Development of a Real-Time Mobility Control and Visualization System with Predictive Vehicle Speed Control for Connected and Automated Vehicles (CAVs). (5 2019). https://www.osti.gov/biblio/1560405

[8] Meng Li, Kanok Boriboonsomsin, Guoyuan Wu, Wei-Bin Zhang, and Matthew Barth. 2009. Traffic energy and emission reductions at signalized intersections: a study of the benefits of advanced driver information. *International Journal of Intelligent Transportation Systems Research* 7, 1 (2009), 49–58.

[9] Madhava Madireddy, Bert De Coensel, Arnaud Can, Bart Degraeuwe, Bart Beusen, I. Vlieger, and Dick Botteldooren. 2011. Assessment of the impact of speed limit reduction and traffic signal coordination on vehicle emissions using an integrated approach. *Transportation Research Part D-Transport and Environment* 16 (10 2011), 504–508. https://doi.org/10.1016/j.trd.2011.06.001

[10] Andreas A Malikopoulos, Christos G Cassandras, and Yue J Zhang. 2018. A decentralized energy-optimal control framework for connected automated vehicles at signal-free intersections. *Automatica* 93 (2018), 244–256.

[11] Charles Perin, Frédéric Vernier, and Jean-Daniel Fekete. 2013. Interactive horizon graphs: Improving the compact visualization of multiple time series. In *Proceedings of the SIGCHI conference on human factors in computing systems*. 3217–3226.

[12] PTV Group 2019. *Vissim 11 User Manual*. PTV Group, Karlsruhe, Germany.

[13] Jackeline Rios-Torres and Andreas A Malikopoulos. 2016. Automated and cooperative vehicle merging at highway on-ramps. *IEEE Transactions on Intelligent Transportation Systems* 18, 4 (2016), 780–789.

[14] John Thomas, Shean Huff, Brian West, and Paul Chambon. 2017. Fuel consumption sensitivity of conventional and hybrid electric light-duty gasoline vehicles to driving style. *SAE International Journal of Fuels and Lubricants* 10, 3 (2017), 672–689.

[15] James J Thomas and Kristin A Cook. 2006. A visual analytics agenda. *IEEE computer graphics and applications* 26, 1 (2006), 10–13.

[16] Francesco Viti, Serge P Hoogendoorn, Henk J van Zuylen, Isabel R Wilmink, and Bart Van Arem. 2010. Microscopic data for analyzing driving behavior at traffic signals. In *Traffic Data Collection and its Standardization*. Springer, 171–191.

[17] Hong Wang, Meixin Zhu, Wanshi Hong, Chieh Wang, Gang Tao, and Yinhai Wang. 2020. Optimizing Signal Timing Control for Large Urban Traffic Networks Using an Adaptive Linear Quadratic Regulator Control Strategy. *IEEE Transactions on Intelligent Transportation Systems* (2020), 1–11. https://doi.org/10.1109/TITS.2020.3010725

[18] Bao-Lin Ye, Weimin Wu, and Weijie Mao. 2015. A Method for Signal Coordination in Large-Scale Urban Road Networks. *Mathematical Problems in Engineering* 2015 (09 2015), 1–15. https://doi.org/10.1155/2015/720523