Project # 5: "Mobility and Safety of Transportation Systems Measuring Travel Time Reliability of Transportation Systems" (Transportation Project)

RET Participants:	Mr. Brad Hunt, Norwood High School, Norwood, Ohio and Ms. Kate Kulesa, Pre-service teacher, Xavier University, Cincinnati, Ohio.
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Graduate Student Mentors:	Mr. Vijay Krishna, M.S. student and Mr. Zhuo Yao, Ph.D. student in Transportation Engineering, Department of Civil and Environmental Engineering, University of Cincinnati.

Goals and Objectives

Transportation Engineers work in a field where they must collect and analyze data and compare it to other data that has been collected by various organizations, such as ODOT (Ohio Department of Transportation). After collecting the data and analyzing it, engineers think about hypothetical situations of ways to improve traffic flow and keep congestion to a minimum. In this project for data collection the teachers used tools such as GPS data loggers and Jamar traffic counter. For the uploading and analyzing of the data they used Petra Pro software, Microsoft Excel, Highway Capacity software (HCS), and VISSIM simulation software.

When traveling people want to be on time and avoid any traveling delays. In this project the participants determined travel time reliability along the I-71 corridor. This study provided a buffer time index to determine specific travel times along different segments of I-71. This gives the stability of the quality of service of this particular transportation system is supposed to provide to its users. Advanced GPS data collection was used to provide travel times along specific segments of I-71 along with volume data from OKI (Ohio Kentucky Indiana Regional Council of Governments) and ARTIMIS (Advanced Regional Traffic Interactive Management & Information System). In this project travel time reliability and average delay times using the 85^{th} percentile travel speed and the 95^{th} percentile of travel times was determined. The teachers were expected to be able to predict within 95% probability of travel time along I-71. The main goals and objectives of the project are:

- Bring real world applications to math problems and concepts to apply to mathematics curriculum.
- Use various tools and software programs in order to collect and analyze traffic data.
- Use the experiences and knowledge of engineering learnt to enhance existing math curriculum and stimulate students' interests

Equipment, Methods and Experimental Procedures

Content Training: The participants began their investigation of transportation literature by looking at *Traffic Engineering: Third Edition* textbook by Roger P. Roess, Elena S. Prassas and William R. McShane, Prentice Hall. In the opening chapters basic terminology and concepts are introduced, as well as basic responsibilities of a traffic engineer. Chapter 9 examined speed, travel time, and delay studies, which covered the basic concepts of the study. This assisted the teacher's understanding of field study techniques and data

calculations, and graphical representation. Chapter 12 was particularly helpful in explaining level of service, capacity, free-flow speed, and heavy vehicle factor.

Next, the participants examined the 2007 *Urban Mobility Report* by David Schrank and Tim Lomax, Texas Transportation Institute. This resource was helpful in explaining unreliable travel times which are caused by congestion problems. It introduced planning time index, travel time index, and buffer index in a graphical format, as shown in Figure 1.

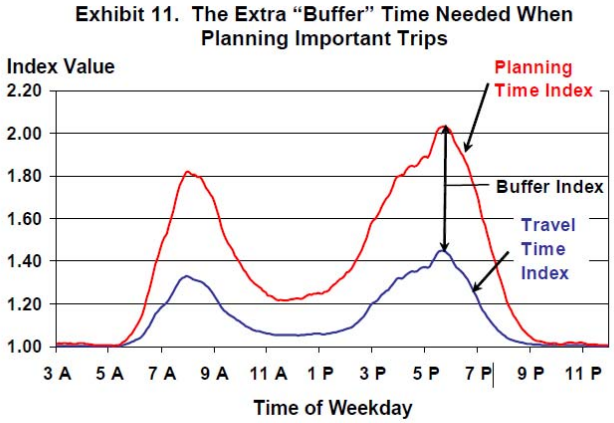


Figure 1. Graphical Representation of Travel Time Index and buffer Index

Next the participants studied the *Manual Of Traffic Engineering Studies* by Paul Box and Joseph Oppenlander, Institute of Transportation Engineers, Virginia. This is a handbook of how to conduct traffic studies. This manual was useful in understanding the floating car method for measuring travel time and delays. The floating car method was the basic principle for how the participants should drive with the traffic flow when going for their field observations. They also used this manual to determine the sample size for their traffic study.

The participants then reviewed the reference *Transportation Infrastructure Engineering: A Multimodal Integration* by Nicholas Garber, Lester Hoel and Adel Sadek, University of Virginia and University of Vermont. This resource helped understand the capacity concept and the level of service concept. The level of service concept is used in the traffic analysis using Highway Capacity Software (HCS). This reference defines the traffic flow parameters in terms of flow (q), speed (u), density (k), headway (h), and spacing between vehicles (d). The three basic parameters of a traffic stream are flow, speed, and density. They are related by the equation: $q = u\,k$.

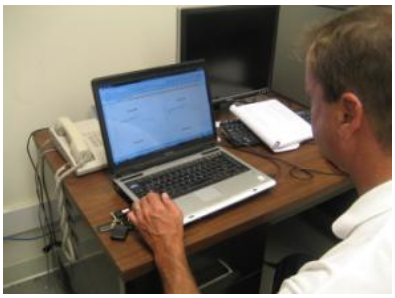
The participants also reviewed the U.S. brochure from the Federal Highway Administration entitled *Travel Time Reliability: Making It There On Time, All The Time*. This reference defined Travel Time Reliability (TLR) and explained why it is important to the field of transportation engineering. It gave formulas and examples of how to calculate TTR, calculate a Buffer Index and Planning Time Index, which are key parts to this transportation project.

Next, the participants' studied the book *Traffic Science* which presents traffic flow theories. Specifically, it defines the ranges of traffic intensity. It divided the traffic intensity into three categories: light traffic, moderate traffic, and heavy traffic. This resource also defined the

capacity of a roadway, bottlenecks, and presented several approaches to model traffic flow theory.

Training in Research Tooks: In order to collect the data the participants used GPS data loggers. The GPS data logger needs to be turned on at the start of a trip and it records the geographic coordinates, timestamps, and altitude. In order to view the data, the GPS needs to be plugged into a computer and uploaded to the Travel Navigation software. The RET participants were trained to import the GPS information, view the map with GPS route, and export the data into Excel. Next they were trained in the use of the Highway Capacity Software during their first few days of research. This software was used to introduce the participants to the concept of level of service (LOS). For input data values, the software predicts the LOS of the highway. The participants were also trained to use the simulation software VISSIM. With this software, an actual satellite image can be used as the background and the road network system can be built around that to simulate different design situations. The roads are built and actual highway volumes can be input into the program and the average travel times of the simulation can be animated and recorded. The participants were also trained on the use of the basics of Microsoft Excel software to compute averages, medians, creating functions, and creating various types of graphs. The photographs shown in Figure 2 show the teachers working on different stages of the project.

Teacher Determining LOS Using HCS



Teacher Conducting Segment Analysis Graphs in Microsoft Excel

RET Team Reviewing Speed Analysis Graphs

Discovery of the 85th Percentile Speed from a Graph

Figure 2. Photographs Showing Teachers Working on the Project

Methodologies Used: The I-71 corridor from Exit 19, Mason Montgomery Road, to Exit 1, at the Ohio River, was selected for the study. Data collection began on June 30, 2009 and continued through July 7, 2009. A GPS Data Logger was used to collect position, speed and altitude data in one second intervals. The position data was recorded in latitude and longitude coordinates. The middle lane was selected for travel and the participants drove consistent with

traffic. Every effort was made to model the traffic flow on each trip. This is known as the floating car method of study. Collection times varied throughout the peak hours between 7 a.m. and 9 a.m. Data collected consisted from twenty four trips southbound and fourteen trips northbound.

Using Google Earth, I-71 was then divided into sixteen segments southbound and fourteen segments northbound. The segments were divided in a manner such that an interchange fell in the middle of each segment. This method was chosen as to model the effect each interchange had on vehicle travel time and delay. The geographic latitude and longitude coordinates of the end points of the segments were recorded for further use.

After the data collection period was complete, the GPS data was then downloaded into the Travel Recorder software and exported as Microsoft Excel files. The data was then sorted by the day of the trip, as well as the direction of the trip. The data was segmented using the latitude and longitude coordinates of the segments. Once segmented, the travel times for each segment were calculated and cataloged. Segment times were then organized as to calculate various traffic indicators outlined below. Using Microsoft Excel, the 85th percentile speeds were calculated for the segments. Average travel time, buffer time, and planning times were calculated. Additionally, each segment trip time was graphed with the median speed as the horizontal axis. By using the data calculated for the given segments the level of service (LOS) was calculated using Highway Capacity Software (HCS). Using these graphs two southbound segments and one north bound segment were identified to have major delay times which was verified using the input data in the VISSM simulation software.

The graph in Figure 3 shows the travel time in critical segment number 4 going southbound. The travel time seemed to be more unreliable than the other graphs and that is evident by looking at the peaks on the graph and noticing the varying distances of the peaks from the median line.

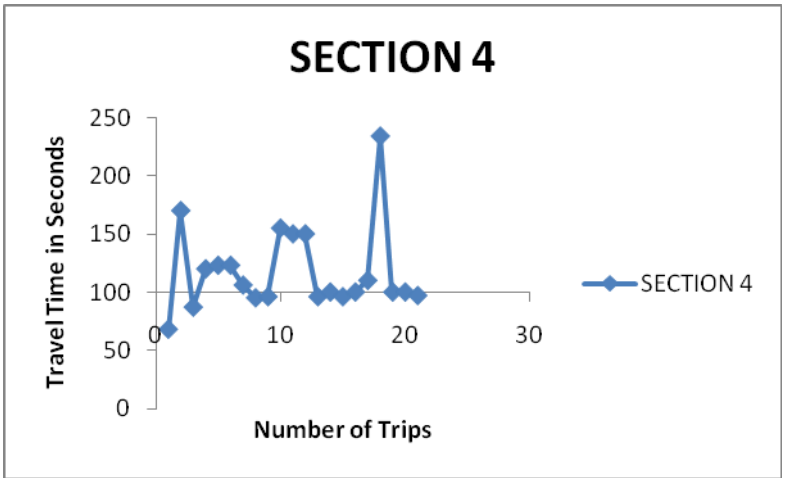


Figure 3. Travel Time in Segment No. 4

Using Microsoft Excel, Speed data was organized to find the 85th percentile speed through 65 mph and 55 mph zones on both the north and southbound lanes of travel. The graph obtained is shown in Figure 4.

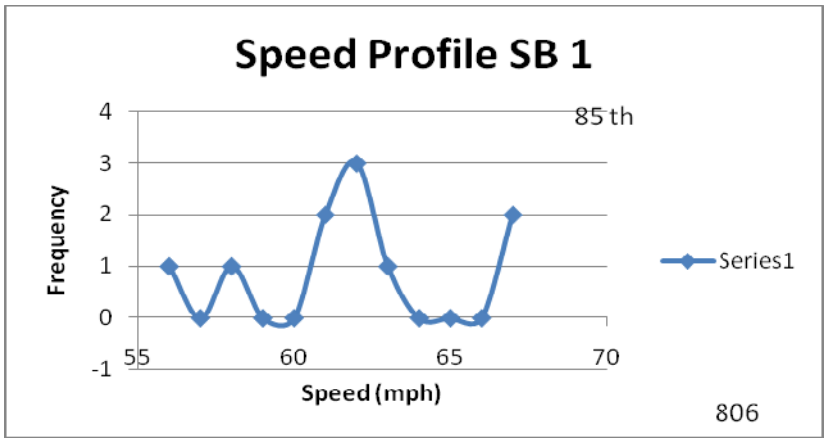


Figure 4. Frequency Plot Between 55th and 85th Percentile

Highlights of the Research Findings

The analysis process began when the segments were profiled to figure out which segments were the critical segments. The graphs showed the frequency of trips and the travel time in seconds. The x-axis of the graph was the median travel time. The graphs that had the most variation from the median travel time were determined to be critical segments.

Next, the teachers used the Excel data to calculate 95th percentile speed for each segment of the northbound and southbound trips. Using this they calculated planning time, travel time, and buffer time. Travel time reliability was determined by calculating the travel time index, planning time index and the buffer time index. This relationship is demonstrated in the graph presented in Figure 5.

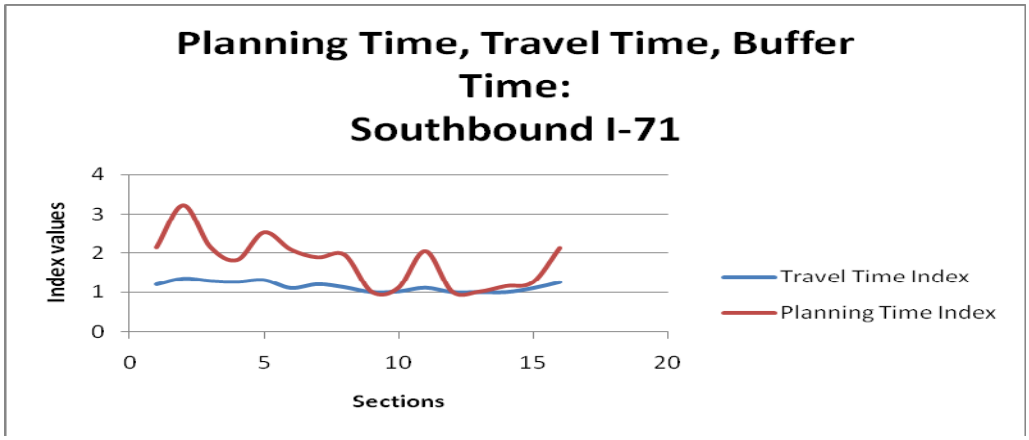


Figure 5. Travel, Planning and Buffer Time Indices

Plans for Classroom Implementation

Mathematics Lesson for 12th Grade Calculus Class: A three class period lesson plan was developed, as presented below:

Learners Overview and Purpose: Was based on the STEMcinnati theme, which included three elements: Application (A), Career (C), and Society (S) as follows:

A: It is important for students to be able to connect graphs of position, velocity, and acceleration.(Differentiation, Integration)
C: Engineers use Differentiation and Integration to solve problems that occur in their designs.
S: Traffic Engineers make decisions that directly impact our daily lives.

Education Standards Addressed:

- Students will be able to graph a function from the graph of its derivative.
- Students will be able to graph a derivative from the graph of its function.
- Students will be able to graph the derivative of a function given numerical data.
- Students will be able to interpret the area under the graph as a net accumulation of a rate of change.

Materials Needed: GPS Data Recorders, Graphing Calculators, and Travel Recorder Software.

Activities:

- Introduction to Traffic Engineering and field trip:
  - Teacher will make PowerPoint presentation on Traffic Reliability and RET project.
  - Students will develop knowledge of velocity, acceleration and position.
  - Students will go for a field trip to ARMITIS and collect data on the way.
- Analyze GPS Data:
  - Teacher will download data into the Travel Recorder software and convert it into Excel data for a trip on SR 562 to Kenwood Road.
  - Students will develop a velocity versus time graph for the above trip.
  - Teacher will show how to graph acceleration versus time graph from a velocity graph.
  - Using GPS Data Logger students will collect data on the bus to ARTIMIS.
- Graphing Activity:
  - Students will develop a velocity versus time graph for the trip to ARMITIS.
  - Students will graph acceleration versus time from their velocity graph for the SR 562 to Kenwood Road data and the trip to ARMITIS.
  - Students will be able to identify constant velocity, acceleration, and deceleration from those graphs.
  - Students will write a newspaper article about the trip to ARTIMIS.
  - Student graphs will be evaluated based on a rubric to be developed.
- Group Graphing Activity:
  - Teacher will provide students with various graphs (as an Excel file) for various traffic flow data.
  - Groups will derive acceleration and position graphs from provided velocity graphs.
  - Student graphs will be evaluated based on a rubric to be developed.
  - Groups critique other groups solutions based on the above rubric.

Mathematics Lesson for 5th Grade Class: A three class period lesson plan was developed, as presented below:

Learners Overview and Purpose: This was based on the STEMcinnati theme theme, which included three elements: Application (A), Career (C), and Society (S) as follows:

A: Anyone who is traveling from one point to another might be concerned with how long it will take. If you are going to work in the morning, and you encounter an accident, you could be late for work and suffer the consequences. How does congestion on the roads affect the traffic flow?

Data collection and the process of the scientific method is something that is very important in research fields. The process of recording data is something that is very applicable and important, and students get to see this as they are acting like scientists.

Graphing is applicable in many fields. After data collection in the research fields the results can be graphed and a best fit line be found. Extrapolation of graphs is a concept which is used in many fields, such as how to predict how a substance might react with continued addition of heat.

C: Researchers and scientists use the scientific method and very meticulously organize and record their data. Mathematics careers, as well as a variety of general careers, use graphs to easily display data.

S: If students can understand and apply the scientific method, such as analyzing the problem, recording data, and discussing results, they can easily share their results with others. This creates the opportunity to share information in professional publications. When they can publish their results, they can inform the general public and create discussion among society.

Education Standards Addressed:

- Measurement Standard: Make conversions within the same measurement system while performing computations.
  - Patterns, Functions, and Algebra:
    - Model problems with physical materials and visual representations, and use models, graphs and tables to draw conclusions and make predictions.
    - Describe how the quantitative change in a variable affects the value of a related variable; e.g., describe how the rate of growth varies over time, based upon data in a table or graph.
  - Data Analysis and Probability:
    - Read, construct and interpret frequency tables, circle graphs and line graphs.
    - Determine and use the range, mean, median and mode, and explain what each does and does not indicate about the set of data.

Goals and Objectives:

- Teacher's Guide for Goals:
  - Teacher will engage students and provide a question to intrigue students so that they will brainstorm a method to collect data.
  - The teacher will encourage students to think of an organized way to record the data. The teacher will scaffold students to analyze and compare the results from the data in graphical form.
- Teacher's Guide Objectives:

    - Students will organize recorded data into a chart, or something similar.
    - Students will interpret graphs by reading specific points on the graph, as well as creating points on the graph.
    - Students will create a graph of their recorded data.
    - Students will determine the mean, median and mode of their data.
- Student Guide for Goals and Objectives:
    - Students will work cooperatively in groups. Students will organize recorded data into a chart, or something similar.
    - Students will interpret graphs by reading specific points on the graph, as well as creating points on the graph.
    - Students will create a graph of their recorded data.
    - Students will determine the mean, median and mode of their data.

Instructional Strategies:

- Teacher's Guide for Instructional Strategies to Engage:
    - Ask students how much time they think they spend in traffic on the way to school each day?
- Student's Guide for Instructional Strategies to Engage:
    - Have students brainstorm a way to calculate time spent in traffic.
    - Calculate: time they spend in traffic each week, each quarter, each year, up until fifth grade, and from K-12th grade.

Technologies to be Utilized:

- Student's Guide for Technologies to be Utilized: Students will use charts, data tables, and graphing tools to organize and analyze data.
- Teacher's Guide for Technologies to be Utilized: Videos, PowerPoint, graphing software (Excel), and interactive white board (Smartboard).

Assessment Guide:

- Have a checklist for each group, with subsections for individuals. Are students:
    - Cooperating in groups?
    - All contributing to the work?
    - Individually providing a verbal explanation of the problem and methodology?
    - Producing a written summary of the problem?
    - Drawing a picture to help solve the problem?

Guide for Other Resources (e.g., Websites, books, etc.):

- NCTM: Illuminations website:
    - "Finding Our Top Speed" lesson from http://illuminations.nctm.org/LessonDetail.aspx?ID=L254.

Learner Participation Activity:

- Teacher's Guide for Activities:
    - Explore:
        - Have students walk in the hallway. Teacher causes a disturbance in the flow of students (obstacle blocking hallway).
        - Ask students what this is similar to? (traffic...).

        - Pose a word problem. Example: We need to figure out how long it will take our class to walk to specials. If we encounter another class blocking the hallway, will it slow us down? (Incorporate specific distances to the destination).
        - Ask students to draw a picture they can use to help to visualize and solve the problem. Have students write a few sentences that will summarize the problem in their own words.
        - Discuss with students possible ways to segment the trip. While students are performing trials, provide some obstacles during some of the trials. The teachers can simulate wrecks, construction, lane closures, bad weather using boxes or people as obstacles.
    - Explain:
        - The class can compare data recorded using the Smartboard in Excel. Did the groups record similar data? What could account for the differences?
        - Have groups plot duration and distance. Discuss and interpret the overall graph and various points (using one example on a Smartboard).
        - Ask students what could simulate entering and exiting ramps (classrooms) onto the highway (hallways).
        - How easy is it to move around? Did anything make it harder to move around? Have students categorize this on a scale from 1-4. One being the easiest to move around, and four being very difficult to move.
    - Expand:
        - Have students interpret some of the teacher's (simplified) speed graphs from research.
        - Talk to students about highway level of service, how they are built, and the volume of traffic.
        - Have students create other types of graphs to display their data.
- Student's Guide for Activities:
    - Explore:
        - Students connect simulation to traffic
        - Students brainstorm how to record data
        - Draw a picture of the problem
        - Summarize problem in their own words
        - Segment the hallway
        - Time how long it takes to pass specific marks
    - Explain:
        - Compare and discuss the class's data
        - Plot duration and distance
        - Discuss the relative ease of movement in the hallways
    - Expand:
        - Interpret some of the teacher's speed graphs from the project
        - Create other types of graphs
- Guide for Assessment of Activities:
    - Are the groups participating in comparing the data with the class?
    - Are students contributing to the discussion?
    - Can the student verbally explain the different types of graphs?

- Can the student explain what a point is in terms of the coordinates and in the context of the problem
- Evaluate Using a Rubric:
  - Student graphs (majority of points): Data points, labeling, title, craftsmanship
  - Summary and picture of the problem
  - Exit slip: Completion of questions (assess responses)