ABSTRACT

MOTORSPORT PERFORMANCE ANALYSIS:
A SPATIO-TEMPORAL APPROACH

By

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As data logging technologies advanced, a point was reached where amateur motorsport enthusiasts could now log their vehicle's data while competing in motorsport events. Many drivers take advantage of these new data logging technologies but lack options for analyzing the data during and after motorsport events beyond standard tables and two-dimensional graphs. This thesis investigated the use of GIS as a tool for analyzing data collected during a motorsport event through time geography approaches and three-dimensional geovisualization techniques. Data were collected from the vehicle to analyze the speed and handling of the car while heart rate data were collected from the driver to help understand the driver's emotional state while navigating the course. Analysis of the data showed that time geography visualizations in a three-dimensional environment could help drivers better understand the data that had been collected from their vehicles and themselves and use it to improve their future performances when driving in motorsport events.

MOTORSPORT PERFORMANCE ANALYSIS:
A SPATIO-TEMPORAL APPROACH

A THESIS

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ACRONYMS

BPM	Beats Per Minute
CSV	Comma Separated Value
g	Acceleration
GIS	Geographic Information System
GPS	Global Positioning System
hp	Horsepower
MPH	Miles Per Hour
OBD-II	On-Board Diagnostics System II
OS	Operating System
RPM	Revolutions Per Minute
SAE	Society of Automotive Engineers
SCCA	Sports Car Club of America
TIN	Triangular Irregular Network

CHAPTER 1

INTRODUCTION

Auto racing has been a part of history dating back to the nineteenth century and as competition levels rose, technologies developed to allow for better performance of racing vehicles. In the 1970s race team engineers began equipping vehicles with computer components which gave them the ability to make adjustments to the vehicle more easily and provide configuration systems to more accurately dial in the best performance for the vehicle (Haney 2001). These systems enabled racecar drivers to work with their team engineers to find a setup that was as perfect as possible for the vehicle through its configuration, which boosted the driver's confidence and positive emotions while driving. This gave them the confidence to push their vehicle closer to its performance capacity and drive faster (Watkins 2006).

For racing teams, vehicle components need precise tuning and computer systems that provide higher accuracy for the tuning and better monitoring of the vehicle components (Khan and Sonti 2009). As racing teams developed engineering and software systems that could monitor their vehicles' components and related performance on the track with utmost precision, the technologies began to be incorporated in standard road vehicles. The U.S. Federal Government mandate that vehicles sold since 1996 would require on-board diagnostic (OBD-II) systems has led to a quick and easy way for any driver to plug-in and access their vehicle's computer and sensor system (EPA420-F-

02-014). With that inclusion of computer systems and advanced sensor units in vehicles that are available from a dealership, the technology is accessible for a broad audience to monitor their vehicle's performance.

At the same time, recent Global Positioning System (GPS) technology has been advancing with the introduction of smaller devices that provide high levels of accuracy. GPS has been incorporated into many devices such as cameras and smart phones—e.g., the Apple iPhone or Android —to enable users to geo-tag (attaching GPS metadata) their location when taking pictures or using other applications on their smartphones. Standalone GPS devices with Bluetooth technology are also available to provide an option for even higher accuracy and increased data collection rates, such as one tenth second, in comparison to typical camera or smart phone devices which collect every second or slower.

As ODB-II and GPS technologies have advanced, a point has been reached where people who race as a hobby can now log their vehicle's data while competing in motorsport events. Statistics from a 2007 Sports Car Club of America (SCCA) Membership Demographics study found that in October of 2006 there were over fifty thousand registered members in the club (SCCA 2007). This represents only a small fraction of people racing in their free time, as there are a number of other racing groups which have competitions running year round. Many of these racing drivers are taking advantage of these new data logging technologies, as can be seen by the number of devices and phone apps now on the market. Drivers can log their data using an assortment of high end data logging units or off-the-shelf OBD-II readers that communicate with many different smart phone applications. The downfall for these hobbyists is that they have no useful way to visualize their data during or after an event due to the limitation of existing data logging technologies.

The majority of people in the racing community are unaware of what GIS is, resulting in large amounts of untapped data that could be more informative in a GIS setting. There might be some people who bring their data into online mapping services such as Google Earth to create their data as maps, however it is difficult for them to spatially analyze the data and visualize it without advanced Google Maps development knowledge. Currently, GIS systems are used little in the motor racing community and industry that are largely relying on tables and advanced scripting tools through languages such as Java or Python.

The Purpose of the Study

The research ideas, processes, and work put forth in this thesis come from the personal experiences and insight of the author that indicate GIS could be used successfully with motorsport data. Goals of this thesis include to (1) develop a GIS application for motorsport analysis, (2) demonstrate that the application provides the drivers with more advanced ways to analyze their data than existing applications without GIS, and (3) understand relationships between the driver’s emotions and his or her performances. The GIS application developed in this thesis was based on existing knowledge of time geography concepts. Data for this research were collected including spatio-temporal information of a vehicle and heart-beat rate and emotions of the driver using a system that is common amongst hobbyist racers. The data and the GIS application were evaluated from a data-quality perspective, assessing the suitability of data accuracy and visualizations. Specifically, the research addresses the following procedures: (1) use GIS to model the performance of a driver and vehicle based on approaches of time geography; (2) geovisualize the combined aspects of racing performance to determine where a driver could perform better; and (3) assess the capabilities and limitations of motorsport data in a GIS environment. Time geography has rarely been used in motorsports and there exists a gap in the existing research of a topic. Therefore a new study that applies GIScience methodologies to motorsports application is necessary.

Outline of the Thesis

This thesis consists of six chapters. Chapter 2 reviews existing literature that will set the basis for this research, but which also leaves much to be researched. In chapter 2 data logging equipment, its use in motorsport applications, approaches of time geography and emotional geography will be reviewed through literature. Chapter 3 discusses data collection in the field study and analysis methodology used in this research. The chapter consists of a device for data acquisition, a vehicle used in the experiment in the field, and the location where the motorsport data were collected. The vehicle's engine, chassis and sensor specifications will be discussed to justify why each was used. The methodology of the data analysis introduces specific time geography concepts that were modified for use with motorsport data, specifically the *performance prism*. These concepts are discussed from their design based on time geography concepts to their application in motorsports data and other possible topics. In addition, data collection and analyses of the heart rate and emotional data of the driver are included in chapter 3. Chapter 4 introduces the empirical data recorded from the vehicle and the results of the combined data discussed through each type of analysis done in this study. Chapter 5 summarizes the findings of this thesis and highlights the contributions to the field of geography.

CHAPTER 2

LITERATURE REVIEW

This chapter will address three focused areas of interest for this thesis: I review existing studies that deal with (1) data acquisition equipment and the current use of those data in motorsports, (2) time geography methods and their application in both sports and vehicle movement, and (3) comparing literature that provides standards for GIS data in regards to accuracy, usability, and visualization. I will argue that the lack of geographical setting in a map environment and also the absence of three-dimensional visualization can leave much of the data unused. Second, I will focus on existing methodologies of time geography approach and their limitation of application in both sports and urban vehicle movement.

Data Acquisition and Analysis

Data acquisition refers to computer systems which are used to collect and process signals that measure conditions in the real world. These signals typically come from a sensor of some kind. The sensor will record physical parameters and convert them into electrical signals which are then sent to the computer to be recorded. Data acquisition can be used in practically every subject matter to record some sort of signal, with common uses in fields such as meteorology, biology, engineering, and chemistry.

Data acquisition equipment was first developed by IBM in 1963 with the announcement of the IBM 7700 data acquisition system. The technology could collect data from up to thirty-two sources simultaneously and then process and transmit them to up to sixteen remote display or printing devices. And with computer technology advancing at a very fast pace, data acquisition systems were constantly being upgraded to use less space, collect data from more sources, and process results more quickly.

Data Acquisition Use in Vehicles

Data acquisition eventually made its way into the automotive market to collect vehicle data for businesses, educational research and civic applications. The wide variety of uses for vehicle data has led to a large offering of devices which can be used in applications, such as analyzing traffic flow (Hassan and Patterson 2006).

Data Acquisition Use in Motorsports

Before data acquisition was first used by Chevrolet in the 1970s (Haney 2001), the process of engineering a better racecar was acquired from the direct input of the driver as they spent long periods of time in the vehicle, driving it around a test track. This was done to determine if changes to the engine and/or chassis gave the car better handling and/or speed (Parker 2010). With the technological advancements in computers and monitoring systems, these traditional methods of driving by experiences and intuition have taken a back seat to the more scientific approach to improving the driver and vehicle (Purnell 1998). While a driver's personal opinion is still accounted for in vehicle setup, the tools brought forth by computer technology improve upon the development of a racecar when compared to a driver's seat time alone. These tools are very complex and can be difficult to implement correctly. Before engineers can log a vehicle's data, they must first design the system for monitoring and collecting data. This design takes into account the data acquisition unit itself with its weight, size, and power usage, and also the variables which the unit will record and the sensors that will collect those variables (Meyer 2002). Complex data acquisition systems bring large amounts of data to engineers and there is often times discussion of the problem regarding how to handle the data that has been collected. Often times, the first thing a team will do is cut down on the number of variables they monitor (Hemingway 1990).

For motorsports there are two distinct data acquisition device types that are often used, in-car and out-of-car (Stanfield and Temple 1987). In-car hardware is designed to monitor different attributes of the vehicle, such as engine temperature or oil pressure, and display the data in the car itself for the driver to view. The out-of-car system records the same types of data and processes it outside the vehicle for modeling and analysis. Out-of-car systems are more complex than in-car systems because they allow for more data to be recorded with the option to store it on the device or transmit the data to a computer where someone else can process the data.

A racecar is a vehicle with a complex design of components that allow it to travel faster and handle better than a typical road car. Many of the components are adjustable to allow for precise changes that need to be made depending on the location of a race, the weather, and the driver using the vehicle. Team engineers constantly monitor these components and the vehicle's overall performance using a number of sensors within the vehicle to determine if there are issues with the car, or if the driver is taking advantage of the vehicle's optimum performance (Purnell 1998). Sensor data are used both in real time analysis and also after a driver has finished to understand what has occurred with the vehicle and driver during a race (Purnell 1998; Stoffman et al. 2004; Southward and Conner 2008).

Successful racing comes down to the fundamental idea that the vehicle must complete a lap as fast as possible. This is done by having a vehicle that can have a higher speed and can handle turns better than other vehicles in the competition. There are a number of sensors that can record both speed and handling that range in accuracy and complexity. When determining speed possible sensor choices may include: wheel rotation, differential air pressure, optical, GPS, and Doppler phase shift (Ramsay 1996; Ditchi et al. 2002; Corrsys-Datron 2009). Of these devices the Doppler and optical sensors provide the highest level of accuracy but are extremely expensive (Ramsay 1996; Ditchi et al. 2002; Corrsys-Datron 2009). GPS accuracy is dependent on the device used and also the area surrounding the vehicle's location as interference can occur. The handling abilities of a vehicle are recorded through the vehicle's longitudinal and lateral acceleration (Milliken and Milliken 1995) and can also be recorded by a number of different accelerometer sensor options. These sensor options all use a similar design of a mass suspended by a protective casing. The casing is mounted to the vehicle and when the vehicle moves, the acceleration of the mass connected to the casing creates the acceleration data. The differences between sensors are based on the supports used and include a piezoelectric material, a piezoresistive material, or a capacitive plate (Westbrook and Turner 1994; Segers 2008).

Vehicle health is also an important aspect to monitor in a racecar, as an unhealthy vehicle can eventually stop working if problems are not addressed early. Two common problems that arise in a vehicle relate to pressure and temperature of different liquid components in a vehicle. The pressure and temperature is often monitored to determine engine health. Fuel, oil, and coolant are the three major liquids that are measured using pressure transducers (Westbrook and Turner 1994). Temperatures for oil, water and air are typically monitored using thermocouple, thermistor, infrared, or resistive temperature sensors (Segers 2008). Along with vehicle health, pressure and temperature systems are also being used to monitor the abilities of the driver. Pressure is used specifically for brake pedal use and temperature can be used for both brake disc temperature and also tire temperature. These sensors help determine if a driver is pushing the car too hard, or not driving it hard enough.

The next most important datasets relate to vehicle positioning on the track and include sensors for vehicle yaw and vehicle ride height. Vehicle yaw is the rate of change of the heading angle of the vehicle (Meriam and Kraig 1998) and ride height is the distance between the race track and the floor of the vehicle (Milliken, Milliken, and Best 1995). These two factors help determine handling performance as yaw can help determine if a car is experiencing understeer or oversteer (Pi Research 1997) and ride height changes can affect the vehicle’s aerodynamics which can result in loss of handling performance (Milliken, Milliken, and Best 1995). There are sensors that monitor other aspects of a race car, such as aerodynamics, wheel load, and torque, however they are much more specialized and do not apply to this research and will not be covered. Many of the sensor systems found in race cars are now also found in standard vehicles available from a car dealership. Typically these will consist of the vehicle health sensors to monitor if the vehicle needs service or is having a major problem. But some car manufacturers sell performance cars that include more unique sensors such as accelerometers, torque and yaw sensors. Vehicles manufactured after 1996 include plug-in systems that allow mechanics and owners to access the sensor systems with specialized hardware (Environmental Protection Agency [EPA] 2002).

Data Analysis in Motorsports

Data analysis in motorsports can be traced back to a single person, Chuck Carrig (Nisley 2007). In 1963, while working for Ford Motor Company, he completed a computer program called PG 1493. The program, which was written in the computer language Fortran and run on an IBM 704 computer, was used to develop suspension geometry design for the Ford GT40. Users would input a number of desired vehicle suspension variables, run the program, and receive printed results and graphs of how the vehicle would perform with the input variable. The computer program took two weeks to run the process, but when compared to the typical twenty-three week drafting design, this was considered a leap forward. The program led to suspension geometry designs that helped Ford claim wins in a number of racings series and sell production model vehicles.

There are currently a number of software applications available that can visualize data collected from vehicles that include two tiers, racing grade applications and public applications. Both allow for visualization of the data collected from a vehicle and simple visualizations with maps or graphs. Many racing applications provide additional analysis abilities, with each having specialized analysis unique to their software.

There are a number of features that are typically found in racing data analysis software suites (Parker 2010). These tools include:

1. Distance Plots--A plot of vehicle attributes on the Y axis in relation to distance on the X axis.

2. Time Plots--A plot of vehicle attributes on the Y axis in relation to time on the X axis.

3. X-Y Plots--Typical a scatter plot of vehicle acceleration rates to view the handling of the car, commonly referred to as the traction circle.

4. Histograms--Charts that allow data to be split into bands which represent attribute types. The bands are shown on bars with the bar size representing the amount of time that the band was recorded.

5. Math Channels--Mathematical calculations that combine multiple attributes to determine a represented encompassing attribute which is then shown on a chart.

6. Track Maps--A basic map of the race track can be either pre-generated and part of the software or can be created based on the data collected, as the data will take the shape of the track. Using the data to create the track map typically shows the lines that the car drove on the track, but not the true track area.

Applications available to those not in professional auto racing typically include the basic visualizations mentioned above but do not include any kind of advanced visualization possibilities with the data. Advanced visualization would be features such as vehicle animation, driver control animation, or math channels that display computed attributes. Users can import their data into some existing software such as Microsoft Excel or other spreadsheet tools. Users of such tools can create graphs, charts, and maps that display the data from an event in a very simple visualization.

Applications used in a professional auto racing environment enable the engineers to display data in the basic formats listed above, along with specialized analysis that will be available depending on which software they use. With the advanced tools, often racing teams are able to analyze and visualize vehicle handling data and other specific aspects of the race car while it is actively driving. This is a feature that a basic system does not support. However, neither the common data visualization methods for advanced nor basic software provide the ability to visualize the data in three dimensions on a map.

The Emotions of Motorsport

As Saville (2008) stated of his parkour experiences, “My emotional engagements with space changed along with my mobility in it” (896). The same can be said of “automotive emotions” (Sheller 2004) and the feelings associated with car use. Traveling through a landscape, be it motorsports, parkour, or anything else, sights and feelings are taken in different ways and little has been done to relate the place with the movement and meaning (Spinney 2006). “Emotions are felt in and through the body, but are constituted by relational settings” (Sheller 2004) and understanding the relationship between the location on the track and the emotional meaning behind it for that driver will allow for a greater level of understanding of his/her performance. The work in this thesis uses heart rate data from the driver to provide a snapshot of the emotional relationship to the track in order to better understand the overall performance data. A rise in heart rate in an already intense setting will most likely reveal a location where the driver experienced fear. If the driver experiences a perceived fear of the car not performing up to standard in a location on track, there needs to be a reason behind this that can be analyzed (Saville 2008). This is especially true in motorsports, as those fears due to car setup can be realized: the vehicle may be improperly balanced, or running incorrectly. A driver not only feels the vehicle itself, but can feel the changes through the vehicle as well (Sheller

2004). Team engineers can determine what adjustments to make to a vehicle's setup as a response to the emotions that have been shown (Katsis et al. 2008). Sometimes the vehicle does not need to be corrected but emotions are still detected. When an emotional response like this occurs, which could possibly alter the behavior of the driver, the engineers can provide the driver with guidance and support to help them overcome this response (Katsis et al. 2008). In this thesis, the drivers can use the heart rate data to determine where they are having emotional responses on the course. Knowing where on the course they are having an emotional response will allow them to focus on their performance in those locations.

Along with the emotional response of fear is risk, which is common in motorsports as pushing a car harder means a greater risk of losing control of the vehicle. Risk is also combated in motorsports with practice, as perceptions of risk become clearer, and therefore lessened, with continued movement (Saville 2008). The negative emotion associated with risk begins to fade as the driver becomes more comfortable with himself and the vehicle. The measurement of the driver's heart rate should help visualize this, as there should be an indirect relationship between the two. As comfort level rises, heart rate should drop. Risk and comfort will be factors for the driver in this thesis, as they will be driving a vehicle which they have never driven before. With no prior experience with the vehicle there will be greater risk driving the car quickly, as the driver will not know the vehicle's limits. A driver that is overcome with negative emotions such as fear (associated with risk) or a general level of stress will have impaired perception, thinking, and judgment which can lead to misinterpretation of events (Katsis et al. 2008). Misinterpretation of events is a situation that those in the sport wish to avoid, as a driver may not only compromise himself, but also other drivers, endangering lives (Katsis et al. 2008).

Feelings and emotions for particular time and space can be taken into account to dictate a person's reaction in that location (Katsis et al. 2008). Similarly, there are multiple feelings and emotions that occur when a driver is navigating a race track (Watkins 2006). These feelings are neither solely created by the driver or the vehicle, but are a result of the affective relationship between the two (Sheller 2004). Whether it is a hesitation with the way the vehicle "feels" or a personal hesitation due to not trusting one's own abilities, a driver's lap time can differ greatly because of these emotions (Katsis et al. 2008). These emotions can play a major factor in contributing to an increased heart rate during competition, among other things. For example, a comparison of two drivers shows that Villeneuve, a more emotionally composed driver, keeps his heart rate 25 bpm slower than another driver, Pironi, while accelerating vehicles to one hundred miles an hour (Watkins 2006). These differences in heart rate partially controlled by emotions, lead to differences in driving performance. In this perspective, "emotions are not simply felt, but invoked, regulated, and managed" (Sheller 2004, 226) from the routine movements through which a driver moves through a track.

Representing spatio-temporal emotions along with the performance data of the vehicle in maps might allow for a more complete picture coming from both the brain of the vehicle and the mind of the person. The emotions in maps are often represented with multiple colors (Nijdam 2005) and can be brought into time geography very easily. Color-specific visualization of emotions can help with the larger picture of how and why drivers navigated the course the way they did.

Time Geography Approach

Time geography consists of a number of concepts which study humans in space and time, using spatial analytical methods and visualization to geographically construct their individual movements (Kwan and Lee 2004). Torsten Hagerstrand (1970) developed the approach as a way to provide a more detailed structure to generalized spatio-temporal social processes. Space and time are represented in time geography through the use of three dimensional cubes, which represent the locations traveled--i.e., X and Y coordinates--and also the time spent during traveling or being stationary--i.e., Z coordinate. Dubbed the "aquarium" (Hagerstand 1974; Miller 2005), other time geography concepts such as domains, stations, bundles, lifelines, and prisms are found within this space, as seen in figure 1 below.

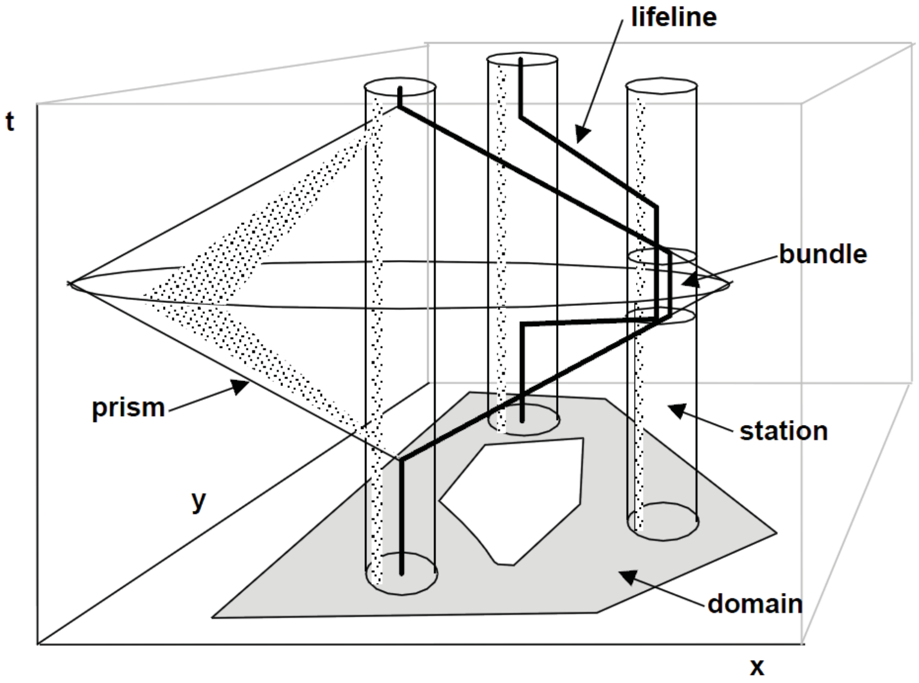


Figure 1. The Space-time Aquarium and Related Pieces (Moore et al. 2003).

The space-time aquarium and the time geography concepts can be useful to analyze and visualize motorsport data. The aquarium's time dimension can represent a lap of a race track. Figure 1 above shows how the "domain" is a "control area" (Hagerstrand 1970) which confines travel and which very much resembles a race track space used in a motorsport race. The "lifeline" is typically a path which an individual travels in the time frame of the aquarium and that is modified to become the path of the vehicle through the track environment. The "station" is used as a geographic space where separate lifelines tend to "bundle" together. In the case of motorsport research, locations of the stations on the track will be used where individual performance can more change lap times than a portion of the track that is simple, such as a straight. An example of a track location where people will perform differently would be a very sharp left turn, so a station would be designated there to highlight data in that location. The bundle will be used when more than one lap's performance is found to be close to identical in a station, meaning on two separate laps, a corner was driven with similar performance numbers. Bundles would be used to visualize locations where lap performance is consistent between laps.

Lastly, motorsport data can be analyzed and visualized by using the space-time prism (Miller 2005), another concept of time geography. Typically, a space-time prism exists within a space-time aquarium and represents the total space which is reachable by an individual in a specific amount of time. In motorsports the space-time prism would take on a new representation as a friction circle, a diagram which shows vehicle handling as well as speed. A friction circle is a two dimensional visualization of vehicle handling relative to speed, as seen in figure 2 below (Milliken and Milliken 1995).

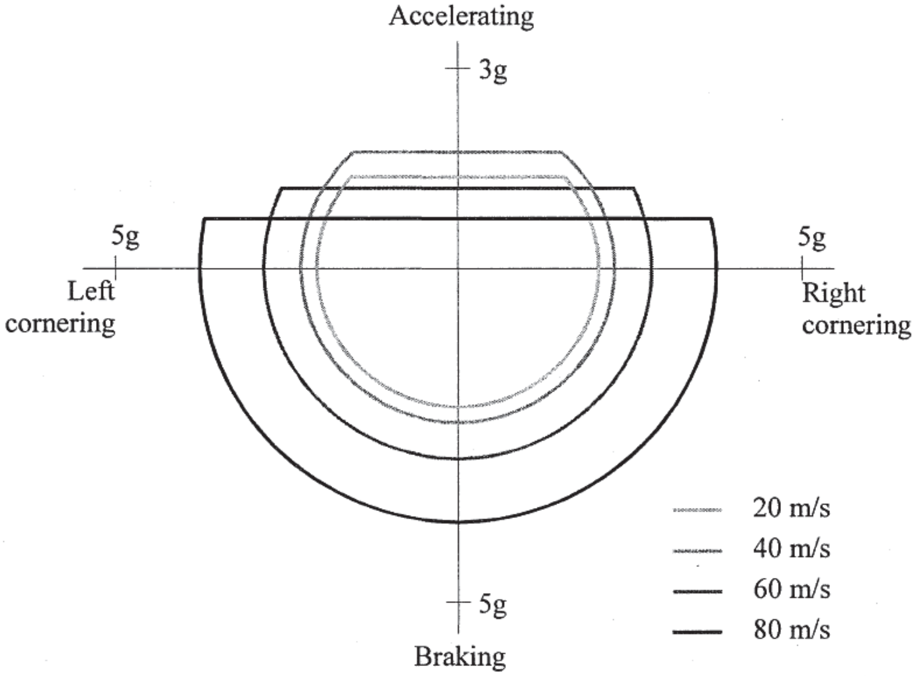


Figure 2. A Formula One Racecar's Friction Circle (Casanova 2001).

Figure 2 visualizes how speed changes the handling of a race vehicle. In the case of a Formula One car, traction would be higher at faster speeds, due to the downforce of the vehicle. In figure 2 you can see as the speed of the car increases, the g forces in cornering rise as well. Because this example is two dimensional, you cannot see a full relationship between handling and speed easily. If the example was in three dimensions, speed could be represented on the third axis to create a prism type shape to distinguish the performance relationship between handling and speed of the vehicle. As racing data is collected the potential performance that the vehicle can achieve can be represented in a space. As the driver travels through stations, their handling of the vehicle can be visualized within a prism of their potential ability. The space-time prism typically shows the potential path space (Tebmann 2006). In this research the prism is used to visualize the potential performance of the vehicle, rather than the potential path. For the purpose of this study this approach will be referred to using the term “performance prism.”

The space-time prism is useful concept of time geography, as can be seen with its applications in other studies. Often these applications modify the space-time prism. An example of this would be trip planning within transportation networks, where a prism is designed in which the shape becomes a triangle which visualizes how speed would affect the individual’s ability to reach a destination in a given time (Tebmann 2006). The prism has also been used in transportation with distinct networks, showing the possible network paths within the prism (Downs and Horner, 2012). Similarly, with three dimensional visualization software becoming more commonly used, space-time prisms have taken on new shapes with expanded variables such as obstacles in space that impede travel (Delafontaine et al. 2011). In 3D environments the space-time prism has been a key success to expanding time geography as a way to model geographic concepts (Kraak 2003).

The space-time activity density surface can be useful to represent the intensity of activity in space (Kwan and Lee 2004). A 3D raster dataset can be generated using kernel estimation in a cube which consists of X/Y/Z axes. In the cube, time can be represented on the X-axis and distance from home can be represented on the Y-axis. In the cube, the 3D extrusion on the Z axis can represent the density of the type of activity occurring at that particular time and distance from home. In their work, three density surfaces were created to visualize the non-employment related activities of employed women, employed men, and the differences between the two.

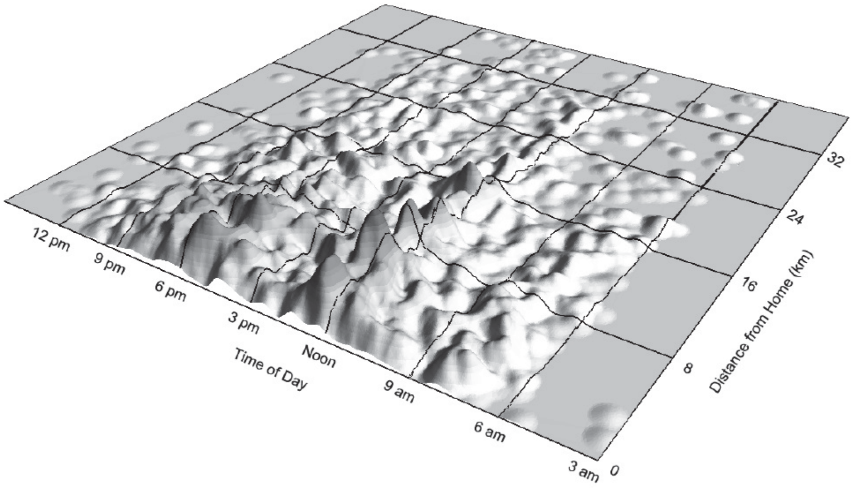


Figure 3. Kwan's Space-time Activity Density Surface (Kwan and Lee 2004).

Activity density of employed women is shown in figure 3. This figure demonstrates a number of activities occurring close to home around 12:00 p.m. and around 6:00 p.m. As part of their study, the density for employed men show a similar overall pattern, but nowhere near as spatially correlated as that of women. This type of relationship would not be easy to visualize if the data were presented on a typical two dimensional map. The visualization of events based on time allow for clustering of related data by distance, which on a map might not have been clustered due to being in opposite directions from the original location. Visualizing a confining distance is done more effectively with the time-distance chart and could be modified with different attributes to show other patterns in time.

CHAPTER 3

DATA ACQUISITION AND ANALYSIS METHODOLOGY

In this study data were acquired from the field study and analyzed and represented using GIScience methodologies. This research demonstrates how informed decisions can be made based on data acquisition in regards to performance of both vehicle and its driver. One of the goals of this study is to collect data while the vehicle is driven that can provide the driver real-time feedback. This is because the time it takes to complete a lap may change based on vehicle setup (e.g., suspension, engine, chassis), vehicle health (e.g., air, fuel, internal parts), driver emotions (e.g., fear, confidence, confusion), and so on. GIS software can provide analysis of driving performance data in a cost-effective manner, allowing weekend racing-enthusiasts who participate in motorsports on a budget to gain knowledge that will help them improve their performance. In addition to numerous open source GIS software choices, ESRI offers a single-use license of their ArcGIS software suite for one hundred dollars (ESRI 2014). This software suite, which will be used for this research, is one of the standard choices for well-known GIS software for major GIS-related industries. Providing this type of methodology and model to amateur race drivers who do not have professional race team budgets might help them to gain more detailed knowledge of real-time performance of their vehicle which would lead them to more enjoyable racing experiences. As stated at a Honda training school, “Better performance is measurable, even just looking at one corner” (Mitchell et al. 2000, 16).

This chapter covers the methodology used to collect data for analysis in GIS, including the location, the vehicle, and the hardware used for data collection. It will also cover the methodology used for analyzing and visualizing the data both at the track and afterwards. Because the author has been racing cars in various ways for over a decade, there were a number of options for data collection locations for this research based on the type of racing to compete in. After looking at possible options it was decided to collect data at an Autocross event described below.

Autocross events are a standard type of time-trial event where drivers compete one at a time on a course marked with cones. A driver tries to complete a lap as fast as possible taking penalties to time when cones are hit or navigated incorrectly (SCCA 2009). Autocross events are unique in that they do not occur on a race track, but instead are held on large areas of open pavement with cones marking the course that will be run. This allows drivers to lose control of their vehicle in a safe environment and only hit cones, instead of a barrier found on the edge of a typical race track (SCCA 2009). Typical autocross courses last up to two minutes and are roughly three quarters of a mile long, but the intense focus and quick movements of the vehicle can still lead to driver fatigue during that time. These events can have well over fifty entrants, with each driver typically receiving four runs of the course to record their fastest lap time. Event winners are determined based on car class and who has set the fastest lap time (SCCA 2009). The difference in lap time between the drivers who place first and second will typically be tenths of a second. Monitoring the vehicle to see where time was lost or gained would allow drivers to better understand how they could achieve their fastest possible lap.

Since Autocross events are held on open pavement, there are not many locations which allow for this type of event to occur. In Southern California, U.S.A., there are three locations where Autocross events are typically held; El Toro Airfield in Irvine, CA, Qualcomm Stadium in San Diego, CA, and Auto Club Speedway in Fontana, CA. An Autocross event at Auto Club Speedway was chosen as the location for data collection to be used in this study. This location was selected because they hold multiple events every year allowing for ample opportunities to collect data. Auto Club Speedway is a motorsport complex that includes a full sized Nascar oval track with grandstands, a road track within the oval, and a number of small track areas outside the main grandstand area. The autocross event for this thesis took place in one of the parking lot areas of the complex on May 4th, 2014, shown in Figure 4 below. The weather was sunny with the temperature reaching 88 degrees Fahrenheit.

Figure 4. Aerial View of the Autocross Event.

Autocross is a popular racing series because it allows for any vehicle, from a four-door sedan to a pickup truck with a racing engine, to enter and compete. The vehicle used for this research to record data was a 2013 Nissan 370z. The 370z is the latest model of Z sports car from Nissan which dates back to the original 1970 productions model. The car has a 3.7 liter V6 engine which produces roughly 330 horsepower (Edmunds 2013). The car used for the data collection has a six-speed manual transmission instead of the seven-speed automatic transmission, as manual transmission is preferred for racing as you have direct control of which gear the car is in. This is especially important in Autocross, as a driver will technically spend their entire time on the course in second gear and prefer to have the car not shift into third gear. Shifting into third gear would result in a brief lull in acceleration and also reduce engine response as the RPM falls. The current Nissan 370z, along with older models, is commonly seen at Autocross events and is also used by many racing teams in professional racing series. The field experiment was intended to use the data and analysis from this study to showcase what can be done with GIS to other drivers to peak their interest in trying to do the similar type of analysis of their driving. The car was chosen because it is a car that the author has never driven before and has no experience with. The author wanted to collect data in a vehicle where he would have to learn its handling and performance with each lap he completed. Between laps the author looked over some of the data briefly to see whether he was doing right or wrong on the course.

Before the Autocross event, the vehicle went through maintenance to insure that it would be running correctly for data collection. Basic engine maintenance was completed to install new spark plugs, air filter and oil for better engine health. The brake system fluid was replaced with high-temperature racing fluid and new brake pads were also installed. At the event, tire pressures were set at specific levels and between each run the radiator was sprayed with cold water to help keep the engine temperature down. Tire pressure changes can change the handling of a vehicle (Kasprzak and Gentz 2006) and during an autocross event handling is key to a fast lap time, so drivers are constantly checking their tire pressure at an event. This maintenance was done to help the car perform better and give the author more confidence in pushing the car to its limits, knowing that is was in good shape for each run through the course.

Data Acquisition Hardware

There are many options for data acquisition in vehicles, from off-the-shelf pre-built systems to custom-built systems with specific sensors and processors that enable the users to collect specific data during a race. An advanced data-acquisition system for vehicles may allow new sensors to be easily installed or removed from the setup of the vehicle. The system must also be small and light weight as to avoid changing the overall vehicle weight significantly (Hemingway 1990). For this research it was important to have equipment that would be both accurate but also affordable to amateur drivers. For amateurs, professional-level systems may or may not be necessary due to their over-specification required, as some drivers may not need to have large amounts of data. The ability to log data of basic handling and speed in the vehicle during a race and compare differences between laps will be the most important data acquisition for amateur drivers. Along with that, having the option to log other attributes using the data acquisition system would be beneficial, allowing a driver to further enhance their data logging equipment and add new variables.

Comparing the way a driver maneuvers the course based on handling and speed between laps of the course will allow them to visualize their driving. In addition, if a driver could use data from other drivers they could compare their performance with the other drivers. Considering accessibility to amateur drivers, a data logging system which supports basic functions built-in and that can be upgraded for better performances could be necessary. Such a system would include at a GPS device for logging location data of the vehicle with decent positional accuracy, which would be sub-meter. As smartphones have become more popular, a number of applications have become available which could help an amateur driver utilize the built-in GPS, accelerometer, and Bluetooth capabilities of the phone for collecting data. As of 2013 on the Google Application Store (play.google.com), there are over three dozen vehicle data acquisition applications being sold. Most smartphones have an option to setup a wireless connection with external GPS devices, which would allow for a higher level of GPS accuracy if so desired. The variables of driving performance collected for this thesis were much less than those used by professional racing teams, who monitor a number of systems that have few effects on drivers with little to no skill. Because of this, relatively small amounts of data were collected in this study. This work is, in a way, a continuance of a training system discussed in an existing research of Society of Automotive Engineers (SAE) using vehicle data and simple graphs to show test drivers how their performance compared to an instructor (Mitchell et al. 2000). In their work, the data collected and used to train the drivers included speed, throttle position, lateral force and steering angle. The attributes the author chose to log in the data collected in this study included speed, throttle position, lateral force, brake force, engine RPM, and the driver’s heart rate.

There are multiple options of sensor hardware for vehicle data acquisition, depending on what attributes a driver wants to collect. When using a custom data acquisition device, a driver may have many types of sensors to choose that can be installed in a car for data collection. Recently-built cars which use OBDII systems have sensors built into the car already, providing easy access to the vehicle's data through a single plug. In this thesis, sensor hardware was used due to its low cost and acceptable accuracy that was average of available hardware in the market. The goal of the field experiment in this thesis was to collect data in a way that an amateur driver could afford, therefore the author chose to go with an inexpensive device that provides acceptable accuracy. This was done through using an OBDII plug which could wirelessly transmit data to a smartphone that collects GPS location and accelerometer data.

To collect the data for this research, a Samsung Galaxy Note 2 smartphone, a Scantool On-Board Diagnostics (OBDII) reader and a Zypher HxM wireless heart rate band were used. On the smartphone two applications were running to collect the data, Torque and iCardio. Torque is an application available for Android operation system (OS)-based smartphones which is used to collect OBDII data. This process is done by first connecting the Scantool OBDII reader to the OBDII plug in a car. Once it is plugged in, the Torque application and the Scantool OBDII reader can connect wirelessly, recording data from the vehicle's sensors to a file in the Torque application. Torque allows the driver to select from many available sensors in the car to log the selected data. Torque uses the smartphone's GPS to record real-time location data of the vehicle and its internal accelerometer records the lateral and horizontal forces of the vehicle. Torque combines the vehicle sensor data with the smartphone's sensor data at one second intervals that can be saved as either a .kmz file or a comma separated value (.CSV) table format from the smartphone. The application also lets the driver upload the data in real time to the internet so that it can be downloaded instantly to a computer by other user(s). ICardio, another application that is available on Android O/S-based smartphones can be connected through Bluetooth to the Zypher HxM band to collect heart-rate data in beats per minute (bpm). The application collects data from the Zypher HxM band at three-second intervals and the data can be uploaded to the web where a user can download it to a .csv file format. The total cost of hardware to collect the data with the setup in this study, not including the smartphone, came to $226 including: Scantool OBDII reader ($140), Zypher HxM Bluetooth Heart Rate Sensor ($75), Torque ($5), and iCardio ($6). The smartphone as hardware was not included in the cost calculation, as someone would only be using these applications and devices if they already own a smartphone device. Overall this is relatively an inexpensive setup when compared to advanced systems which would typically cost thousands of dollars (Aim Sports 2014).

Data Collection and Processing

Because this research is based upon an empirical dataset collected during an individual amateur motorsport event, the first step was to collect the data by using the hardware mentioned in the previous section. During the motorsport event, data were constantly being collected and recorded to the smartphone device installed in the vehicle used. This data was also sent directly to the cloud through the smartphone's data service. During the event the author, as the driver, was able to view the data processed in GIS and represented in 2D maps to get an idea of how the vehicle was performing each lap. This was done by downloading the raw data from the cloud to a laptop running ArcGIS. The laptop was not available in the car, but was retrieved after each lap to download and process the data to view the 2D maps. The data was collected from the vehicle in CSV format. Data in the CSV format can be used in GIS, but it must first be pre-processed before it can be analyzed and visualized correctly in GIS. Once the motorsport event was completed, the author was able to put together advanced analysis visualizations using three-dimensional time geography GIS visualizations (e.g. space-time paths, space time activity density surface, and the space-time prism) to get better knowledge of how the vehicle was performing during the event.

For this thesis, the data were reviewed by using GIS during the motorsport event after each lap. At an autocross event time is crucial since a driver only has a few minutes of free time between laps. To allow a driver the ability to see the data quickly during the short free time, a number of ArcGIS tools were developed in this study to process the data through automated GIS. Processing the data through automation allows for the analysis and visualization of the data being available much more quickly than manual processing, so that the performance could be reviewed at the motorsport event. The GIS tools developed in this study processed attribute field names in the CSV tabular data, created new attributes based on calculation of the data logged, and also automated visualization of the data in two dimensional maps. The tools were developed using ArcGIS Model Builder as well as Python, a common computer programming language. The author chose to develop the tools using Python because it is a language that is well-integrated with ArcGIS, Microsoft Excel, and many other software packages that allows seamless automation between multiple programs. Python provides this study the option to further expand the developed tools in the future.

Development using Model Builder and Python Language

Model Builder is a visualization tool in ArcGIS which allows for the user to create a visual representation of processes which automate operations on GIS datasets (Pfaff 2004). A model for ArcGIS was developed in this study using the Model Builder to run a process on the data that comes directly from the vehicle during the motorsport event. The model cleans attribute field names in the data, creates new fields, and converts the X/Y coordinate information into spatial data. Sequencing these steps using the Model Builder helps to create an automated structure which can save post-processing time after the data collection. It allows a driver to convert the tabular data into GIS data and calculate important attributes in seconds, rather than minutes that a manual processing may take for the same procedure.

The developed tool was used immediately after data had been collected from a driver's lap through the course. In the tool, the generic attribute fields from the data logger file were cleaned up and renamed for easier comprehension when accessing them for mapping in ArcGIS installed in the laptop. The data logger fields included names that should be cleaned up such as "g(x)" which were renamed to remove the parentheses because they cannot be used as field names of GIS data. Once this step was completed the model added new attribute fields to the data including the driver's name, change in speed, the lap name they just completed, and track location.

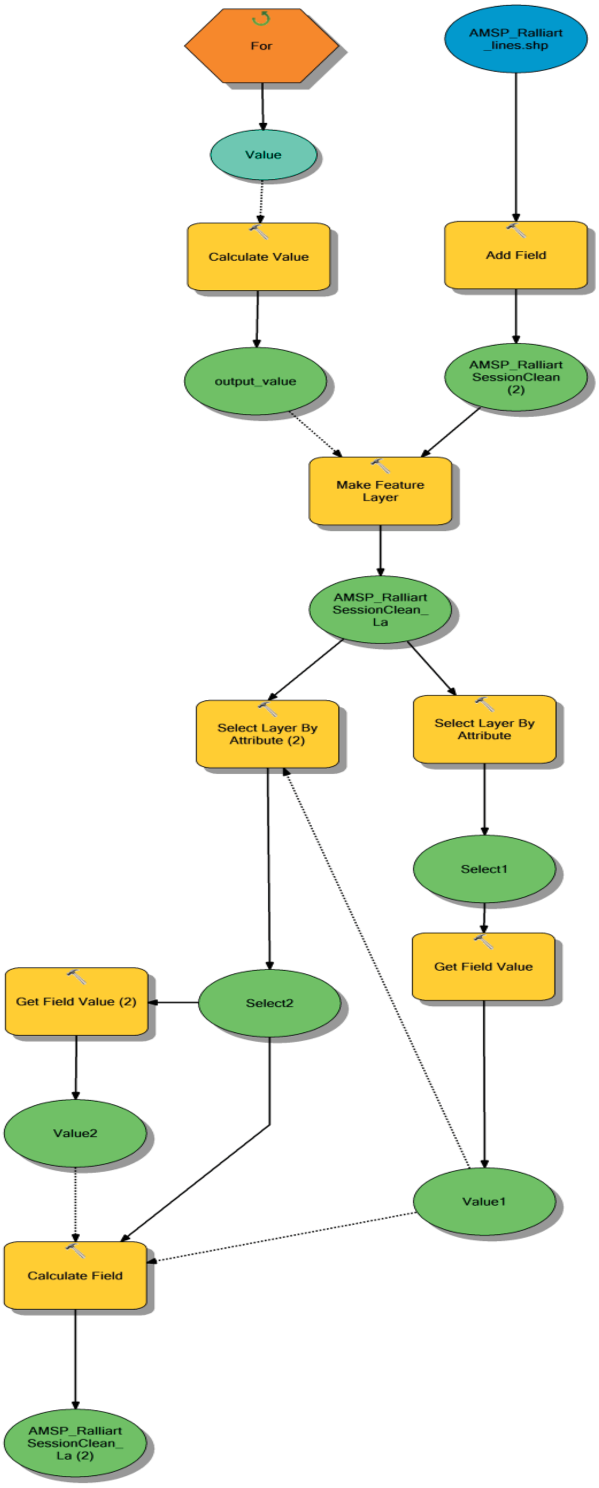
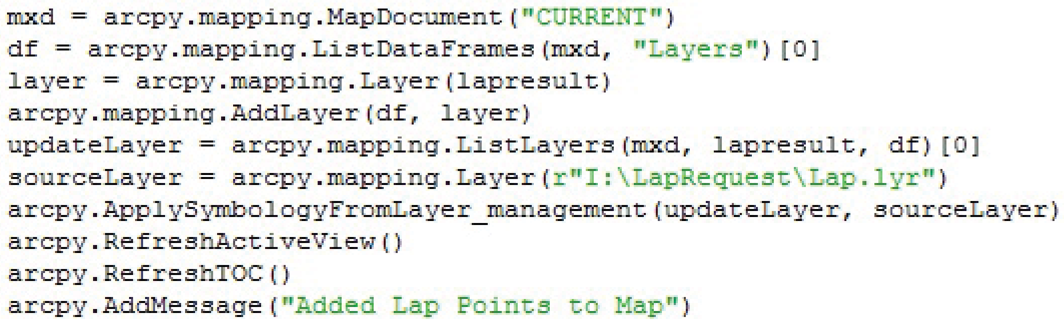


Figure 5. Change in Speed Tool.

New fields were created by using the attribute values from the collected data and also from a separate GIS shapefile which marked each section of the course by a location name. Change in speed was calculated by subtracting the speed of the current data point by the speed of the previous data point. To automate the calculation of the location on the track where the driver was, track data was created before the event started. Generally, drivers are allowed to walk the track before an autocross begins to examine the course layout that they will be competing on. After walking through the course, a polygon shapefile was created for this study to mark the major parts of the course. During the processing after a lap, this shapefile was spatially joined with the point data of the vehicle to calculate its location on the track. Once the data was calculated the model created a spatial dataset of the table by using the Latitude and Longitude information to plot each data point on a map. The spatial dataset was then saved to a geodatabase for use in ArcGIS software. Once the data was finished with this process, a Python script was used to quickly create geovisualization.

Python is an open source language that can be used with a variety of software to automate processes (Wei-Bing Lin 2012). While Python has been used for many years by some developers, it is only recently becoming a commonly-used scripting language as more developers are tailoring its use for specific applications by creating targeted packages of tools for themselves (Wei-Bing Lin 2012). Python has been an integrated part of the ArcGIS software since version 9.2 of the software which was first introduced in 2007 for ArcGIS community. As Python grew in the GIS community, more scripts were developed to be used for spatial processes such as data clean up, georeferencing, and data creation (Abdella 2010).

In this study, Python scripts were developed as part of the automation process to more quickly create two-dimensional geovisualizations based on the collected data. ArcGIS has its own set of development tools specific to Python through the use of a module called “arcpy.” For this research the arcpy module was used to automate the two-dimensional mapping process. This process was developed so that a driver could generate quick reports of the driving data and use it within minutes of completing a lap. That way the driver could analyze the mistakes and possibly do better on their next lap with the knowledge gained.



```
mxd = arcpy.mapping.MapDocument("CURRENT")
df = arcpy.mapping.ListDataFrames(mxd, "Layers")[0]
layer = arcpy.mapping.Layer(lapresult)
arcpy.mapping.AddLayer(df, layer)
updateLayer = arcpy.mapping.ListLayers(mxd, lapresult, df)[0]
sourceLayer = arcpy.mapping.Layer(r"I:\LapRequest\Lap.lyr")
arcpy.ApplySymbologyFromLayer_management(updateLayer, sourceLayer)
arcpy.RefreshActiveView()
arcpy.RefreshTOC()
arcpy.AddMessage("Added Lap Points to Map")
```

Figure 6. A part of the Python Script.

The Python process was developed to have a pre-designed map document ready to be used for producing geovisualization. For this thesis a base map document was created that allowed the driver to choose a location on the track and an attribute to visualize, and the Python script would output a map in a short time. The steps of the python script were to add the data to the map, select the location they wanted to see on the map, zoom to the location and then symbolize the data by the requested attribute with the predetermined symbology settings. The map document was also modified to provide the details of what was being looked at on the map. The driver’s name, the lap, the location on the track, and the attribute being visualized were all represented on the document to provide comprehensive information about the performance reviewed.

To generate maps using Python, the pre-designed map document must have elements and symbols setup so that they can be referenced in Python. Python will replace the referenced element with input text from the data to modify the layout of the map. The processing time of the model developed takes about a minute, which is much faster than manual creation of a map, which typically takes 10 to 15 minutes for basic geovisualization. With the ability to create maps in a short time, maps including specific data were quickly put together after each lap, allowing the driver to analyze his data efficiently. Having the geovisualization of data available between laps quickly and effectively provided better understanding of how the driver could do better on upcoming laps.

For advanced analysis, the data was post-processed after the event to be represented in 3D visualization. To do this the original data collected from the field was used to create completely new data sets that would be further analyzed and visualized in time geography approaches. First, the data was converted from point feature data to line feature data using the ArcGIS Model Builder. A single line feature data of each dataset were created and then broken into pieces based on the point data locations. The line feature data was given attributes of the start speed and end speed of the vehicle and the differences in both types of speed. Next, the tabular data were brought into GIS and mapped not by its latitude and longitude data, but by the lateral and horizontal force data. Doing this put all of the data points into a spatial area very close to 0. All of the data for lateral and horizontal force fell between negative 1.5 and positive 1.5 creating a dataset that could visualize the friction circle, which is discussed in the next chapter.

Heart Rate Data Collection

Heart rate data was collected during the event and was visualized after the race to help determine how emotions might have affected the driving performance during the event. The heart rate data were collected on a separate application from the vehicle data, so it had to be joined to the vehicle data after the motorsport event. The heart rate data were combined with the vehicle data set by joining the tabular data using the time fields from both datasets together. The main issue between the datasets was that the heart rate dataset was logged at three-second intervals whereas the vehicle dataset was logged at one-second intervals. When the two datasets were joined together there were gaps in the heart rate for the seconds that were not recorded when the vehicle did record the data. These gaps between the two datasets were filled in manually once the datasets were joined based on the logged intervals of the heart rate between neighboring time values. For example, if the heart rate was logged at 115 bpm and then three seconds later at 118 bpm, the gaps were filled in at 116 bpm and 117 bpm.

Heart Rate Data Analysis

Once the heart rate dataset was joined with the vehicle dataset, the heart rate dataset could be analyzed with the vehicle dataset based on attribute comparison or geographic location. Analyses were done to determine if certain locations on the autocross course caused the heart rate to rise in comparison to other locations. For example, if the heart rate suddenly spiked coming to a specific turn, it would be easy to determine that this turn was affecting the way the driver handled themselves while navigating that location. If heart rate accelerated it might mean that the performance of the car in that location was not correct and the driver could have suddenly focused more which resulted in a higher heart rate, as heart rate will rise with level of focus in driving situations (Mullen 2012). Comparing the heart rate between laps of the course and also between locations on the track would help determine the emotional factors at play during the event.

The Space-Time Path

Geovisualization has been applied to analysis of spatio-temporal data in time geography studies especially utilizing the space-time path and the three-dimensional representation of moving objects in space and time (Kwan and Lee 2004). At a basic step, this type of analysis could analyze and visualize a single attribute of a moving object at a time. For example in this thesis, the driver could see the speed at a location and also see how the speed changed between data points. Generally, a line of a space-time path does not represent an attribute and only ties data points together. The line will move from one location to another over time in a direction, or stay stationary at a location and move vertically to express the time spent at the same location. For this research, the path of the vehicle can be represented as a line feature at a location for the corresponding time, and more detailed information could be conveyed through the data by including more attributes of the vehicle's movement for the line feature. For the visualization used in this research, the line feature is visualized as a polygon shape in a three-dimensional space between the locations. The polygon shape is a line feature that is extruded in a vertical direction based on a particular attribute being represented. In the case of figure 7 below, change in speed in mph is the attribute represented.

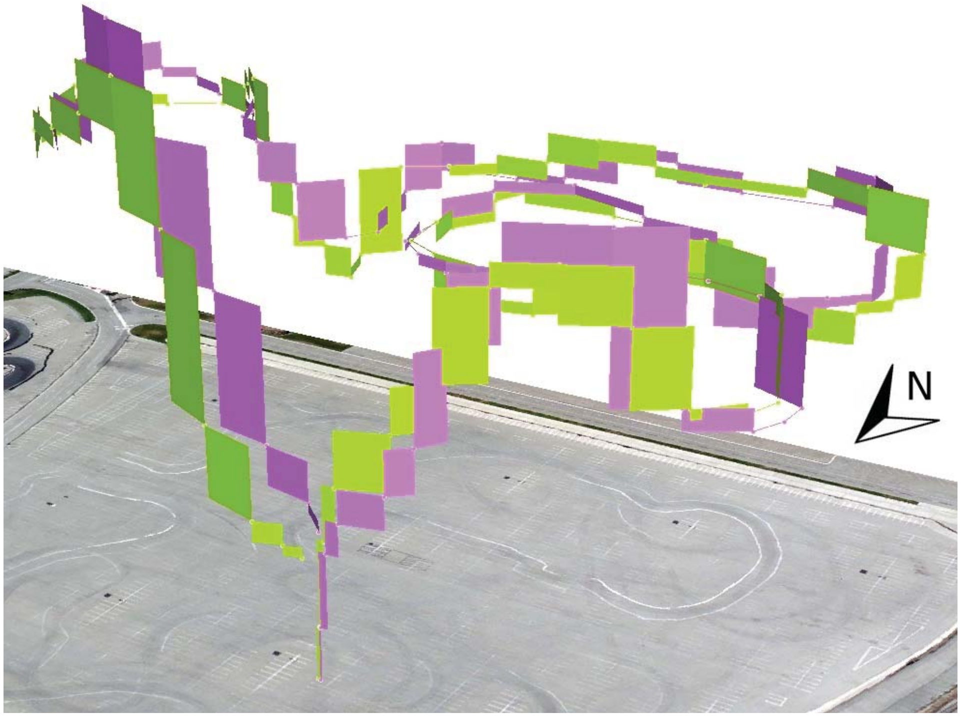


Figure 7. Space-time Path Example Showing Change in Speed.

With the line representing a change in speed in mph, the space-time path makes it intuitive for a driver to understand how the speed is changing as the vehicle traverses the autocross course. The driver is also able to compare different laps of the data easily in this type of visualization since multiple three-dimensional features can be visualized to represent multiple laps of data. This can be a comparison of laps of the driver's own data or laps between multiple drivers' data. Comparison of lap data between multiple drivers would allow them to quickly see where their speed was better or worse compared to others, as seen in figure 7 above.

To generate the space-time path of the vehicle, the first step is to convert the point feature data to line feature data. Once that is done, the speed data from the point features need to be transferred to the line feature data. Because a line is defined by the distance between two points there exist three specific attributes that should be included in the line data: start speed, end speed, and the difference in speed. The start speed is the speed at the beginning point of the line feature and the end speed is the speed at the end point of the line. The difference in speed between the points is used to generate the extrusion that occurs to the lines in the three dimensional visualization. At the same time, the base height of the line is set at the speed of the start speed. Doing this creates a line feature shapefile that displays in three dimensions the speed difference between the two adjacent data points. This is just one example and the data could be geovisualized in three-dimension based on other attributes if needed.

In a 3D environment the track location and the attribute can be shown vertically with height values. The space-time path visualization in 3D is able to provide a much more clear view of what a driver is doing in comparison to a simple table or a chart. In a table there are only numbers and/or texts and it rarely gives the driver intuitive information about the vehicle's performance. A chart or a graph would provide visual information of the performance in real-time, but it still may not provide a spatial reference as maps that show where the performance was taking place. The 3D space-time geovisualization allows the driver to see where such performances were taking place.

The Space-Time Activity Density Surface

The next visualization that was developed for analyzing the motorsport data is the space-time activity density surface. This three-dimensional visualization is typically used to represent geographic activities based on time and distance from the point of origin (Kwan and Lee 2004). For this research, the visualization was used to develop different density surfaces that could represent vehicle data in a non-geospatial visualization. The purpose of this type of visualization is to provide the driver an information visualization in a third dimension. That third dimension is density of a certain attribute of the vehicle's performance, which would assist the driver in determining if the vehicle was driving consistently regarding the particular attribute. This can be done by using any two attributes from the attribute table of the GIS dataset of the vehicle performance for the X and Y axes in the non-geospatial visualization and having the density of occurrences of the chosen attribute for the third axis. An example would be plotting the time attribute as the X axis and the speed attribute as the Y axis. The visualization would help the driver understand the consistency of the vehicle's speed on the course based on the time attribute in the data collected.

To generate space-time density activity surfaces, the tabular data were generated in a non-geospatial space. The space consists of the time attribute as the X plot and the speed attribute as the Y plot, and produces a dataset of points. The point dataset can be run through a spatial statistics tool to generate the third dimension, the density attribute and creates a raster dataset as the result. The raster dataset can then be brought into a three-dimensional space and visualized with color hues and height values to represent the consistency of the data.

The Space-Time Prism

The final visualization based on time geography that was used for analysis in this thesis is based on the space-time prism, modified from the standard space-time prism. Generally, a space-time prism visualizes available paths in a time frame within a space-time path (Miller 2005). For example, it could be used to determine where someone could travel within a 30-minute time span. The modified version of the space-time prism in this thesis was created as a three-dimensional visualization tool that compared handling data from a lap to the maximum limits of performance that the vehicle might achieve. In this thesis the prism is referred to as the "performance prism" and it is designed to be a three-dimensional visualization used to replace a standard visualization used in motorsports called the "friction circle" (Milliken and Milliken 1995). The friction circle enables a driver to visualize the vehicle's handling performance based on the horizontal and lateral forces experienced during driving. Typical friction circles are two dimensional, but because the space-time prism is three-dimensional, it includes a third attribute with the horizontal and lateral force data. In the analysis of this thesis, the third dimension is the speed attribute of the vehicle. The speed attribute is used in this study because it is the main attribute that causes horizontal and lateral forces when driving the vehicle. With the ability to visualize the speed attribute directly with the forces to the car, it is possible to create a prism which visualizes the handling abilities of the car.

The space-time prism used in this study was not included within a space-time path of the vehicle, however, data points from key locations on the track were visualized within the space-time prism based on where the driver wanted to analyze their data. Placing the location data within the prism was chosen rather than placing the prism in a geographic location due to the simplicity of the former versus the latter. The space-time prism is visualized to see how the car was handled by the driver in a turn during a lap. The performance prism shows the maximum abilities of the car to turn that can also be compared with the data points of the car through a specific turn. The comparison is visualized in a 3D environment that shows how well the driver performed. If a performance prism has already been created for a car but new data points are beyond the limitation of the performance prism, it means that the driver was able to exceed the previous limits of the assumed performance of the car and a new prism will need to be generated to account for the new data. With more data the performance prism will become more refined and accurate to address the vehicle performance.

To create the performance prism, the following steps must be completed. The first step is to convert the tabular data using X/Y coordinates, however instead of using the latitude and longitude fields the lateral acceleration X and horizontal acceleration Y fields are used. This process is necessary to plot the point data in a dataset that visualizes the data in what would typically be a two dimensional friction circle graphic. Once the points are created they are brought into the program ArcScene, an application of ArcGIS, where they are visualized in three dimensions, with the speed attribute used as the height attribute. The speed attribute must be brought into a scale which is easily graphed with the X and Y attributes, which fall between 1.5 and -1.5, therefore the height values based on the speed data are divided by 50, bringing the data into a roughly similar scale for visualization. Once the data are represented in a 3D space, points are selected that represent the top-most layer through the data. The highest Z values anywhere in the X and Y surface are selected and made into a temporary dataset. Then the same is done with the lowest points and a temporary dataset of these values is created. Both of these datasets are then converted into triangulated irregular network (TIN) files.

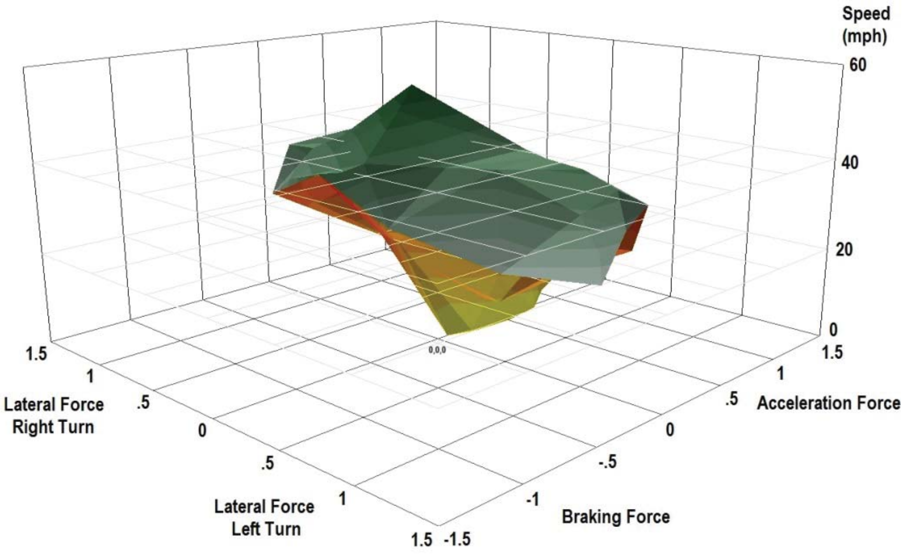


Figure 8. Triangulated Irregular Network

A TIN depicts a surface as a set of non-overlapping triangular faces of different sizes (Wang 1999) and are used to display surface data by partitioning geographic space into non-overlapping triangles based on X, Y, and Z values. In this study the TIN files are used with the tool “Extrude Between” in ArcGIS. The tool uses two TIN features to generate a 3D polygon feature that fills in the space between the two TIN features. That 3D polygon feature is the finished performance prism and it shows the vehicle’s handling performances based on the relationships between horizontal force, lateral force, and speed. This 3D polygon can be viewed in a three dimensional space with vehicle data points to compare specific points with the optimal performance capabilities of the vehicle.

CHAPTER 4

DATA ANALYSIS RESULTS

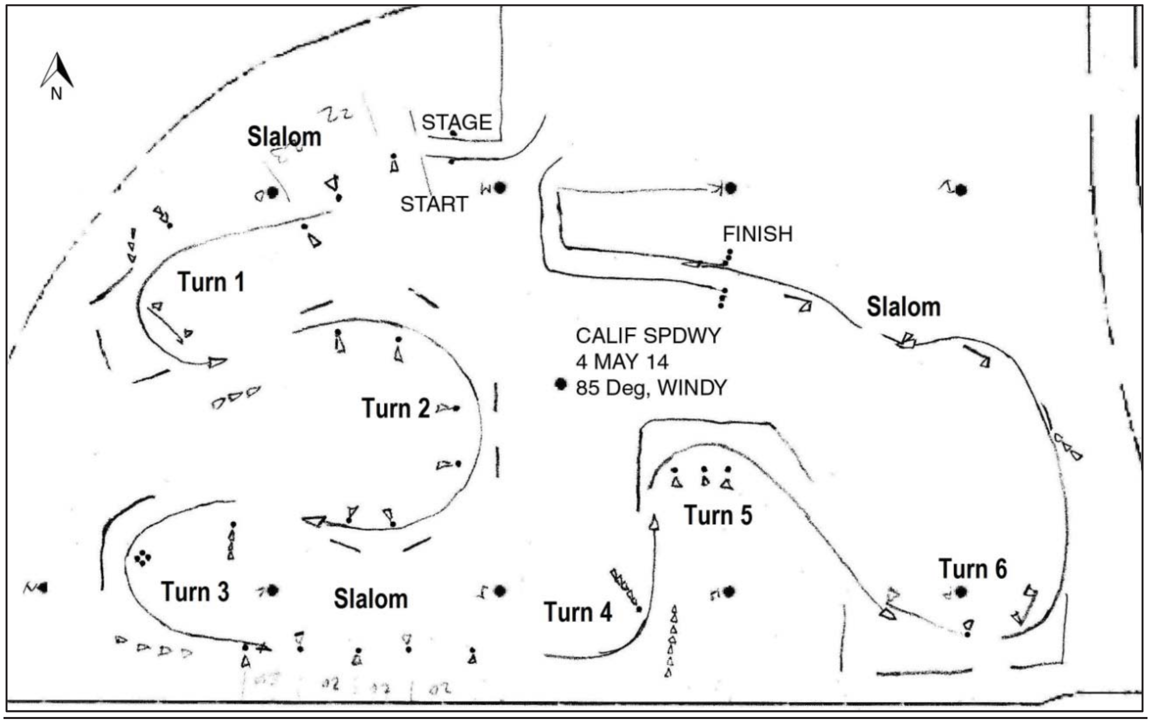


Figure 9. Hand Drawn Autocross Course Map.

The data for this study were collected on May 4, 2014 at an SCCA autocross event held at Autoclub Speedway in Fontana, California, U.S.A. The weather was sunny with a temperature of 85 degrees Fahrenheit. The event had 143 people registered to compete, and there were 13 registered non-competitors in a “time only” group of which the author was one of the participants. The “time only” group consists of people who are not competing but participating in the event for fun. Between 12 p.m. and 1 p.m. on the day of the autocross event the author was allowed to walk the course that the vehicle for this study would be running. The author was able to study a map of the course before walking the course to get a better idea of how to navigate it while driving. The course consisted of six turns and three slaloms as seen in Figure 4.1. Coming off the starting line there was a short slalom before entering “turn one”, which was a tight 180 degree turn. This led into “turn two” which was also 180 degrees, but was much wider and allowed for faster speeds. The exit of turn two led into turn three which was tight and guided the driver into the second slalom. By exiting the slalom turns four, five, and six could be completed. Turn six opened into the final slalom before the finish line.

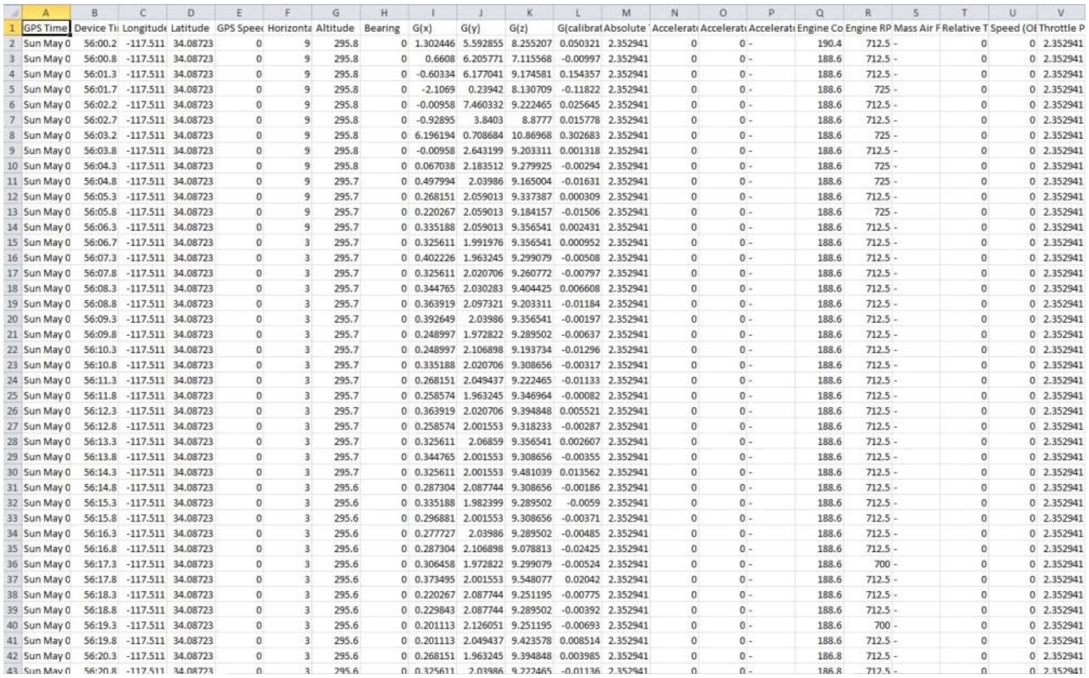
After examining the course, I used the laptop to draw data in a map to represent each piece of the track of the vehicle. The data were stored in a shapefile that would be used in the Model Builder tool for ESRI ArcGIS created for this study to calculate the track location of the collected vehicle data. Drawing the track pieces in a map was challenging, as there were no existing detailed maps or spatial data of the parking lot available for this study. With an aerial image used as a background file in ArcMap, lamp posts and parking lot paint lines were used at to figure out where each piece of the track was located.

Figure 10. The Author Navigating the Final Slalom

The author completed the laps in the afternoon between 2:30 p.m. and 3:30 p.m. of the day of the autocross event, collecting data from four laps of the autocross course. The author drove a 2013 Nissan 370z seen in figure 10, which had no performance modifications done to it. The data were collected using a Samsung Galaxy Note 2 smartphone, a Scantool OBDII reader, and a Zypher HxM Bluetooth heart rate monitor for hardware and two smart phone applications, Torque and iCardio. During the data collection there were no issues with any hardware or software used for this study. Signal of reception from cellular network tower was good in the area so the data were transferred to the internet from the smartphone and were downloaded by the laptop quickly. The laptop was located at outside of the track while the author was driving the vehicle and the data were downloaded to the laptop from the internet after the author's run was finished.

Data Results Reviewed During the Event

Data were downloaded and ready to be used when I would bring the vehicle in from each lap. Using the laptop computer I would run the downloaded data through the Model Builder toolset to post-process the raw data seen in figure 11 and create GIS data from it. This process first cleans the table by renaming fields or columns so that they are easier to understand. Then the data is plotted as point features in the map using values in the latitude and longitude fields. Using the point features generated, the track location polygon data were spatially joined based on intersecting locations and the track location name was calculated to the points. The data were saved locally on the laptop computer and then the Python script was run, which generated a map of the selected data. This was done by modifying a pre-produced map document for ArcGIS using the arcpy commands developed in this study to select specific data, zoom the map to the location, symbolize the data in the map in a specific way, and create a PDF document of the map. The PDF document then was used to quickly analyze the author's driving performance on the previous lap while waiting to be called for the next lap.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
1	GPS Time	Device Ti	Longitude	Latitude	GPS Speec	Horizonta	Altitude	Bearing	G(x)	G(y)	G(z)	G(calibrat	Absolute	Accelerat	Accelerat	Accelerat	Engine Co	Engine RP	Mass Air F	Relative T	Speed (OE	Throttle P
2	Sun May 0	56:00.2	-117.511	34.08723	0	9	295.8	0	1.302446	5.592855	8.255207	0.050321	2.352941	0	0	-	190.4	712.5	-	0	0	2.352941
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5	Sun May 0	56:01.7	-117.511	34.08723	0	9	295.8	0	-2.1069	0.23942	8.130709	-0.11822	2.352941	0	0	-	188.6	725	-	0	0	2.352941
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9	Sun May 0	56:03.8	-117.511	34.08723	0	9	295.8	0	-0.00958	2.643199	9.203311	0.001318	2.352941	0	0	-	188.6	712.5	-	0	0	2.352941
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12	Sun May 0	56:05.3	-117.511	34.08723	0	9	295.7	0	0.268151	2.059013	9.337387	0.000309	2.352941	0	0	-	188.6	712.5	-	0	0	2.352941
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21	Sun May 0	56:09.8	-117.511	34.08723	0	3	295.7	0	0.248997	1.972822	9.289502	-0.00637	2.352941	0	0	-	188.6	712.5	-	0	0	2.352941
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27	Sun May 0	56:12.8	-117.511	34.08723	0	3	295.7	0	0.258574	2.001553	9.318233	-0.00287	2.352941	0	0	-	188.6	712.5	-	0	0	2.352941
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33	Sun May 0	56:15.8	-117.511	34.08723	0	3	295.6	0	0.296881	2.001553	9.308656	-0.00371	2.352941	0	0	-	188.6	712.5	-	0	0	2.352941
34	Sun May 0	56:16.3	-117.511	34.08723	0	3	295.6	0	0.277727	2.03986	9.289502	-0.00485	2.352941	0	0	-	188.6	712.5	-	0	0	2.352941
35	Sun May 0	56:16.8	-117.511	34.08723	0	3	295.6	0	0.287304	2.106898	9.078813	-0.02425	2.352941	0	0	-	188.6	712.5	-	0	0	2.352941
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37	Sun May 0	56:17.8	-117.511	34.08723	0	3	295.6	0	0.373495	2.001553	9.548077	0.02042	2.352941	0	0	-	188.6	712.5	-	0	0	2.352941
38	Sun May 0	56:18.3	-117.511	34.08723	0	3	295.6	0	0.220267	2.087744	9.251195	-0.00775	2.352941	0	0	-	188.6	712.5	-	0	0	2.352941
39	Sun May 0	56:18.8	-117.511	34.08723	0	3	295.6	0	0.229843	2.087744	9.289502	-0.00392	2.352941	0	0	-	188.6	712.5	-	0	0	2.352941
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41	Sun May 0	56:19.8	-117.511	34.08723	0	3	295.6	0	0.201113	2.049437	9.423578	0.008514	2.352941	0	0	-	188.6	712.5	-	0	0	2.352941
42	Sun May 0	56:20.3	-117.511	34.08723	0	3	295.6	0	0.268151	1.963245	9.394848	0.003985	2.352941	0	0	-	186.8	712.5	-	0	0	2.352941
43	Sun May 0	56:20.8	-117.511	34.08723	0	3	295.6	0	0.325611	2.03986	9.222465	-0.01136	2.352941	0	0	-	186.8	712.5	-	0	0	2.352941

Figure 11. Downloaded Data Before GIS Clean Up

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Between the laps it was decided to focus on three attributes: speed, engine RPMs, and the horizontal force. It was expected that these three would be the best attributes that would give the author—the driver—a good idea of where the vehicle could go faster. With each lap that was completed, the author had a new set of data to compare to the previous lap that helped understand the bigger picture of what would be the fastest way around the course.

Lap One Analysis

The first lap of the autocross of the author in this study was mostly a learning experience of the course and the vehicle. Since every autocross course is not identical, the course was not familiar to the author. The vehicle was also unfamiliar to the author since it was intended to drive an unfamiliar vehicle in this study, as to not already be confident with how the vehicle handled. The author had no experiences about how well the vehicle would handle or how fast it would accelerate. These two factors, along with the fact that data were being collected for this thesis, caused the author to be nervous and worried about issues such as the data collection not working correctly, or accidently damaging the vehicle. As the first lap began, the author was instantly surprised by how quickly the vehicle would accelerate and it likely caused him to be timid about driving fast on the first lap. The vehicle had a tendency to lose tire grip due to some small bumps on the pavement, and the author was worried about the back end of it having oversteer. Oversteer occurs when the vehicle turns more than what was intended by the driver which results in the tires losing grip and slowing the vehicle. After racing through the course, the lap time for the first run was 58.168 seconds. After the first lap the author felt that the two important locations where he might be losing the most speed would be turns three and six on the course, which are both followed by slaloms. It would be important to carry as much speed as possible through those turns to set up the vehicle for a clean entry into the slaloms, otherwise the vehicle's speed would drop and the overall lap time would be higher. The corners that would lead into the locations reviewed, corners two and five, had exits which would result in fast speeds and so there would be higher entry speeds into turns three and six. Due to this, the author felt it would be good to review the data of driving performance of these two locations and make sure that he was using the vehicle to its full potential at both locations.

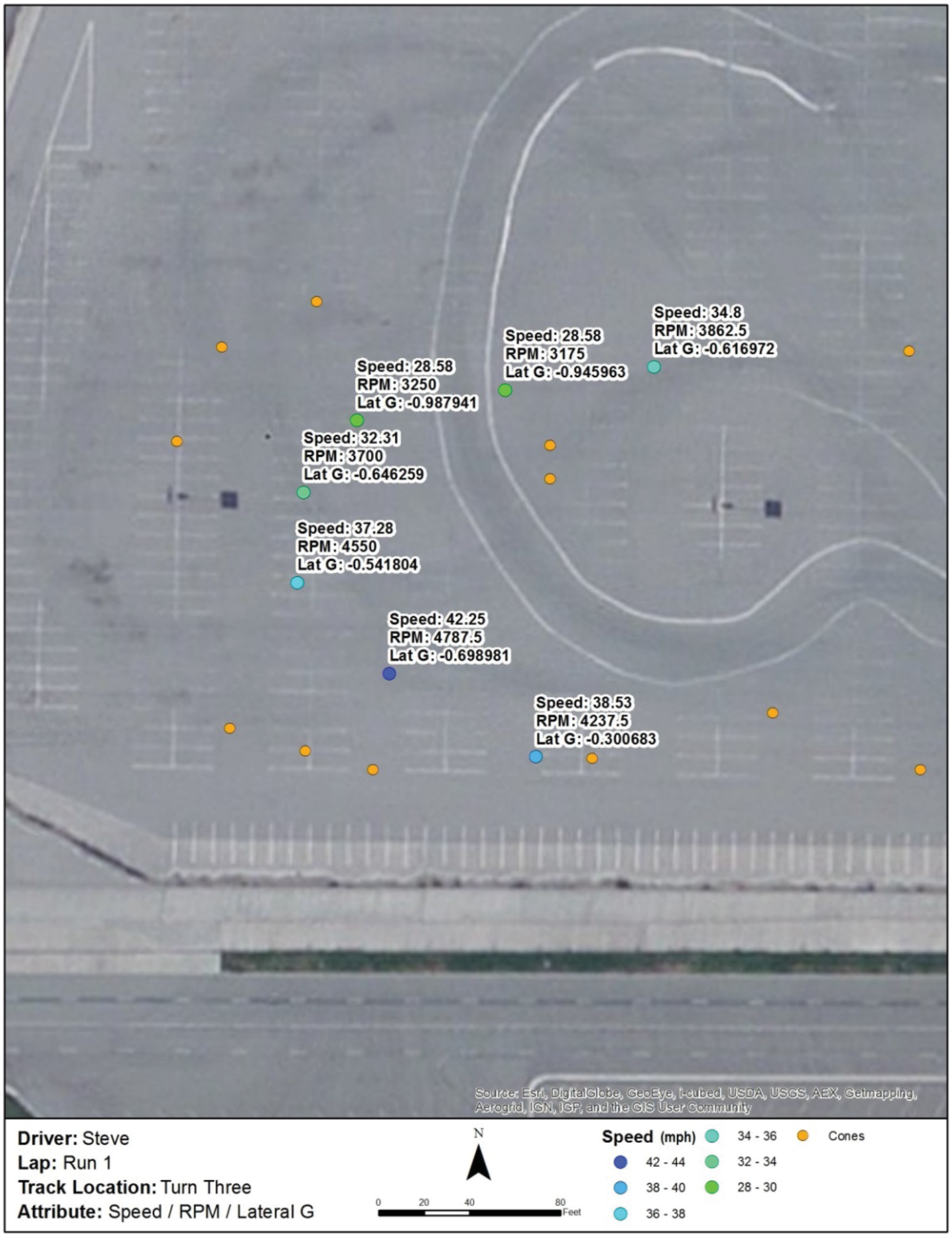
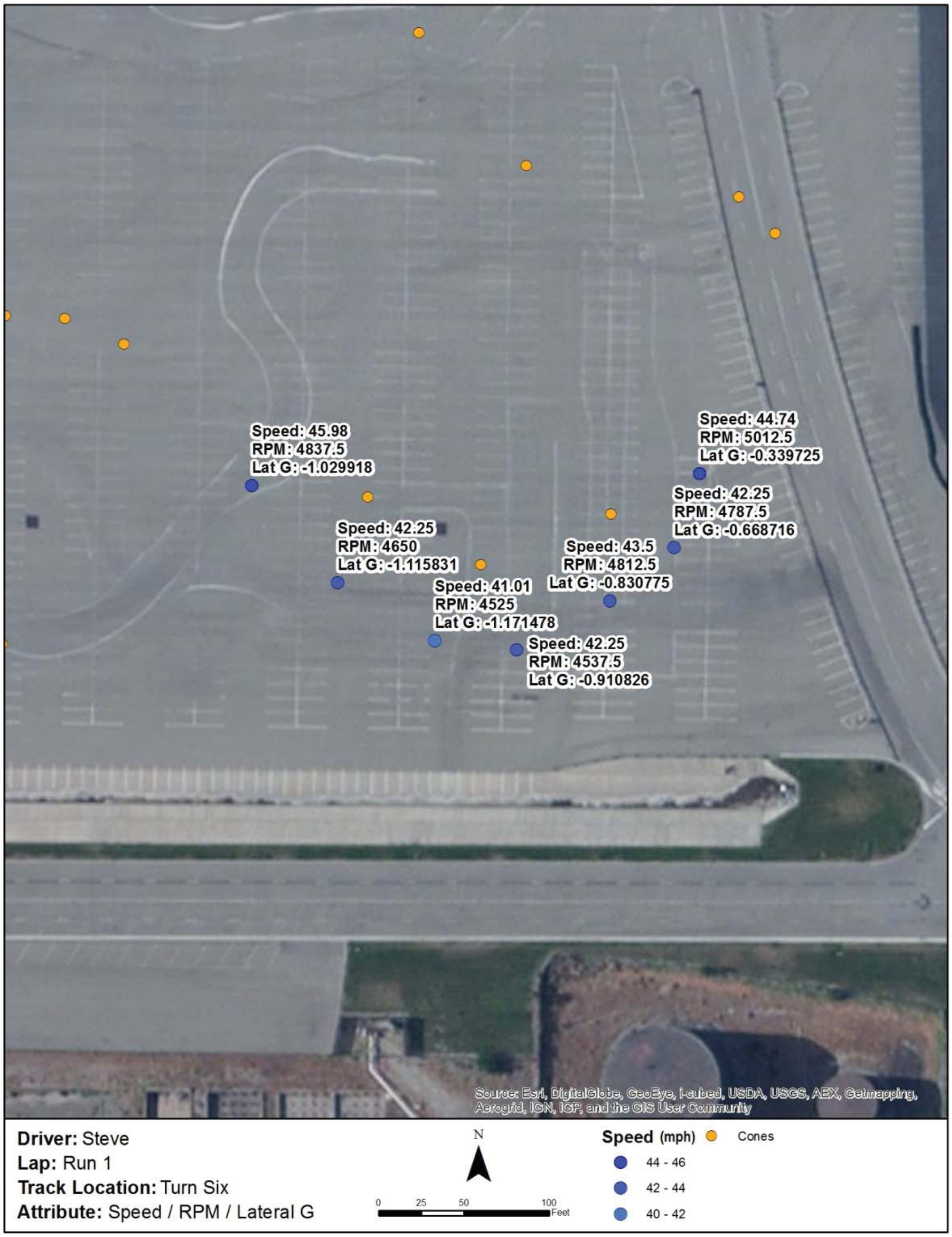


Figure 12. Lap One Turn Three.

Lap One, Turn Three:

Figure 12 shows tracking data of the vehicle collected from the run one, turn three. This map and following maps were created through the python script developed for this thesis. The entry of turn three is following a quick exit from turn two, therefore speeds of the vehicle should not be too low. However, since the turn is sharp it is not a surprise to see that the speed of the vehicle dropped into the high 20 mph range. The author did wonder if he was going too slow through the turn, as there were two signs in the data that pointed to this. First, Figure 12 shows that two point features were collected at which the vehicle's speed was 28.5 mph, and it means that the author kept the speed of the vehicle constant for a portion of the turn. This indicates that the author could have applied the brakes on the vehicle later as they entered the turn and keep the vehicle's speed up slightly longer than they did on this run, as the speeds of the vehicle should constantly be changing. Second, on the exit of the turn, the lateral force data showed that the vehicle only reached -.698g which is much lower than the values that vehicle could perform as seen from the entry of the turn, where the vehicle had reached -.987g. This means on the exit of the turn the author only used 66% of the vehicle's handling performance in comparison to what it had done at the corner entry. To have a better performance the author could either take the turn more sharply or go through the corner at a higher speed.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, and the GIS User Community

Figure 13. Lap One Turn Six.

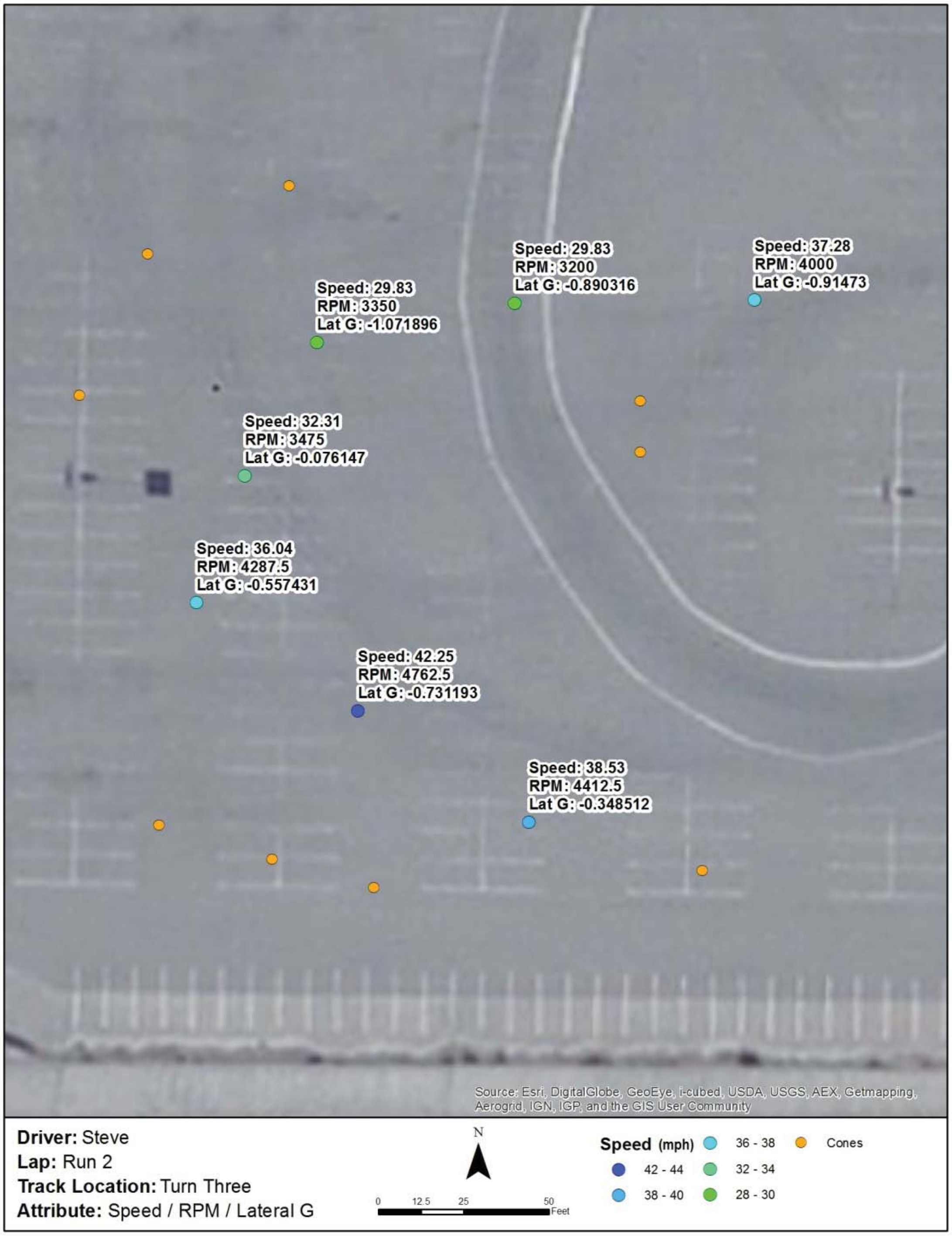
Lap One, Turn Six:

Turn six is a wide left turn that allows for higher speeds, however in the turn a driver could be hesitant to increase the speed due to the upcoming slalom into the finish. This is how the author felt going through the turn on his first run, making sure that he didn't exit the turn so fast that he might miss navigating the slalom correctly. Figure 13 shows that there was hesitation, as the vehicle's speed was not consistent through the turn. In the entry of the corner the speed of the vehicle dropped from 45 mph to 41 mph before it began to rise, heading back up to 43 mph. At this point the author hesitated, as the speed dropped back down to 42 mph before picking back up to 44 mph at the exit. Had the author been consistent through the turn, the speed at the exit could have been 2-4 mph higher heading into the slalom. A higher speed was easily obtainable and this was apparent just by looking at the lateral force data. Entering the turn six the author was aggressive with the vehicle, reaching -1.171g when the vehicle was at the apex, however as they exited the turn the vehicle's lateral force dropped through each data point. This clearly shows that the author could have been exiting the turn with higher speed than they had.

The data for the first lap of the course showed that the author was driving carefully; hesitating to push the vehicle to its limits, leading to slower speeds and an overall longer time to finish the course. Noting these records, the goal was to have a shorter time through every turn as the author drove the second lap. The author remembered that focusing on having a higher speed through the entire course would lead to about one second off their time, putting the vehicle’s lap time somewhere in the 57 second range to finish the course.

Lap Two Analysis

The goal on the second lap was to drive the course faster to cut a full second off from the previous lap time. On the second lap the author did his best to ignore the feeling of over-steering in the vehicle and just see what would happen with the vehicle. One of the most important things about autocross is that if a person drives the vehicle too fast and loses control, they will only spin to a stop on an open pavement with no risk of hitting a wall. Knowing that, the author drove the course more aggressively and by the end of the lap felt accomplished about how he performed. The author was surprised to see that he was able to take over two full seconds off compared to his previous lap, with a new time of 56.082 seconds. After returning to the waiting area, the author ran the reports of the second lap on the same two corners that had been studied on lap one to compare the previous lap.



Source: Esri, DigitalGlobe, GeoEye, i-cubed, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, and the GIS User Community

Figure 14. Lap Two Turn Three

Lap Two, Turn Three:

On the second run through turn three the author tried to be more aggressive while driving. However, the vehicle's performance was not better than the previous run as can be seen in figure 14 when compared to figure 13. In the first run there had been two major flaws: one was braking too early entering the turn and the other was exiting into the slalom too slowly. The data collected from the second run shows that the author was going slightly faster as they entered the turn and that the lateral force was higher than the first run through the course, with the peak going from -.987g to -1.071g. After this peak though, the vehicle's speed was slightly slower than in lap one, though the lateral forces are slightly higher than in lap one. This shows that for the most part, the author was not able to push the vehicle through this turn any better. Similar to lap one, he held the speed for a moment, meaning he once again used the brakes on the vehicle too early coming into the turn. Due to the slightly higher speed, the author must have just used slightly less braking than before, but what he needed to do was to wait a moment before pressing the brakes at all. Instead of pushing the vehicle harder using the same trajectory the author took through the turn in lap one, he instead cut the turn harder through the entry. This aggressive move resulted in a slightly higher speed coming into the turn, but then resulted in a loss of some speed when exiting it. It was difficult to determine whether or not this led to any loss or gain in lap time. However, it is obvious that the author did not drive through this turn any better on the second lap in comparison with the first. The author would need to be able to push the vehicle correctly and get more from it through the entire turn in the third lap to show an improvement.

Figure 15. Lap Two Turn Six

Lap Two, Turn Six:

The first thing noticed about the data for the second run through turn six was that, similar to turn three, performance was better in some aspects than the previous lap and worse in other aspects. As can be seen in figure 15, the author entered turn six at a slower speed than on the first run, 43 mph v 45 mph and also held the lower speeds through the apex of the turn longer, with two data points at 43 mph and two points at 41 mph. Therefore, not only did the author enter the turn at a slower speed but he held the slower speeds longer through the turn. While the lateral force entering the turn started off higher than the first run, it dropped slightly below what the author had held through the entry of the turn the first time through. Combining the aspects of slower speed and high lateral force, it seems that the author had taken the entry of the corner much more sharply than their first attempt. Similar to the second attempt through turn three, the author tried to be more aggressive and ended up completely changing the way he drove through the turn compared to the first lap. While the entry of corner six was not better compared to the first lap, performance at the exit was much better. Speeds were very different, as the author held close to 46 mph exiting the turn, compared to 42 mph and 44 mph data points on the first run. At the same time the lateral forces were higher than on the first run, holding a more constant number around -.6g. This is still fairly low in comparison to what the vehicle can do, however compared to the previous lap where one data point was at -.339g it was almost a doubling of handling performance between laps.

Overall, for the second lap the author was more aggressive with the vehicle, but it led to him navigating the course in a completely different manner. Generally, it affected the data points through the two turns that were studied, but the different routes made it more difficult to determine what exactly caused the overall lap time to drop two seconds. Regardless of speed numbers changing both up and down, one factor that was constantly improved was the lateral force. The data points were constantly higher than on the first run. That meant the author was driving the vehicle harder through each turn and in the end that resulted in a faster overall lap time. After reviewing the data the author decided to focus on keeping the lateral force as high as possible, as the exit of the turn was where they were not using the full cornering ability of the vehicle.

Lap Three Analysis

Lateral force was the factor that consistently improved in the author's driving between laps one and two which led to more than two-seconds off the overall lap time. For lap three the author continued to push the vehicle harder out of the exit of each turn, as this was where he was still missing out on the vehicle's potential. After completing the lap the author felt positive because he felt that he had pushed the vehicle harder than the previous laps. However, the author was aware that he was still not near the maximum limit of what the vehicle could do. The final time for lap three was 55.680 seconds, meaning four tenths of a second was taken off versus the previous lap time. That was definitely better than the previous lap's performance, however the author made a goal to have a better result in the next lap.

Figure 16. Lap Three Turn Three.

Lap Three, Turn Three:

For the third run through turn three, the author's driving once again was not consistent through the turn as seen in figure 16, posting both faster and slower speeds compared to lap two. Entry speed was the same as lap two, changing from 37 mph to 29 mph between data points, however on lap three it then increased and decreased before increasing consistently with higher speeds out of the turn. The inconsistency of speed shows that the author was still not traveling through the turn with a smooth rhythm, which a more skillful driver would perform. Lateral forces remained high during the turn in comparison to lap two. This shows that while the speed might be fluctuating significantly the cornering of the vehicle was higher in comparison to lap two. The last data point in the turn shows that the vehicle was at .772g, showing that the author must have been turning into the slalom earlier this lap. In laps one and two the lateral force at this point was around -.3g therefore the vehicle was still coming out of turn three on those runs. Overall the lap was better than both of the previous as the author pushed the vehicle harder in regards to lateral force. Still there was room for improvement with speed, as the author was still hesitating half way through when he should have been staying on the throttle, which would give the vehicle a greater speed through the rest of the turn.

Figure 17. Lap Three Turn Six.

Run Three, Turn Six:

On the third run through turn six the author felt better since he was able to perform better overall through the entire turn in comparison to the previous two laps. Both speed and lateral forces through the entire turn were significantly higher than in runs one and two as can be seen in figure 17. The lowest speed point was 42 mph, compared to 41 mph previously and the vehicle achieved a new top speed exiting the turn, reaching 48 mph, while the previous best was 45 mph. The lateral force held strong through the turn and never dropped below -.663g. The goal of pushing the vehicle harder and more aggressively was achieved in turn six, with the lowest lateral force data points in turn six being better with each lap, from -.339g to -.585g to -.663g. Even with the improvements on the third lap in turn six since there was still a possibility to improve on the final lap, in terms of performance. The top speed of 48 mph at the lowest lateral force reading which was at -.663g, and it means that while the author sped up they were not turning the vehicle as sharp as they could, or they could have been at a higher speed. Another spot on the course where there was possibility of improvement was in the corner entry, where the car held the 42 mph speed through two data points. It was another lap where the author was decreasing the speed of the vehicle and ended up holding the vehicle at a constant speed, resulting in slower entry speeds than what would have been possible. At this point in lap three, patterns are obviously emerging, showing that the author was braking too early into turns and then on the exits they were not fully utilizing the vehicle's ability to turn at a faster speed. While there was improvement with each lap, the author was still not reaching the full potential of the vehicle's performance, resulting in lap times that could have been faster than what had been accomplished. For the fourth and final lap the author planned to try and remember these experiences and run faster than lap three. He did not want to become too aggressive and lose control of the vehicle, ruining the time of final run of the course.

Lap Four Analysis

During the fourth and final lap the author did not have any issues that he had from the previous lap through the course. The lap time from the fourth and final lap was 55.677 seconds, meaning the author only took three thousands of a second off of his previous lap time. Data collected from this lap showed the consistency of speed of the vehicle through laps three and four since the times were almost identical between them. If the author's driving was not consistent it might mean that he was not able to keep the vehicle on a similar line of driving through the course and any number of variables could be keeping the vehicle from faster lap times. The author was interested in seeing the results of turns three and six as well as complete analyses of laps three and four later on to find out what could be determined from his driving.

Figure 18. Lap Four Turn Three.

Lap Four, Turn Three:

Looking at the report for the final run through turn three, the author was disappointed to see that his speed dropped down compared to lap three, shown in figure 18. The vehicle's lateral force numbers overall were lower as well, however the low point, -.558g, was higher compared to all previous laps. Consequently, with the overall speed of the vehicle being lower through turn three on the final run, the performance for the final lap through turn three was very similar to the first lap. A lower performance than the previous lap with a faster overall lap time means the author achieved greater performance in other places on the track to make up for this.

Lap Four, Turn Six:

The author was pleased at the results from the fourth run of turn six. The map of run three through the turn showed that the author had the best performance in the last run compared to the previous ones, shown in figure 19. First, the speed of the vehicle at the turn was at 48 mph, compared to the previous highest speed at 45 mph. It was because the author not only came into the turn at a faster speed, but kept the overall speed higher than 42 mph. The author then accelerated out of the turn without dropping any speed. The performance in terms of lateral acceleration was improved, as it was held between -.9g and -1.15g through the majority of the turn. Both the higher speeds and lateral force show that the author was able to finish the turn with the best speed and handling compared to previous runs.

Figure 19. Lap Four Turn Six.

Data Results Viewed After the Event

Once the event was complete the author post-processed the data collected from the field study and applied several spatial analysis methods based on a time geography approach. The space-time path, space-time activity density surface, and the space-time prism concepts were all used to analyze the data to develop three-dimensional visualizations that would help better understand how the author was performing while driving on the track. The author created geovisualization works to analyze and represent each of the attributes logged during the event, to see how they might explain performance beyond the maps shown in Figures 12 to 19 above that were created during the autocross event. The geovisualization works included a number of heart-rate focused analyses to help understand the emotional aspect of the event. The following sections provide the results of these geovisualizations.

Space-Time Path Analyses

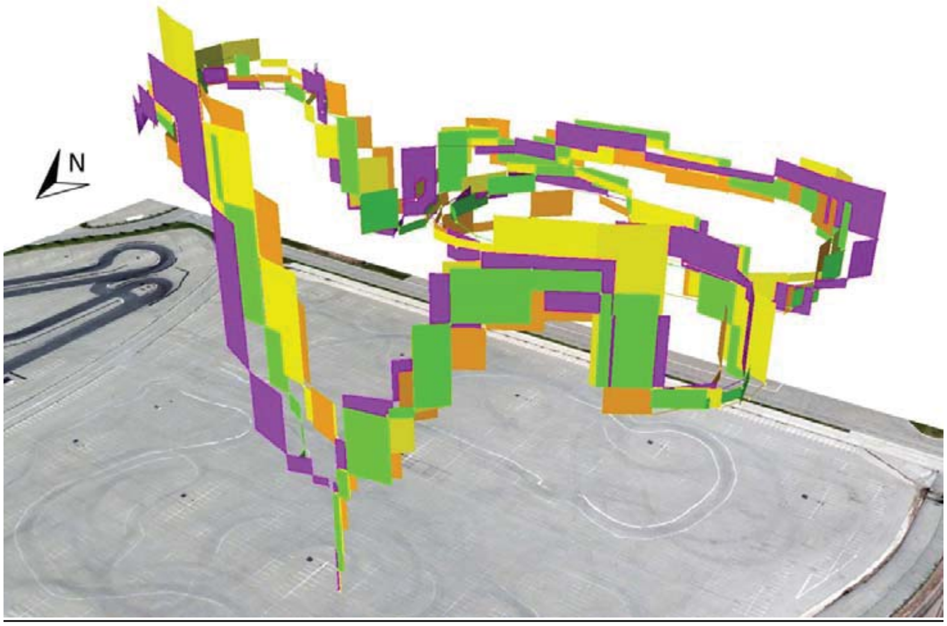


Figure 20. All Laps – Space-time Path Change in Speed

After the event was completed the data were processed to be used in a three dimensional environment and the author created space-time path visualizations using GIS and geovisualization techniques. These were used to analyze the speed of the vehicle through the entire course. Figure 20 above shows the space-time path data for each lap through the autocross course. The paths have a block-look between each data point which represents the change in speed between data points. This visualization was chosen to easily understand the speed changes without reading numeric values of speed for each data point. The taller a block is, the greater the change in speed. In some locations blocks cannot be seen at all, meaning the speed did not change between data points. Showing multiple space-time paths in the same visualization can make it difficult to see what is going on beyond which color is higher than the other, which means a faster speed in the case of figure 20.

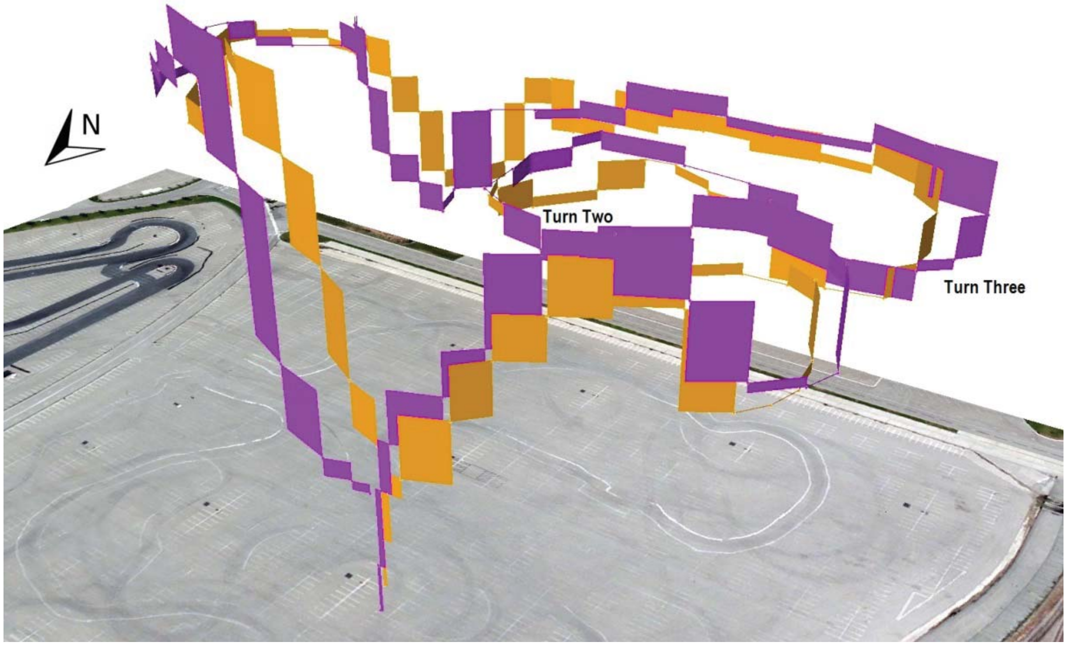


Figure 21. Lap One and Lap Four – Space-time Path Change in Speed.

In figure 21, the space-time paths for the lap one and lap four are compared to see the differences between the slowest and fastest laps through the course. Using the space-time path it is easy to see that the speeds through the course during the lap four are almost always higher than those of the first lap. The purple blocks in many locations on the track are significantly higher than those in orange. Between turn two and three the purple block is not shown, meaning the speed was held steady at this point, while the orange block is dropping lower, showing that the speed on the first lap was dropping at this location.

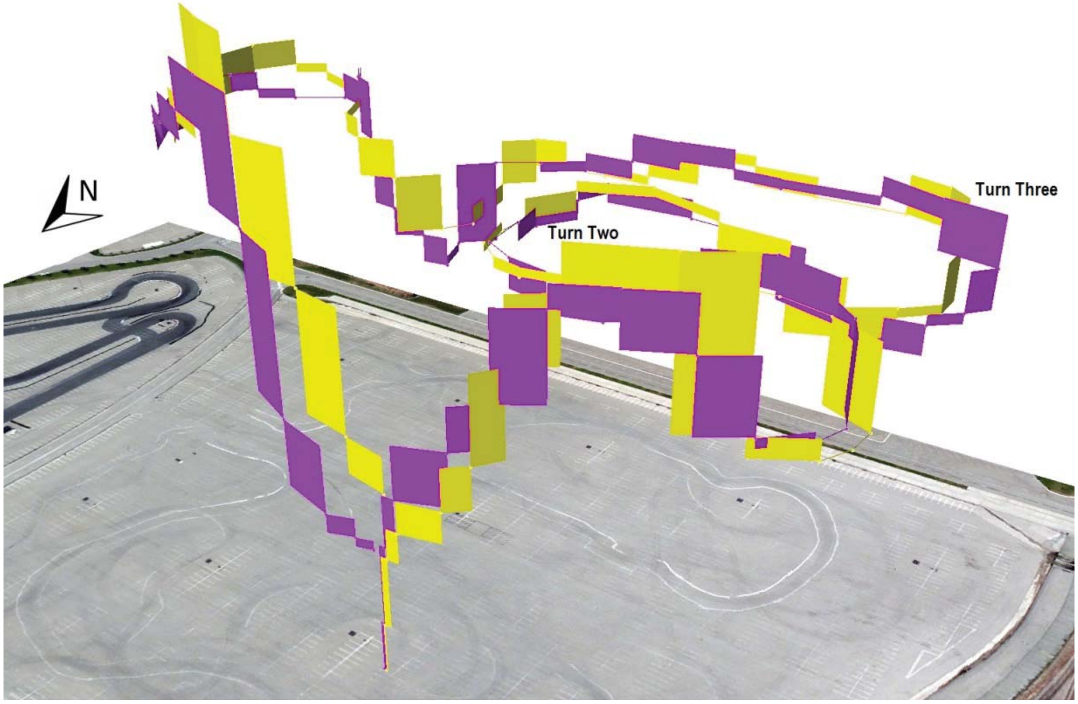


Figure 22. Lap Three and Lap Four – Space-time Path Change in Speed.

In figure 22 above space-time paths are shown for laps three and four. Numeric data collected from the field showed that there was only three thousandths of a second difference between the lap times for laps three and four (55.680/55.677), however the space-time paths shows the speed changes very clearly. The space-time paths in the figure highlights the inconsistencies in driving the author had while on the course. It is a back-and-forth battle for which lap has higher speeds through the entire course, with no locations on the track showing similar speeds. The visualization in figure 22 could help the driver easily figure out optimal speeds through the course to combine the best sections from both laps to complete a faster lap time.

The space-time path visualization in figures 20, 21, and 22 allow for the viewer to see the differences between the laps in the graphics without having to read numbers from the data. The three-dimensional aspect in the visualization can help highlight large and small differences that might be missed if the viewer looks at the numbers only. As was shown in figure 4.14, the visualization demonstrates that despite two laps having similar times, the changes in speed through the course are very different. This can allow drivers to quickly understand where they doing better or worse on a lap to try and focus on better driving in specific locations on the track.

Space-Time Activity Density Surface Analyses

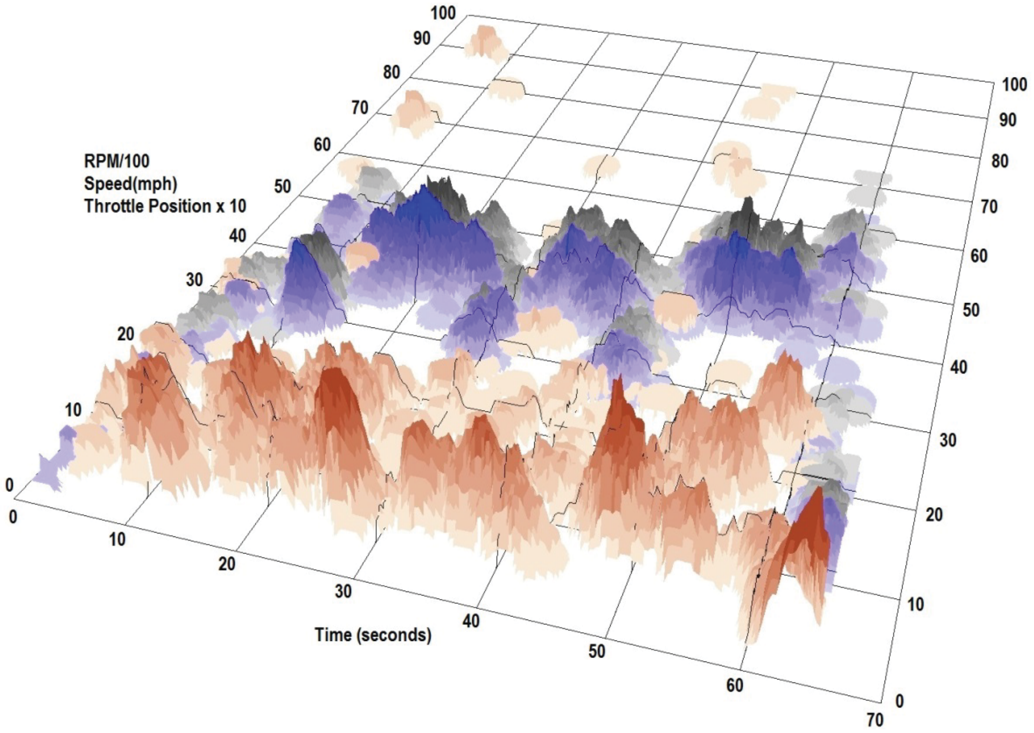


Figure 23. Space-time Activity Density Surface – Speed/RPM/Throttle.

Space-time activity density surfaces were created for this thesis to visualize the consistency of vehicle's performance on the track as seen in figure 4.15. These figures were created using the combined data from all laps, to compare consistency throughout the day. The surfaces were plotted in a three dimensional environment where the X axis represents time, the Y axis represents the attribute that is being analyzed and the Z axis--height--represents the density of the attribute in the X/Y location. A higher value on the Z axis means the value in the data was more densely populated at this location on the graph and that the author was driving in a similar way regardless of the lap. In figure 4.15 the space-time activity density surface shows analyses for three attributes: speed, RPM and throttle position, all represented on the Y axis. To fit the three attributes into a single chart for comparison, the attributes were normalized. For example, the RPM data were divided by 100 and the throttle position data were multiplied by 10 so that both would better match the speed data.

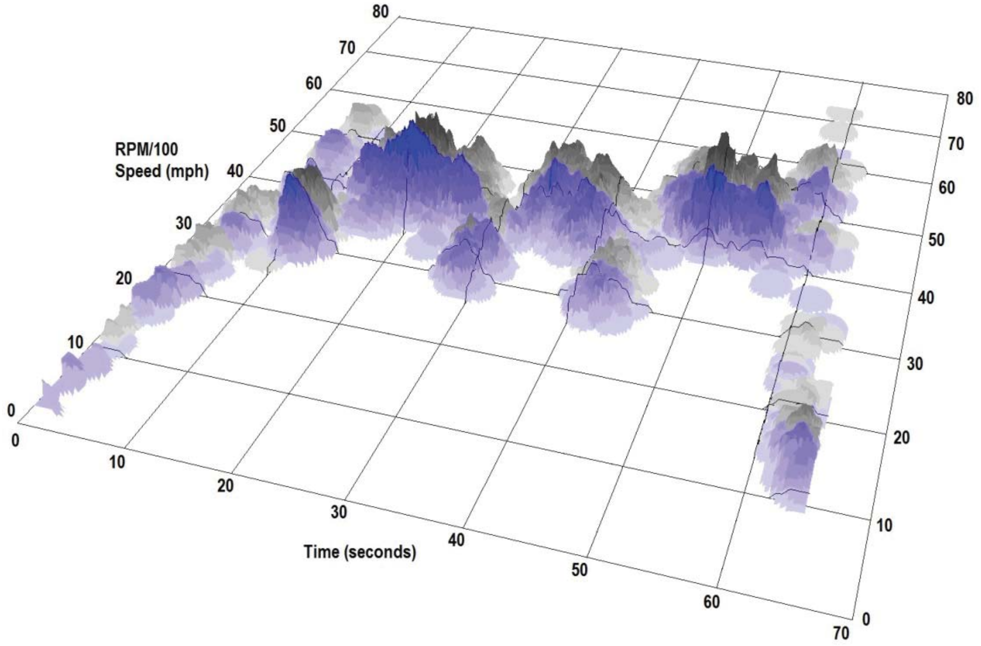


Figure 24. Space-time Activity Density Surface – Speed/RPM.

As can be seen in figure 24, the speed and RPM data of the car match up well which is exactly what should be happening due to the car being in the same gear through the entire course. Had the author shifted the vehicle into third gear during a lap, there would be a noticeable gap in relationship between speed and RPM, as the speed would keep its current level whereas the RPM would have dropped lower. Through the entire course, the speed and RPM data points are densely packed together, but it can be seen that there are many flat spots where there are single data points which are not consistent with the rest of the data. Between the 20 and 30 second time marks there are a number of flat spots in the speed density surface which are lower than the rest of the data, meaning during one of the laps speed was much lower in this time frame. This would note for further analysis in the data to determine the reason why the speeds were lower and what could be done to prevent it from occurring in future laps.

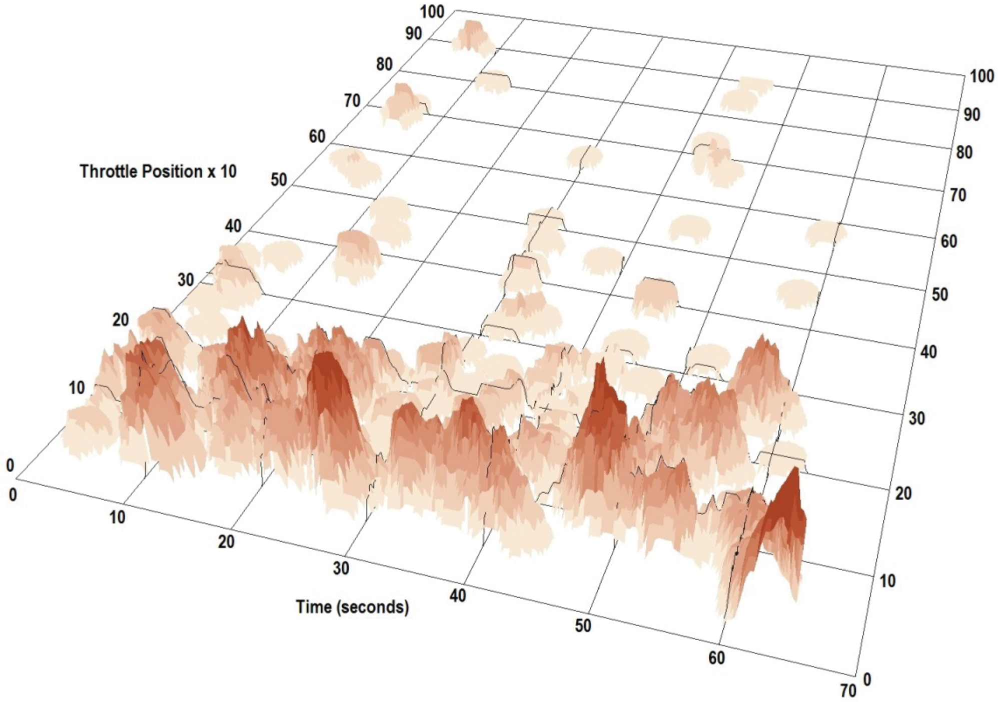


Figure 25. Space-time Activity Density Surface – Throttle.

The space-time activity density surface to analyze the throttle position is visualized by itself due to the multiple locations with single data points, which look like flat circles on the graph, as seen in figure 25. Many of these flat circles would not be visible when visualized with the speed and RPM data. Multiple flat circles in figure 25 show that the throttle position used during laps was not consistent, and also did not directly relate to RPM or speed. If a driver takes his foot off the accelerator pedal, the throttle position data will drop quickly but the car's speed will drop much slower, creating a disconnect between throttle and speed data. The randomness of the throttle shows that the author was in no way consistent with their footwork while driving. It would be useful for future research to compare the throttle position of an amateur driver and a professional driver to see whether a professional has more consistent throttle positions.

The space-time activity density surface is useful to determining the consistency of a driver, but beyond that there would not be much use for it. This is because that even if it shows a driver being consistent on the surface, it does not mean that he or she is driving well. The driver could be consistently driving slowly and in that aspect, the density surface would not provide any insight for what is missed during the driving. Instead, the density surface would be useful to find locations where a driver is inconsistent while driving, and check the data and analyze it in different ways to determine what happened in that time frame and location.

Space-Time Prism – Performance Prism Analysis

The performance prism was created to analyze vehicle performance in this thesis by using a space-time prism (Miller 2005) which visualizes the relationship between distance and time in travel. The performance prism uses speed and handling rather than time and distance to generate a three dimensional representation of the vehicles optimal handling abilities. This prism can be combined with specific data points to compare the optimal handling of the vehicle to what happened with the car in specific locations on a track.

To generate the performance prism, the data collected from the vehicle goes through a number of steps to create the final three-dimensional figure using ArcGIS. The first step is to bring the table into ArcMap, an application of ArcGIS and use the 'Display XY Data', and select the vehicle's accelerometer X and accelerometer Y data as the attributes to create a map. Once the dataset is created in this manner, it is brought into ArcScene, another application of ArcGIS to be visualized in a three dimensional mapping space. The height of the point data is set based on the speed attribute to show the relationship between the vehicle's handling and speed as shown in the point cloud in figure 26 below.

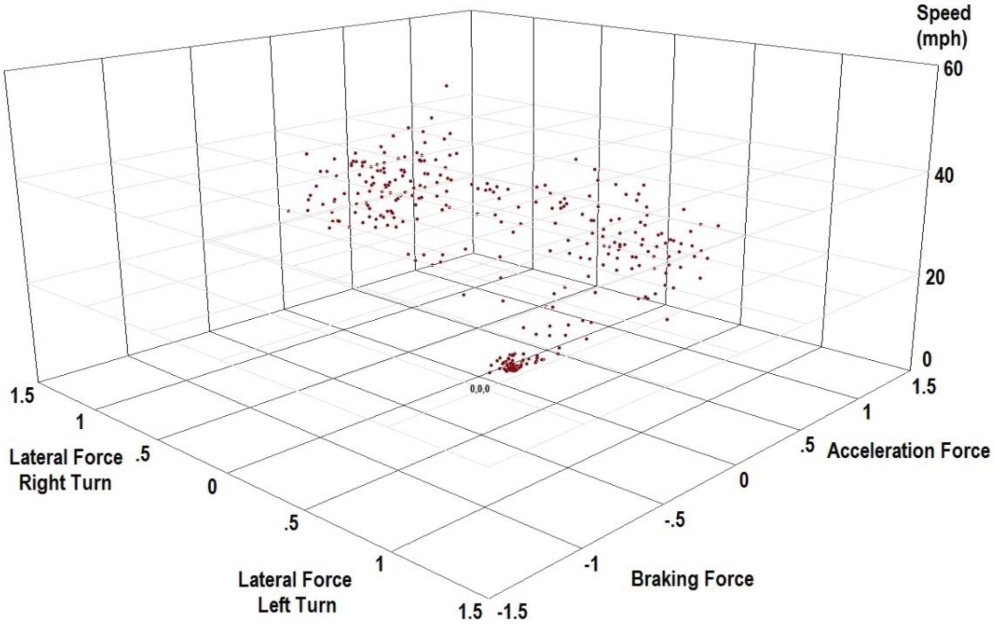


Figure 26. G-Force Data Point Cloud.

Once the point features are displayed correctly, the author navigated through the point data to select points that were on the outer limits of the point cloud and put them into two groups, top and bottom. The top and bottom point groups were then used to generate TIN (Triangular Irregular Network) files.

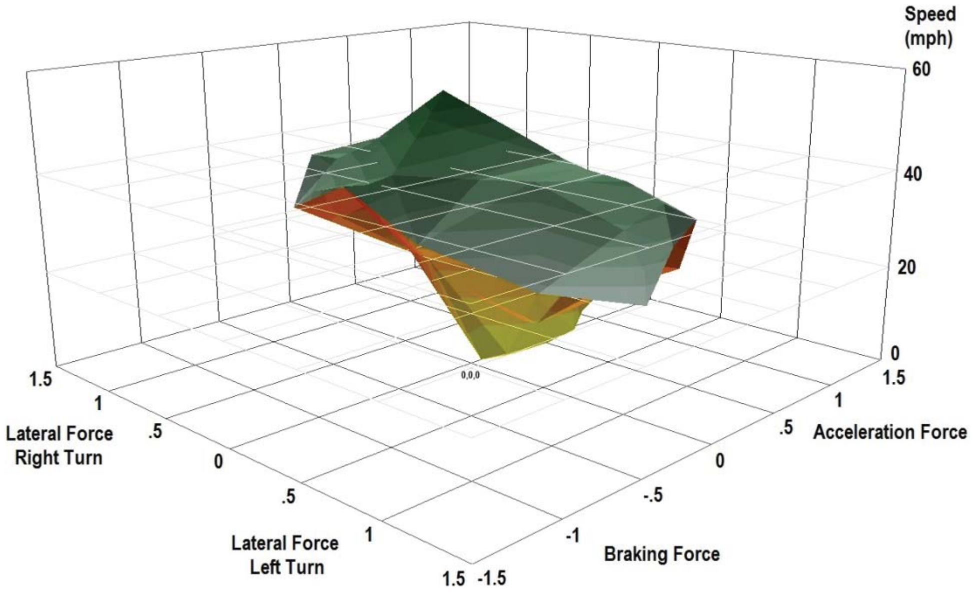


Figure 27. G-Force Generated TIN File.

As shown in figure 27, the top and bottom TIN features create the upper and lower limits of what will become the performance prism. The final step in creating the prism uses the ‘extrude between’ tool in ArcGIS to create the polygon shape that will represent the performance prism. The tool uses the top and bottom TIN features to generate a 3D polygon feature that fills in the space between the two TIN features. The 3D polygon feature is the final version of the performance prism, and it represents the vehicle's handling performances based on the relationships between horizontal force, lateral force, and speed data.

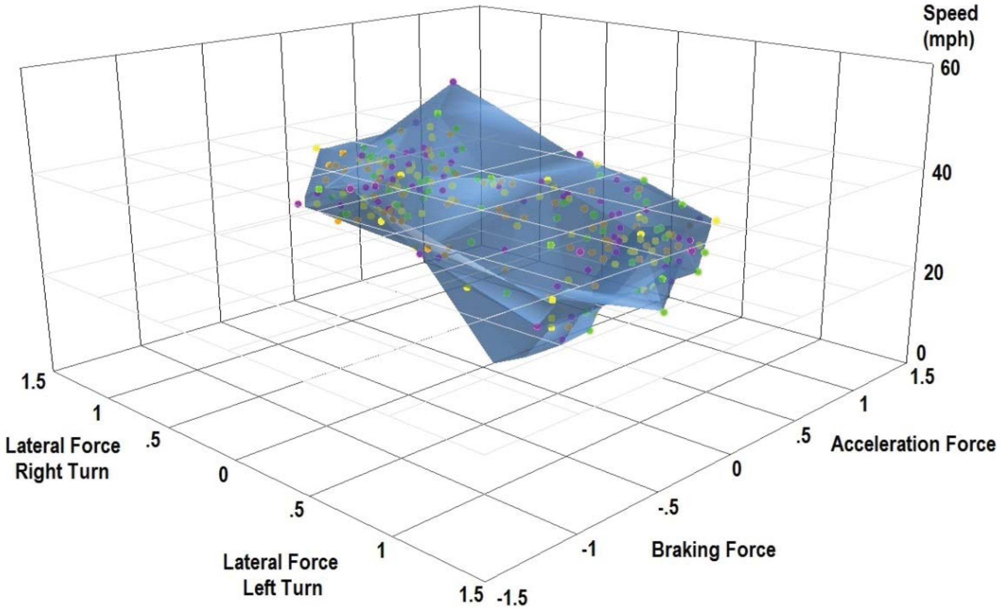


Figure 28. All Laps – Performance Prism.

The performance prism helps to visualize the relationship between vehicle handling and speed by representing the optimum performance of these attributes from the data collected. Then point data are compared to the performance prism to help understand the overall driving performance for specific locations or laps. Figure 28 shows the performance prism from the autocross event in this study and also the data points for each lap through the course with lap one in orange, two in yellow, three in purple and four in green. It is clear to see that point features from laps three and four are lining up at the outer boundaries of the top of the performance prism, showing that these data points were times where the car was being driven at its peak performance during the event. At the same time, the outer points on the bottom sides of the prism tend to be data points from the first and second laps where the car was not performing as well as it could have been.

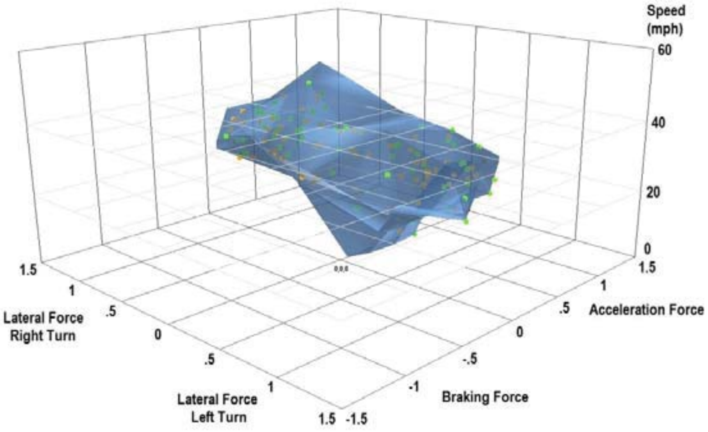


Figure 29. Lap One and Lap Four – Performance Prism Front.

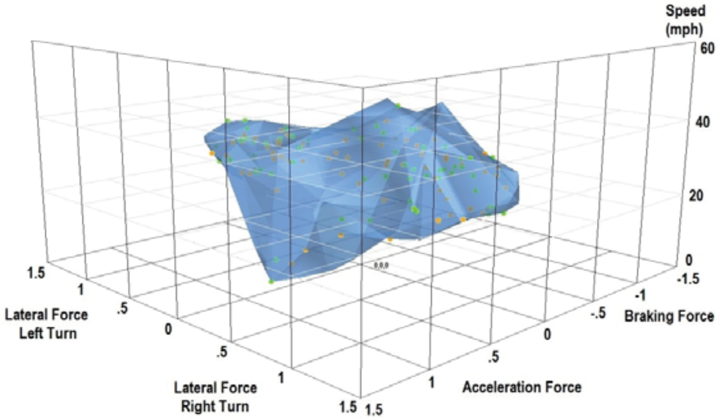


Figure 30. Lap One and Lap Four – Performance Prism Rear.

Figure 29 and 30 show a comparison of lap one in orange and lap four in green. Dots that are bright in color are on the outer boundaries of the prism, while points which are dull are located within the prism itself. As can be seen in the front and rear prism images in figure 29 and 30, there are a number of green dots which are representing the outer limits of the prism on both the top and sides of the prism. The data points from lap four which represent the highest levels of performance in the car help visualize why the fourth lap had the fastest lap time in comparison to the other laps. At the same time, there are a number of orange dots at the outer limits of the prism on its bottom side, where speeds and lateral forces are lower. This coincides with the first lap being the slowest of all the laps recorded.

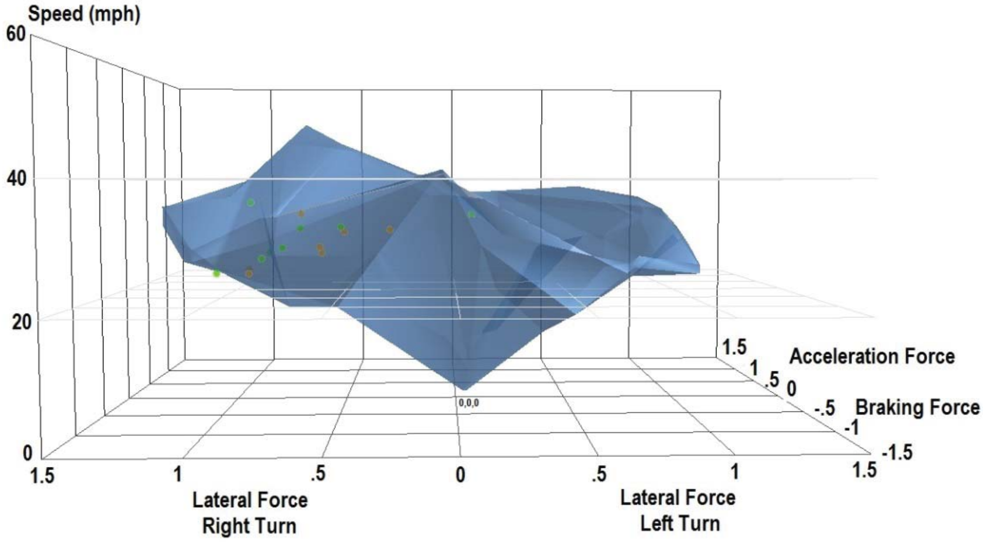


Figure 31. Lap One and Lap Four Turn Three – Performance Prism.

Figure 31 shows the performance prism along with point data from laps one and four in turn three. Comparing the points within the prism it can be seen that the data from lap one is much slower and confined within a smaller area whereas the data from lap four covers a much wider range of both speed and lateral force. These differences in handling and speed over the span of the entire course led to a 2.5 second difference between laps one and four. A hypothetical perfect lap of the course would have the majority of the data points placed on the outer edges of the prism shape. It must also be noted that only collecting data for four laps does not fully represent the abilities of the vehicle. With more laps included, the prism's shape would be better defined as new data points would help expand the representation of the performance of the car. In future studies, the performance prism will be further refined with more data provided to better determine the maximum performance of the vehicle.

Emotions of Autocross Analysis

The last set of analyses done by the author used the heart rate data that was collected during the event. The author had never monitored his heart rate during an autocross and was curious how the data would represent it. After each lap the author would check his heart rate data but did not run analysis as it couldn't be joined to the performance data quickly enough. Instead the data was used for 3D analysis later on. Space-time paths were generated for each of the laps through the course, visualizing the heart rate of the author as he drove through the course.

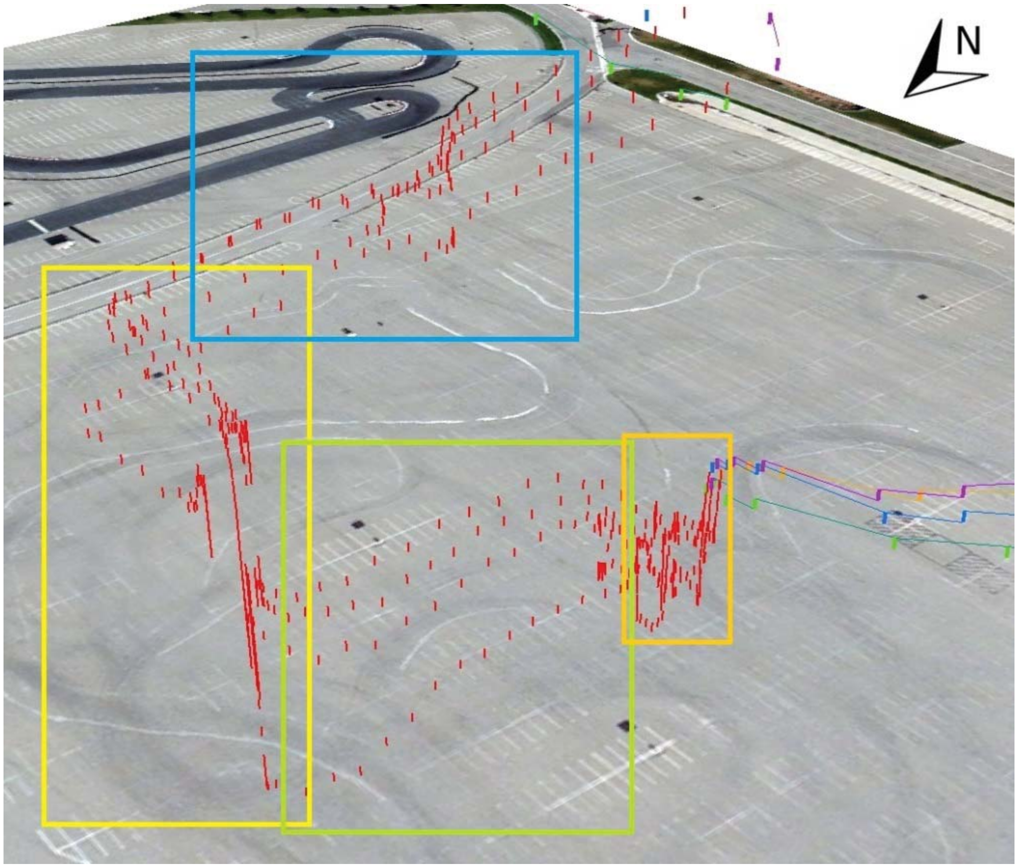


Figure 32. Heart Rate Data While Not Racing.

In addition to the heart rate data of the driver during the driving, the same data were collected while not driving the autocross course. As seen in figure 32, the heart rate data shows four distinct zones of heart rate change. First, the section highlighted in blue shows the heart rate of the author as he exited the course and drove slowly back to the waiting area. During this slow drive, the author's heart rate slowly dropped down with each data point as he calmed down from the intensive driving. As was discussed early with the heart rate of each lap through the course, the overall heart rate is lower after each lap through the course. A high heart rate of 151 bpm through this zone was recorded while a low heart rate of 139 bpm was recorded.

Once the author returned to the waiting area, highlighted in yellow, the heart rate dropped significantly, reaching its lowest points of anywhere in the data. The waiting period between the laps was roughly ten to fifteen minutes, so it gave the author plenty of time to relax. Even with relaxation, the author's heart rate never dropped below 101 bpm and was typically in the 110 bpm range. The author believed that the heart rate also dropped significantly in the final lap waiting period since he was not worried as much about the equipment failing, as it had already been through a number of laps on the course successfully. The waiting period brought the heart rate down to its lowest data points before the driver would head back to the starting grid.

The third significant zone that showed a change in heart rate, highlighted in green, was the drive from the waiting area to the starting grid. It was at this point that the author's heart rate would climb again, despite the drive being slow and easy to do. The author's heart rate at this point climbed to reach bpm's in the low to high 130's depending on which lap he was lining up for. This climb in heart rate could be attributed to most likely one of two things. Either the author was becoming nervous as he drove to line up for his next lap or his adrenaline was rising as he became excited to complete another lap. Based on the bpm falling throughout the course relative to the lap, it might have even been both, with nervousness causing the rise at first and adrenaline causing the rise later.

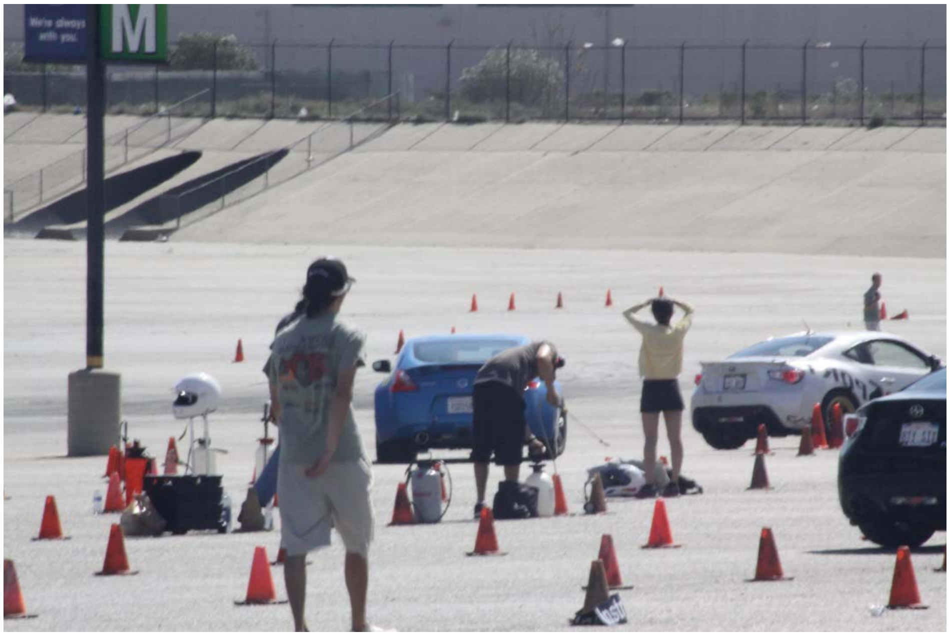


Figure 33. The Author on the Starting Grid.

The final zone, which is highlighted in orange in figure 32, was the final starting grid area. At this point the author was in a single file line with three other cars waiting for their turn to run the autocross course, as shown in figure 33. It was typically a one to two minute wait at this point until the author started driving a lap of the autocross course. The data at that point showed an interesting change, as the author's heart rate would drop slightly at this point. After having climbed into the 130 bpm range while driving to the starting grid, the heart rate would then drop back down into the 120 bpm range, with the lowest value being 121 bpm as can be seen in figure 32. This may have happened because the author was not moving the vehicle and instead was stationary. The author noted that he was also spending this period trying to picture the course in his head and what changes he needed to do when navigating the course. It is possible that the concentration distracted the author from the fact that he was lining up to run the course and that distraction cause the lowered heart rate. After sitting in the starting grid for a short time, the author started a new lap of the autocross course and his heart rate climbed, as covered previously.

The author's first assumption of what the heart rate data would show was that through each lap, the overall heart rate would be less than that of the previous lap, as a familiarity with the course would lower stress levels. After looking at the data, it was found that in the first three laps the author's heart rate was constantly changing and there was never a significant overall drop. It wasn't until the fourth lap that the overall heart rate through the course showed a significant drop that was consistently lower than the previous laps. The heart rate data also seemed to give hints as to where laps possibly went wrong, showing quick changes in heart rate in comparison to the steady climb that was typically seen through the course on all of the laps.

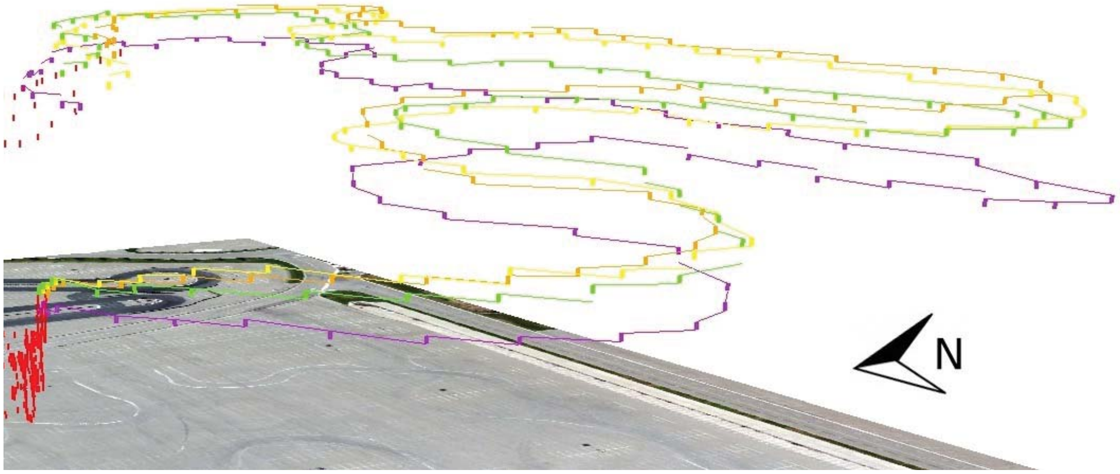


Figure 34. All Laps – Heart Rate Data.

Figure 34 above shows the heart rate data collected for all four laps of the event. Lap one, colored orange, consistently had the highest heart rate, climbing steadily through the entire course in the Z axis, seen in figure 34. There were no locations on the track that caused a distinct change in heart rate for the first lap. On the second lap, colored green, the author's heart rate was changing much more than the steady climb seen in the first lap. The heart rate rose higher than the first lap through the first two corners of the course before flattening out through turn three and the slalom. At this point the heart rate of lap two stayed consistent with the steadiness of the other laps. Lap three, colored yellow, held a slightly lower heart rate than the previous two laps until reaching turn three, where it climbed quickly to reach the heart rate levels of the first lap. The numbers then stayed at the same level as the heart rate from lap one before dropping more quickly in the last slalom compared to previous laps. On the fourth and final lap, colored in purple, it is easy to see just how much the overall heart rate dropped in comparison to the previous three laps. While there was a steady climb in heart rate through the entire course, the heart rate was consistently lower by roughly 10 bpm in comparison to the first lap.

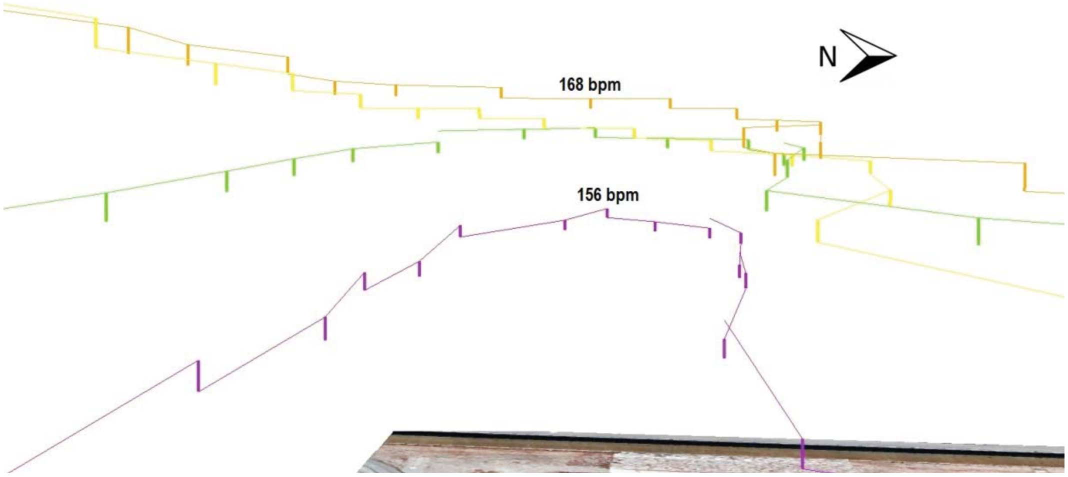


Figure 35. All Laps Turn Three – Heart Rate Data.

Turn three seemed to be the location where the author's heart rate would shift from the steady climb through the course and comparing the heart rate changes from each lap to the speed changes covered previously might help determine what happened that could have caused the changes in heart rate. For the first lap it is understandable that the heart rate would be the highest, as the first run of the course would be the most stressful due to not knowing the course or how the car would handle. At the same time the author was not pushing the car extremely hard, so there was less chance of something going wrong that could cause a spike in his heart rate. As mentioned earlier, the first lap through the turn three had low speeds and the data did not show any strange occurrences. The same can be mentioned for the second lap through turn three; speeds were slightly higher, but the change in speed was similar to that of the first lap and would explain why the author's heart rate was lower through the turn and was not climbing at all. The author felt comfortable through the turn, repeating what he had done on the previous lap.

The third lap is where the quick rise in the author’s heart rate occurs and it matches with the speed changes from that lap. The speed of the car on lap three changes in an erratic way in comparison to the other laps and coupled with the heart rate change, shows that the author was no comfortable in turn three on the third lap. Something went wrong in the turn that caused the author to re-adjust the speed of the car, and it caused a slight panic and rise in his heart rate which persisted through the rest of the course. Despite the problem in turn three, the author still completed the lap with an overall shorter time compared to the previous two laps, meaning that he made up for the mistake in turn three elsewhere on the course. On the final lap, the author’s heart rate was 12 bpm lower than the first lap half way through turn three. The author’s heart rate stayed consistently low despite having the fastest speeds through the turn compared to the previous three laps. There was a level of comfort for the author through turn three on the last lap that was never experienced during the previous laps. In the future it would be beneficial to continue collecting data for more than just four laps, to see at what point the heart rate would level out and no longer drop, despite the author having comfortable laps. This will need to be looked at in future studies.

CHAPTER 5

CONCLUSION

The purpose of this thesis was to examine how the realm of motorsports can be better understood by approaches of time geography and emotional geography using the GIS application developed in this study. As discussed previously in chapter 2, there exists a limited selection of literature that deals with motorsports in the context of the combined topics mentioned above. Instead, only pieces of each topic are found in other works. Existing methodologies of time-geography approach were applied to this thesis to develop the application and to collect and analyze the data of motorsports. This study contributes to the field of geography and motorsports by demonstrating how the time geography approach can be useful to improve performance of motorsport drivers. This study collected spatio-temporal data from a vehicle during a motorsport event and analyzed the data using a time geography approach to help determine ways in which a driver could complete faster lap times. One of the goals of this thesis was to provide a new way to collect and analyze the motorsport data that could provide other motorsport enthusiasts a guide to improve their performances through an affordable and effective manner. The developed application in this thesis demonstrated how the new way provided the guide through the field study dealing with empirical data. It was argued that GIS could provide multiple methods to analyze performances of amateur motorsport enthusiasts and visualize the results to help them find more effective and easier ways to improve their driving skills than existing methods.

In this research, the author applied a number of time geography concepts to motorsport data and also created the *performance prism* by combining the space-time prism and the “friction circle” of motorsport. The performance prism was represented in a three-dimensional visualization which showed the maximum handling performance abilities of the vehicle. It also visualized driving data to help a driver determine how well s/he was performing during driving in relation to the potential speed and cornering abilities of the vehicle. A major development from this study includes incorporating speed into the standard friction circle visualization which might provide most of amateur drivers a better understanding of vehicle handling. One aspect of motorsports that many amateurs do not consider when monitoring their data is their own emotional responses while on the track. The heart rate monitoring and visualizations used in this work gave the author a new look into their own driving experience during an event. With the ability to see emotional reactions to specific locations of the course gave the author the ability to focus on correctly driving in those locations to boost their confidence and correct the negative emotional reactions that could have distracted them from driving their best.

Limitations of this thesis include the limited amount of the data collected from only four laps of the autocross course for the analyses. In addition, the autocross course area was limited in length and caused lap times to be completed within one minute. Data were collected per second, and this means that for each lap there would only be between 50 and 60 data points to investigate. For all four laps, the author was working with only 200-240 data points that could be used to represent vehicle performance on the track.

The budget also affected the equipment choices. Had the author chosen a larger motorsport event that has longer lap times and more laps of the course, there could have been more data collected. The autocross area in this study was selected for the field study because it was a motorsport event that did not have a high cost to participate, whereas other events could have cost between two and twenty times as much depending on the type of event. With a larger budget, data could be collected using different hardware which could provide more previse data. The two least accurate sensors used in this thesis, the GPS sensor and the accelerometer sensor were also very important equipment that could be improved. Both of these sensors were built into the smart phone that was used for the data collection in this study. With a higher budget for the study, a stand-alone GPS and accelerometer sensor with higher accuracy could be used to collect more precise data that could result in a better analysis of the vehicle and the driver's performance.

This thesis provides many future extensions to study. These include different types of motorsport events, using more accurate and expanded data collection methods, and the opportunity to analyze the data using other time-geography concepts which were not used in this thesis. Higher data accuracy in terms of both location-based and attribute-based would provide better analyses of motorsport data. Also, higher location accuracy would produce better analysis of a driver's performance in relation to their location on the track. Lastly, higher data collection rates would provide datasets which would cover a larger portion of a driver's performance, and there would be more accurate data of the driver and the vehicle. With greater location accuracy and higher data collection rates, the space-time path and space-time activity density analyses could provide much more accurate analyses as compared to what was done in this thesis.

There are also many other concepts of geography that were not used in this thesis which might be applied to motorsports data for further studies. Similar to the emotional geography that was discussed in this thesis, behavioral geography could be applied to discuss the decision making choices a driver faces while in specific locations of a race course. The emotional geography discussion in this thesis was also limited due to small amount of data and methodology applied and could be expanded to include more sensors that monitor the driver's situation while on the course. Heart rate was the only emotional data collected in this research, however, perspiration, eye movement, and mapping a driver's perceived emotions could all be incorporated into motorsport data to understand the driver's emotions while racing.

Another aspect that could be expanded in future extension is collecting data from multiple drivers who are racing together at the same time on the course. Collecting data from multiple drivers and analyzing an event would be helpful to study the relationship between drivers and their performances. Emotional reactions to not only the course, but also other drivers might be an underlying factor to understand the performance of the drivers.

Motorsports are related to many industries and technological advancements in motorsports—i.e., GIS and geovisualization techniques used in this thesis--often are applied to standard vehicles. Currently there are only private companies, such as AiM (www.aimsports.com) or Racepak (www.racepak.com), which develop in-house data logging software to provide analysis to race teams. The development of a GIS suite for motorsport with proper analysis tools could provide GIS users with a new research tools which could help with vehicle tracking and movement studies for fleet vehicles or traffic analysis. It is the author’s hope that data collection in motorsports will expand with higher quality equipment that is easily accessible by drivers of all levels. It might also cause an increased demand for analysis tools such as GIS.

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