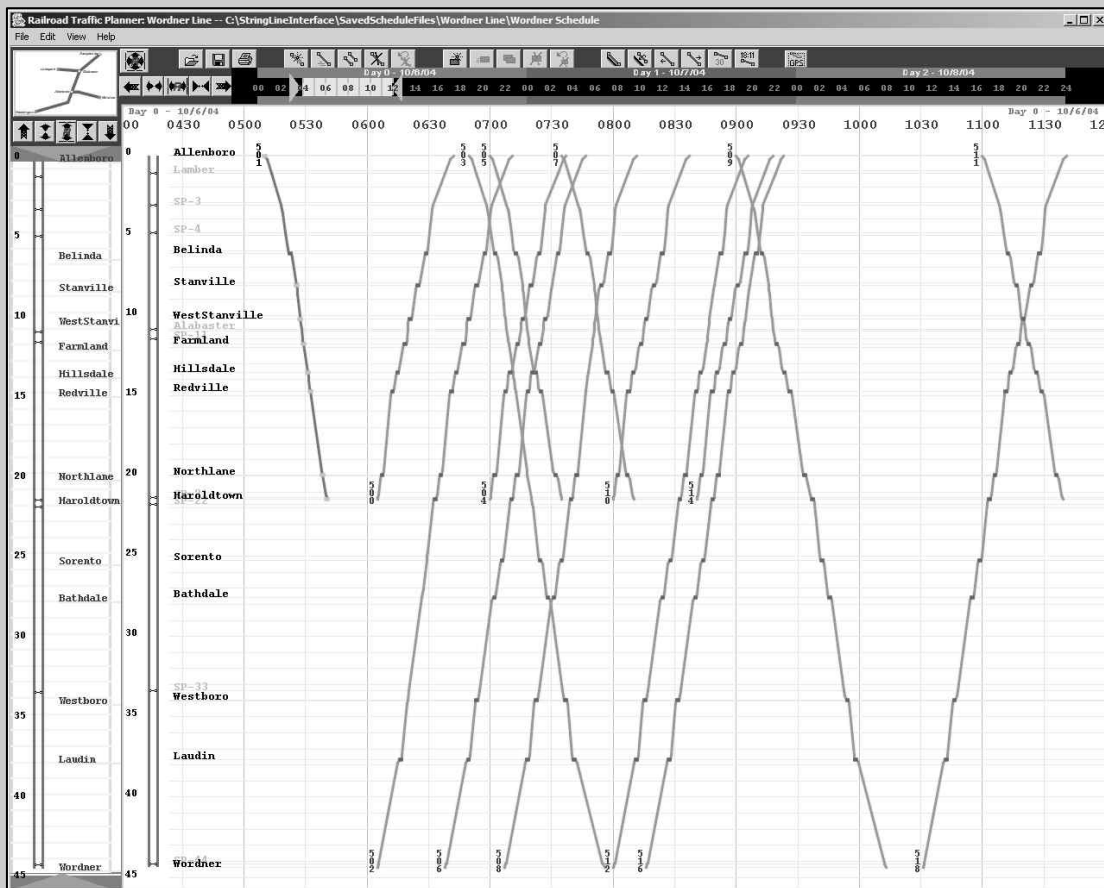




U.S. Department  
of Transportation  
**Federal Railroad  
Administration**

# Visualizing Railroad Operations: A Tool for Planning and Monitoring Railroad Traffic

Office of Research  
and Development  
Washington, DC 20590



## Human Factors in Railroad Operations

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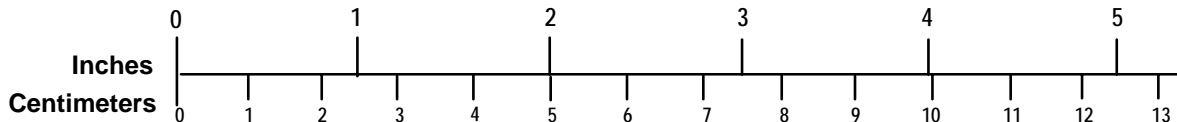
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## ENGLISH TO METRIC

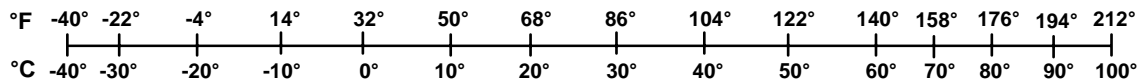
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<p><b>AREA (APPROXIMATE)</b></p> <p>1 square inch (sq in, in<sup>2</sup>) = 6.5 square centimeters (cm<sup>2</sup>)</p> <p>1 square foot (sq ft, ft<sup>2</sup>) = 0.09 square meter (m<sup>2</sup>)</p> <p>1 square yard (sq yd, yd<sup>2</sup>) = 0.8 square meter (m<sup>2</sup>)</p> <p>1 square mile (sq mi, mi<sup>2</sup>) = 2.6 square kilometers (km<sup>2</sup>)</p> <p>1 acre = 0.4 hectare (he) = 4,000 square meters (m<sup>2</sup>)</p>	<p><b>AREA (APPROXIMATE)</b></p> <p>1 square centimeter (cm<sup>2</sup>) = 0.16 square inch (sq in, in<sup>2</sup>)</p> <p>1 square meter (m<sup>2</sup>) = 1.2 square yards (sq yd, yd<sup>2</sup>)</p> <p>1 square kilometer (km<sup>2</sup>) = 0.4 square mile (sq mi, mi<sup>2</sup>)</p> <p>10,000 square meters (m<sup>2</sup>) = 1 hectare (ha) = 2.5 acres</p>
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<p><b>TEMPERATURE (EXACT)</b></p> <p><math>[(x-32)(5/9)] \text{ } ^\circ\text{F} = y \text{ } ^\circ\text{C}</math></p>	<p><b>TEMPERATURE (EXACT)</b></p> <p><math>[(9/5)y + 32] \text{ } ^\circ\text{C} = x \text{ } ^\circ\text{F}</math></p>

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## Preface

This report provides an overview of the development and technology transfer of the *Railroad Traffic Planner* application, created by the U.S. Department of Transportation's John A. Volpe National Transportation Systems Center, the Massachusetts Institute of Technology, and Fulcrum Corporation with funding from the Federal Railroad Administration's Human Factors Research and Development Program. The *Railroad Traffic Planner* is a visualization tool that shows train positions over time. It provides support for scheduling activities and also includes near-real-time position information for trains and maintenance vehicles with associated global positioning system tracking devices installed. One objective of this project was to evaluate the potential for this type of visualization tool to improve safety and productivity in the railroad industry. Another objective was to demonstrate the process of technology transfer by bringing this tool to additional railroads and other interested parties in the railroad industry.

## Acknowledgements

We would like to thank all of the individuals from the many organizations who have contributed to this project. Thomas Raslear and Michael Coplen from the Federal Railroad Administration (FRA) Research and Development Human Factors Program sponsored this project and provided valuable guidance and support. Other FRA contributors have included Steven Ditmeyer and Richard Cogswell who provided useful insights. The John A. Volpe National Transportation Systems Center contributors included Lenore Katz-Rhoads and E. Donald Sussman. Ronald MacNeil from the Massachusetts Institute of Technology provided creativity and enthusiasm, as well as the majority of the software development. Vijay Kohli, Graham Truelove, Mike Foster, Alan Truelove, Apra Rajpal, Dao Ly, Dave Hudock and Linh Nguyen from Fulcrum Corporation enhanced the functionality and helped bring the tool to additional railroads. Emilie Roth from Roth Cognitive Engineering also supported efforts to improve and promote the tool.

We would also like to thank all of the railroad employees who shared their time and knowledge with us. Stephen Jones, formerly of Amtrak and the Massachusetts Bay Transportation Authority, helped with the initial design and provided guidance from a passenger railroad perspective. Dick Miller, Steve Balforti, Larry Ferguson and Sydney Culliford from Guilford Rail System helped test the application and show how the needs of a regional freight railroad varied from those of passenger railroads. Many employees from North Shore Railroad also provided feedback and support, including Dick Robey, Gary Shields, Jeff Pontius, Mike Herman, Brian Robey, Jeb Stotter, John Moraski, Joan Long, and George Fury. Russ Burzynski, Jerry Gordon, Ed Pflueger, Robert Buchanan, E. Dwayne Edwards, John Fillinger, and all of the dispatchers from Paducah and Louisville Railway also provided feedback about how the tool would fit within their work environment.

Throughout the development process, the planner application has been presented at conferences and industry meetings. A demonstration version of the software has also been distributed to share the concepts with a larger audience and collect feedback. We would like to thank everyone from industry, academia, and government who reviewed our demonstrations throughout the project and provided support and ideas.

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## Abbreviations and Terminology

AGPS	Assisted Global Positioning System
Dwell	Length of time a train spends at a station
FRA	Federal Railroad Administration
GPS	Global Positioning System
Guilford	Guilford Rail System
J2ME	Java 2 Platform, Micro Edition
MBTA	Massachusetts Bay Transportation Authority
MIT	Massachusetts Institute of Technology
NSHR	North Shore Railroad
PAL	Paducah and Louisville Railway
Regional Railroad	Railroad that provides transportation between cities and operates at least 350 miles of track and/or earns revenue between \$40 million and the Class I revenue threshold (which adjusts for inflation, but is currently around \$289.4 million)
Short Line Railroad	Either a local railroad or switching and terminal railroad. Local railroads provide transportation between cities, but are below the mileage and revenue thresholds for regional railroads. Switching and terminal railroads are either jointly owned by two railroads for transferring cars between railroads or operate solely within a facility or group of facilities
String line diagrams	Charts with times on one axis and locations along the tracks on the other (in the <i>Railroad Traffic Planner</i> the times are on the abscissa and the tracks are on the ordinate). On these charts points representing the times and locations of a scheduled train trip are connected to form a “string.” Intersecting strings show that trains will meet if on same track or pass if on separate tracks. The slope of the strings indicates direction and relative speed. Horizontal sections of strings indicate that the train will be stopped
Technology transfer	Formal and informal cooperative actions between agencies, federal laboratories, and the public and private sectors intended to result in product improvement, service efficiencies, improved manufacturing processes, joint development to address government and private sector needs, or the development of major new products for the international marketplace

## Executive Summary

Railroad traffic planning and monitoring can be crucial to the safety and efficiency of railroad operations. This report describes the development and technology transfer of a software tool called the *Railroad Traffic Planner*, which was designed, built, and demonstrated to support railroad traffic planning and monitoring.

The *Railroad Traffic Planner* application incorporates an approach to identifying potential schedule problems that has been used in the railroad industry for more than a century—using “string line” diagrams, which show train positions over time. This visualization technique helps planners ascertain the direction and relative speed of the trains, and where and when two trains will either “meet” if going in opposite directions or “pass” if a faster train goes past a slower one. Reviewing the locations of meets and passes in a schedule can help planners identify potential conflicts and make adjustments to resolve them. The *Railroad Traffic Planner* processes for creating and modifying schedules were designed to be more efficient than traditional approaches for creating string line diagrams, such as using paper and pencil or actual string on a tack board. The *Railroad Traffic Planner* also includes near-real-time position information when trains and maintenance vehicles have associated global positioning system (GPS) tracking devices installed.

The *Railroad Traffic Planner* development process was a collaborative effort between the Federal government and private industry to support safety and productivity in railroad operations. The development team included the U.S. Department of Transportation’s John A. Volpe National Transportation Systems Center, the Massachusetts Institute of Technology, and Fulcrum Corporation with funding from the Federal Railroad Administration’s (FRA) Human Factors Research and Development Program. Participants from four railroads helped define, prioritize, and test features for this application, focusing on functionality that would help them work more effectively than with their current techniques. These railroads were:

- Massachusetts Bay Transportation Authority, a commuter rail service for Greater Boston, Massachusetts,
- Guilford Rail System, a regional freight railroad in New England and New York,
- North Shore Railroad, a short line freight railroad in Pennsylvania, and
- Paducah and Louisville Railway, a regional freight railroad in Kentucky.

The development team collected feedback from the railroad users, and also from attendees at conferences and workshops where the tool was demonstrated and discussed with representatives from the government, industry, academia, and consulting.

One objective of this project was to research the potential for this type of visualization tool to improve safety and productivity in the railroad industry. A second objective was to demonstrate the process of technology transfer by bringing this tool to additional railroads and other interested parties in the railroad industry. To achieve these objectives, the development team demonstrated the software at industry meetings, distributed a demonstration version of the software, and developed new features to help with the eventual commercialization of such a product.

The development team identified several potential challenges to developing and using this type of system during this project. For example, railroad operations are complex and frequently changing, which makes it difficult for planners to set up software like the *Railroad Traffic Planner* and keep the data current. As with other software development efforts, resource constraints influenced which features could be implemented. Other challenges involved ensuring mechanical integrity, the test GPS systems, and protecting them from vandalism.

The development team also identified several potential benefits of using string line software and tracking tools during this project. Planners showed that tools like the *Railroad Traffic Planner* can be very useful for “what if” planning, since changes to schedules can be efficiently entered and evaluated. For example, one planner demonstrated how the *Railroad Traffic Planner* helped him better understand the consequences of adding a train or taking a track out of service compared to his previous planning techniques. Other planners showed how the *Railroad Traffic Planner* helped them quickly determine the impact of modifying train speeds. Employees at another railroad found the GPS tracking component useful for helping them predict when locomotives would be back for maintenance and for remotely monitoring locomotive speeds.

The development team also gathered suggestions for other potential uses of this tool. For example, many people said that the *Railroad Traffic Planner* would be helpful for training planners and dispatchers, because it could be used by the students to learn how to recognize potential traffic conflicts and how the decisions they make about one train could affect others. Individuals from other industries, such as military, maritime, and transit, also expressed interest in using this software to support their planning, monitoring, and logistics needs. String line software, like the *Railroad Traffic Planner*, could also be used for security and emergency purposes such as developing contingency plans and helping with schedule modifications during disasters. Fulcrum Corporation has already used some of the GPS tracking capabilities developed during this project for a hazardous tank car security program sponsored by FRA and a container security program for the Office of Naval Research.

Information gathered during this project suggests that railroads should seek string line tools that effectively support, rather than replace, a human scheduler’s decision making. The planning system calculations should be accurate enough to meet the needs of those who will be using them. Additionally, when implementing a tracking system, it is necessary to ensure that the people who will be impacted by it understand its purpose, so that they can support, rather than hinder, its effectiveness.

This project demonstrated that it is sometimes helpful to adapt a product during technology transfer if the recipients are interested in features that were not included in the original design. In this case, tracking features were added to the planning capabilities of the *Railroad Traffic Planner* to support small railroads with few tracks and trains in operation. The development team reached out to many other individuals in the railroad industry as well to learn about and promote the use of visualization tools to improve safety and productivity. This sharing of ideas gave many individuals an opportunity to try the tools and learn from this project. One indication that the technology transfer is having an impact is that technology from this project has already been applied to other projects, including the hazardous tank car security program and container security program.

# 1. Introduction

This report begins with a brief overview of railroad traffic planning and monitoring, and then describes the development and technology transfer of a tool called the *Railroad Traffic Planner*, which was designed to support these processes. Some challenges were encountered during this project, but many potential benefits of string line and tracking tools were identified. Recommendations and conclusions for people interested in developing, transferring, and using systems like the *Railroad Traffic Planner* are offered at the end of the report.

## 1.1 Railroad Traffic Planning and Monitoring

Railroad traffic planning is crucial to safe and efficient railroad operations. The efficiency of the entire railroad system can be disrupted if a poorly scheduled train blocks the path of other trains. Characteristics of the trains, tracks, and stations limit the scheduling possibilities. Train speeds vary based on many factors such as the cargo, the type and number of locomotives, the grade of the terrain, and the weather. Areas with a single track can be especially challenging for planners who must often make one train wait for others to pass. Even when there are two or more tracks, locations in which trains can switch from one track to another are limited, and complications can arise if fast trains overtake slower ones or stations only have platforms for passengers on one track.

### 1.1.1 Consequences of Bad Schedules

Bad schedules can have serious safety implications. If trains are too close together, an increased risk of collisions occurs, especially if the operations are not monitored properly. Schedules that do not appropriately reflect the speeds the trains can travel put undue strain on the dispatchers, who must continually react to the problems caused by the suboptimal schedules. Financial implications of bad schedules occur as well. Freight trains often operate without published schedules, but freight railroads can also prepare schedules to set expectations for their existing and potential customers. In passenger rail service, schedules are essential for communicating expectations to the passengers who ride the trains. If the schedules are unreliable or at inconvenient times, the number of passengers will decrease and the railroad will be less profitable. Financial implications associated with crew scheduling also occur. The Federal Hours of Service Act specifies that train crews cannot be on duty for more than 12 consecutive hours. If a train is scheduled to wait on a siding and the crews exceed the Hours of Service Act, another crew is required to complete the trip. Good scheduling practices can save the railroad money, because fewer crews are needed.

### 1.1.2 Scheduling Challenges

Traditional methods for creating railroad schedules can be very time consuming and cognitively challenging, and therefore prone to mistakes, especially if done quickly. Planners must estimate how long it will take the trains to get from one location to another accounting for the different train types, speed limits along different stretches of track, speed restrictions, and the rate of acceleration and deceleration as the trains change speed. Not only do planners need to determine how long it will take the trains to arrive at the destinations, they must also ensure that no two trains (or other railroad vehicles) are going to be at the exact same location at the same time. All passing traffic must be on separate tracks and/or sidings—trains cannot swerve to avoid

oncoming traffic and they cannot stop very quickly. In passenger operations, the planner must also consider dwell time, which is how long the train stops at the station to drop off and pick up passengers.

### 1.1.3 Scheduling Frequency

How frequently railroads revise schedules can depend on many factors, including changes in customers, traffic patterns, track configurations, and personnel. Scheduling practices vary from one railroad company to another. For example, the Massachusetts Bay Transportation Authority (MBTA), a passenger railroad, normally updates their schedules twice per year. At Guilford Rail System (Guilford), a freight railroad, planners develop schedules occasionally for marketing purposes to help them better communicate with potential customers where and when the trains usually travel. A further consideration for Guilford is that their freight trains must not interfere with the MBTA and Amtrak passenger trains that use the same tracks. If the passenger schedules change, Guilford must change their schedules too.

In addition to creating long-term schedules, planners are often involved in short-term planning activities. For example, if track maintenance is needed, planners are sometimes involved in defining temporary speed restrictions and selecting times for taking the tracks out of service. The planners usually try to minimize the impact on the existing schedule when doing this.

### 1.1.4 String line Diagrams

One approach to identifying potential conflicts that has been used for more than a century in the railroad industry is the string line diagram, which shows train positions over time. Figure 1 shows a sample string line diagram with explanatory notes in gray.

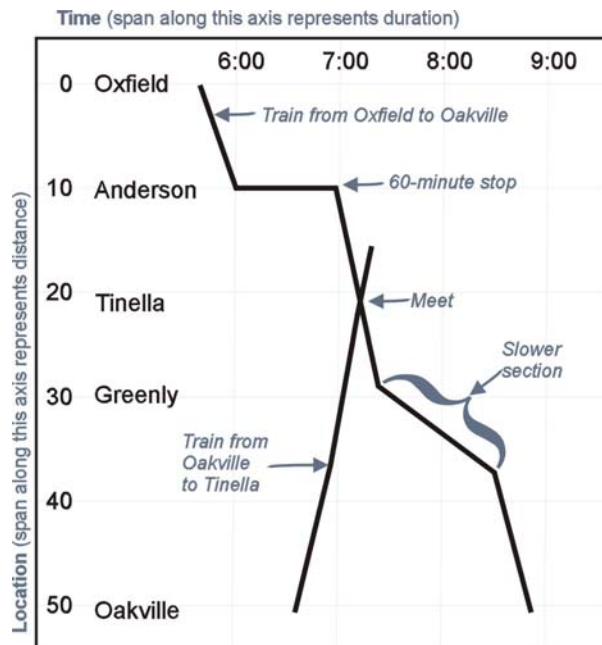


Figure 1. Sample string line diagram

In the string line diagram in Figure 1, the abscissa represents time and the ordinate represents locations along the tracks. Points reflecting the times and locations of the scheduled train trips are connected to form “strings.” Each string shows the schedule for one train. The slope of a segment of a string is based on the direction and relative speed. Faster trains show steeper slopes, because they travel farther in less time. Since stopped trains are in the same location for a while, the string’s slope is horizontal where the trains are stopped. The intersection of two strings indicates where and when two trains will either “meet” if moving in opposite directions or “pass” if a faster train goes past a slower one. To avoid collision, trains should only meet or pass where there are multiple tracks or sidings. Reviewing the locations of meets and passes in a schedule can help planners identify potential conflicts, and subsequently make adjustments to resolve them. For example, planners used string line diagrams in an FRA project to review the consequences of running additional freight trains on tracks with passenger operations, and to analyze where passing sidings would need to be placed based on the expected time intervals between trains (Bing, Mayville, and Nelson, 2005). Also, during the planning of the River LINE in New Jersey, planners created schedules using an iterative process with string line charts to shift all meets into double track areas. These schedules had a high percentage of on-time performance when railroad operations began (Fitzsimmons and Parikh, 2005).

Tufte (1983) indicated that string line diagrams are helpful because they contain information in a compact, yet accessible form. He included a French string line diagram from the 1880s as an example of graphical excellence in one of his books, because it provides information in an efficient manner that greatly facilitates learning and understanding while reducing confusion and errors. In a book on information visualization, Ware (2004) pointed out that “very rapid problem solving can be done with the right interactive display, as we pull out patterns through rapid visual searches.” Because the crossed strings in a string line diagram are so apparent, planners can efficiently verify that the meets and passes occur in appropriate locations and avoid some of the most serious scheduling errors.

Traditionally, planners made string line diagrams using either paper and pencil or actual string on a tack board. Some planners still create string line diagrams without software support. With the complexities of the railroad environment and the number of calculations required, even small changes to schedules may take many hours when using traditional scheduling methods.

### **1.1.5 Computerized String line Tools**

Computerized string line displays have existed since the 1970s, and many of the early systems were either built by people at the railroads or by companies that no longer exist. Some railroads turned to large-scale solutions offered by a small number of vendors, since they were unable to adequately meet their scheduling needs with their own applications (R. Cogswell, personal communication, November 22, 2002). Some large railroads have benefited greatly from the elaborate scheduling software products that incorporate string line displays with a large array of associated tools, such as train performance calculators and schedule optimization features. For example, Canadian Pacific Railway received the Franz Edelman Award for Achievement in Operations Research and the Management Sciences in 2003 because they greatly improved their operations after implementing sophisticated scheduling software (Horner, 2003, June). Software with string line diagrams is also used extensively in Europe; in some countries, like Germany, all dispatching is done using string line diagrams (J. Pachtl, personal communication, September 30, 2004).

Many of the existing software scheduling tools were designed to address the complexities of large-scale operations, so considerable time is needed to effectively learn and work with them. Some railroads contract out the planning process to companies that already know how to use appropriate software (M. Holowaty, personal communication, November 22, 2002). The price of large software packages and/or contractor support is beyond the reach of some small railroads. In fact some of the vendors do not even try to sell to small railroads, since their solutions are the equivalent of using a sledgehammer to drive in a tack. Other vendors want to support small railroads and believe that the costs of their systems are justified when factoring the savings of more efficient schedules (for example, if the schedules were improved, fewer locomotives and sidings would be needed, thereby more than making up for the price of the software). Railroads involved in this project, however, were concerned that those systems were too expensive and/or unwieldy for their needs. One railroad planner said that even if his company stood to benefit from purchasing a \$45,000 application, he did not know where the money to buy it would come from, since he does not have any funds available for that purpose. Planners at small railroads may be reluctant to learn complicated software tools since they have many other job responsibilities competing for their time.

### **1.1.6 Railroad Traffic Monitoring**

Schedules indicate where trains *should be* at various points in time. Sometimes it can also be helpful to know where the trains *actually are* or *were*. Railroad dispatchers monitor day-to-day operations to ensure the safe and efficient passage of trains and maintenance vehicles. Some railroads have sections of track that have been equipped with devices to automatically send track occupancy information to the dispatcher's computer. The train positions provided by this method lack precision because they merely indicate which "block" the train is in, and one block may be several miles long. Some railroads have GPS-based tracking systems that capture their train positions, such as Metra in Chicago, ("Market," 2002, January), but these are still relatively uncommon. Many areas do not automatically transmit the train position information, because those systems are quite expensive. In areas without them, train crews must call the dispatcher and identify the train's location. Some small railroads lack dispatchers, so their train crews report their positions to people in other departments, such as customer service and operations. Some railroads could benefit from an inexpensive method to more precisely determine current train location or to review historical records of train movements so they could identify opportunities to improve their operations.

## **1.2 The Railroad Traffic Planner Project**

A team consisting of government, academia, and private industry professionals developed the *Railroad Traffic Planner* application to help railroads quickly create and modify schedules using diagrams that show train positions over time. They developed this tool through a collaborative effort to improve safety and productivity in railroad operations. Additionally, a focused technology transfer effort was undertaken to bring the *Railroad Traffic Planner* to more railroads and provide the FRA an opportunity to learn more about transferring government-developed technology to the private sector.<sup>1</sup>

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<sup>1</sup> The goal of government technology transfer is to disseminate technologies that were produced for the government. This can involve a "range of formal and informal cooperative actions



### **1.2.1 Project History**

The *Railroad Traffic Planner* project began in 1996 when the John A. Volpe National Transportation Systems Center (Volpe Center) and the Massachusetts Institute of Technology (MIT) developed an early version of this tool as one of many prototypes for the Federal Railroad Administration (FRA). Their work supported a research program focused on identifying improved ways to display information about railroad operations using computer technology. Based upon feedback from railroad operating employees, a string line diagram prototype that showed train locations over time was selected for additional development. The project team chose this display because of its potential to provide substantial benefits to railroads where planners do many planning tasks in their heads, on a white board, or on paper. The objectives of this project were to develop sample string line visualization software, analyze its effectiveness at railroads, and promote its use wherever it might be helpful.

The *Railroad Traffic Planner* development team employed a user-centered design approach to create software to meet the needs of railroad personnel. Two railroads, MBTA and Guilford, received several early versions of the *Railroad Traffic Planner* software. Both railroads provided feedback on how they would use the system and changes they recommended to enhance it.

In 2003, Fulcrum Corporation (Fulcrum) joined the project team to facilitate technology transfer working with two additional railroads: North Shore Railroad (NSHR) and the Paducah and Louisville Railway (PAL). This technology transfer effort was intended not only to increase the overall impact of the tool across the industry, but also to serve as a demonstration of government technology transfer, so FRA could learn more about how to effectively foster technology transfer. Part of the technology transfer, which will be described in more detail later, involved incorporation of new GPS tracking features at NSHR and PAL. Other technology transfer activities included the creation of a Web page devoted to the project (<http://www.volpe.dot.gov/hf/railroad/rtp.html>), presentations at conferences, and distribution of the software to individuals who expressed interest in evaluating it and providing feedback. By interacting with potential users, educators, and developers of other railroad software, the project team attempted to maximize the potential benefits of this project throughout the industry.

### **1.2.2 Development Process**

The *Railroad Traffic Planner* development process has been iterative, with the steps shown in Figure 2 performed multiple times.

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between agencies, federal laboratories, and the public and private sectors.” (*A guide to transportation technology and innovation*, 2004, January). Examples include product improvement, service efficiencies, joint development to address government and private sector needs, and development of major new products.

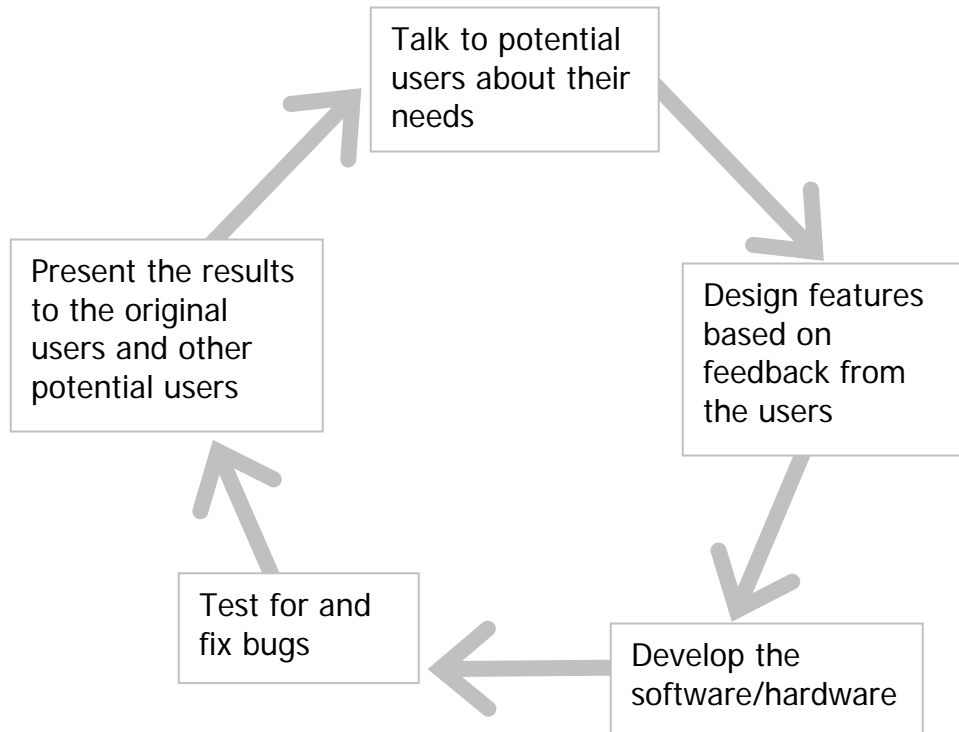


Figure 2. Development process

### 1.2.3 Railroad Participation

As mentioned above, participants from multiple railroads helped define and prioritize the features. They focused on functionality that would help them work more effectively than with their previous techniques. For example, they wanted to more efficiently create schedules, recognize and remove potential conflicts, minimize labor costs, and reduce the training time needed for new employees. They also requested that it assist them in determining how new trains, track outages, and speed restrictions would affect their schedules. Some planners also expressed interest in having it show them the actual locations of their equipment. The development team accommodated as many of the user requests as resources allowed. Because the *Railroad Traffic Planner* was created as part of a research effort to determine potential benefits of such tools, the development team shared demonstration versions with railroads even though some features were not complete nor fully tested. (The development team explained that the software was not designed for safety critical operations, and it was intended to support, but not replace, existing safety procedures.)

The first planner who participated in this project worked for MBTA, a passenger railroad. Several planners from Guilford, a freight railroad, also provided input during the development process. Later in the project NSHR and PAL provided additional feedback. The development team also talked to attendees at conferences and workshops where the tool was demonstrated and discussed with representatives from the government, industry, academia, and consulting. By interacting with potential users directly, the development team identified which features were most attractive and which aspects of the system were most difficult to use. In many cases,

design priorities shifted after conversations with the users, because modifications to the system revealed possibilities that had not been previously considered.

The four railroads that participated in this project differed greatly in terms of their size and scheduling needs. The MBTA commuter railroad has roughly 14 lines that are each between 10 and 50 miles long. Their traffic, which is busiest during weekday commuting hours, runs between 5 a.m. and 1 a.m. 7 days a week. They operate on tracks that also carry freight traffic. Guilford has a main line that is around 475 miles long and five branch lines that are each less than 50 miles long. Guilford has trains that travel all hours of the day, all days of the week. They have approximately 28 road freight trains daily, 60 crews per day (roughly 10 stay in the yard), and 10 local trains on the branch lines. Approximately 118 passenger trains (Amtrak and MBTA) per day use some of the same tracks as Guilford. NSHR operates trains on 8 lines, but only one, the NSHR line, which is about 40 miles long, was used for this project. The NSHR line, which operates Monday through Friday from around 7 a.m. to 4 p.m., usually has one train per day. PAL has roughly 250 miles of main track and some branches. Their trains generally run at night, and they perform track maintenance during the day. All of the railroads involved in this project have dispatchers controlling their traffic, except NSHR, where the trains are required to go slow enough that they will be able to stop if needed. The maximum speed on NSHR track is 20 mph, but the average speed is 15 mph or less.

Working with users from multiple railroads helped the development team better understand which aspects of planning were fundamental to all railroads and which aspects have to be tailored to meet an individual railroad's needs. For example, the average dwell time is dramatically different for passenger and freight traffic—whereas passenger trains might stop for about one minute at a station, freight trains often need more than an hour. For this reason, the dwell time that defaults in the display can be adjusted for each railroad. (More examples of railroad characteristics that influenced the design are provided later in this document where the *Railroad Traffic Planner* features are described.) Throughout the development process, the development team focused on finding ways to accommodate the railroads' specific needs without requiring each railroad to use a different version of the software.

#### **1.2.4 Development Tools**

The *Railroad Traffic Planner* software was developed using the Java programming language. When the development team decided to incorporate GPS tracking at NSHR and PAL, the goal was to keep it as cost-effective as possible, so that it could be feasible for small railroads with limited budgets, while providing relatively frequent position updates (at least one reading every minute). After considering many possible GPS tracking devices, the project team selected the Motorola i730 cellular phone made for Nextel, which is GPS-enabled and programmable. It was selected because it could provide very frequent data transmissions at a far lower cost than other available GPS systems. (More details about the GPS tracking selection process are included in Section 3.2.1 of this document.)

Motorola i730 phones use assisted GPS (AGPS), which augments the GPS data with cell tower position data. The accuracy of these phones is within 10–20 meters, which was considered precise enough for this project (it would not be for devices that must differentiate between parallel tracks, such as Positive Train Control systems). Motorola i730 phones use the Java 2 Platform, Micro Edition (J2ME) programming environment, so the project team was able to

specify which data would be transmitted from the phones and how frequently. The development team programmed the phones to send encrypted GPS messages to a database on a server at Fulcrum every minute. They included store-and-forward functionality, so that when the phones went into an area without adequate cellular coverage, messages were retained and then sent when the cellular service was available. They also developed an algorithm that converted the latitudes and longitudes to milepost numbers, which the *Railroad Traffic Planner* software could receive from the Fulcrum database through the Internet.

The development team placed the cellular phones in enclosures mounted on the exterior of the locomotives and maintenance vehicles used in this project (see Figure 3).



**Figure 3. GPS tracking system**

The GPS units were mounted on the outside of the vehicles because although antennae were available to boost the cellular reception, no GPS antennae were available. The team created several different versions of the enclosures during this project to protect the phone from shock, vibration, moisture, temperature extremes, contact with tree branches, and vandalism. To keep the phone's battery charged, they passed a wire connected to a battery pack attached to the 12-volt power supply into the locomotive or truck cab. This battery pack was fuse protected, reverse voltage protected, and overload protected. It could keep the phone charged for several days if the locomotive were powered down.

## 2. Railroad Traffic Planner Features

Below is a brief overview of the features included in the *Railroad Traffic Planner*. For a more detailed description, see the *Railroad Traffic Planner User Guide*, which is available on the Volpe Center Web site at <http://www.volpe.dot.gov/hf/railroad/rtp.html>.

### 2.1 String line Display

Figure 4 shows the main window in the *Railroad Traffic Planner* with explanatory notes along the edges in gray.

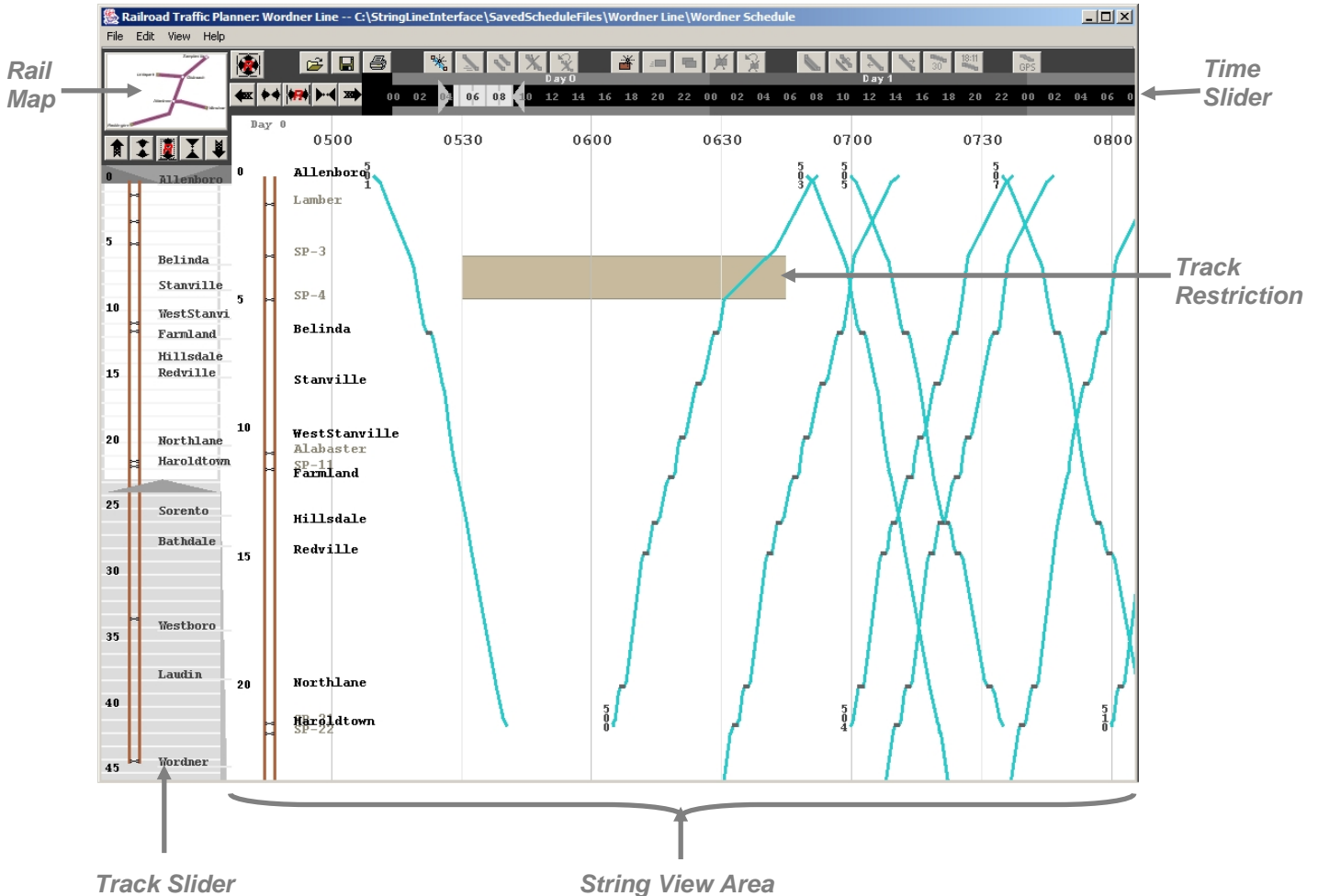


Figure 4. *Railroad Traffic Planner* main window

#### 2.1.1 String View Area

As mentioned previously, a major component of the *Railroad Traffic Planner* is the string line display, which is included in the section labeled *String View Area* in Figure 4. Information about the locations (mile numbers, track configuration, waypoint names) is shown on the left side of this area and the hours are across the top. Strings representing planned trips are in the middle, and so are track restrictions, which are rectangles on the display that show where and when a track will be taken out of service or have a restricted speed. Near-real-time (approximately once

per minute) train and/or maintenance vehicle positions can also be displayed in the *String View Area* when a GPS tracking system has been incorporated.

### **2.1.2 Zooming**

Being able to zoom in on a particular part of the overall string line diagram was important to MBTA since many of their trains are close together during rush hour time periods. Guilford also wanted to be able to zoom, since their main line is over 400 miles long. To accommodate their requests, the *Track Slider*, which is to the left of the *String View Area*, and the *Time Slider*, which is above the *String View Area*, were included. The paler rectangles on the sliders show which section of the overall string line diagram is currently displayed in the *String View Area*. The darker parts of the sliders show which additional locations and times could also be displayed. There are many ways to adjust which miles and hours are visible in the *String View Area*. For example, the pale rectangles within the sliders can be dragged to pan to another section, and the triangles in the sliders can be dragged to increase or decrease the area displayed. Another way to zoom in is to click on the *String View Area* and drag the cursor arrow down and to the right to create a rectangle; when the mouse button is released the view adjusts to the area within that rectangle.

### **2.1.3 Primary and Secondary Waypoints**

Because Guilford's main track is very long, it is not possible to view all of their waypoint names at once, since too many of them overlap. To make the most important waypoints more prominent, two categories of waypoint names were created: primary and secondary. The primary waypoint names are the only ones listed in the *Track Slider*, and they are black rather than gray in the *String View Area*. (The secondary waypoints are gray, so they are visible but capture less attention than the black primary ones, which are more important.) At both Guilford and MBTA, the places where trains were most likely to stop were defined as primary waypoints.

### **2.1.4 Switching Between Lines**

For railroads with multiple lines, the *Rail Map* enables users to choose which line to display in the main window. Users determine which line is portrayed in the *String View Area* by clicking on that line on the *Rail Map*.

## **2.2 Speed and Time Calculations**

As explained previously, many factors contribute to train speed calculations. The development team wanted to provide speed estimates that were at least as good as those the planners generated without using the software, but not requiring so much data entry that the tool would be too burdensome for the users. The planners agreed that it would be important to minimize the data entry required for using the tool, so they helped the development team define a process that would be flexible, but not too complicated.

### **2.2.1 Defining String Speeds**

The software enables the planners to define separate speeds for as many types of trains as they want, so they can focus on the specific factors that most influence the speeds of trains on their tracks. The speeds, track layouts (tracks, sidings, switches), and waypoint characteristics are

defined in separate files for each railroad. These tab-delimited text files (which can be viewed as spreadsheets with tools like Microsoft Excel) include the maximum speed for each segment of track between every set of waypoints for every train type. Separate speeds can be specified for each direction along the track. Because the railroads can create as many train types as they want, they have a lot of flexibility in controlling the speeds represented in the strings. At Guilford, the planners chose to create three train types; (1) for typical freight trains,(2) for freight trains without telemetry braking (which are required to go slower in many areas), and (3) for passenger trains (which travel faster than freight trains in many areas).

The strings represent the location of the train (specifically the very front of it) at various points in time. When creating strings, the *Railroad Traffic Planner* calculates the fastest permissible travel times based on the speeds specified in the files and the temporary speed restrictions. If users decide that the calculated speeds are faster than appropriate, they can adjust the strings to a slower speed. When one section of track is faster or slower than an adjacent section, the system calculates a period of acceleration or deceleration (which is halfway between the two speeds) to account for the speed transition. The speed files have numbers that determine the distance over which the acceleration or deceleration occurs for each train type. These values also represent the approximate train length in the calculations, so that the entire train matches the slowest speed required for the stretch of track it is on.

### 2.2.2 Creating Strings

After setting up the speed files, very little effort is required to create a string. To create a string users can bring up the *Condensed Add Trip* window (Figure 5), which allows them to enter the train ID, type, direction, start or end time, the beginning waypoint, the ending waypoint, and dwells where the train will stop. As the data are entered in this window, the *Arrive* and *Depart* columns fill with the calculated times for that string. Pressing the *Add* button inserts the string in the *String View Area*.

The screenshot shows the 'Add Trip' window with the following details:

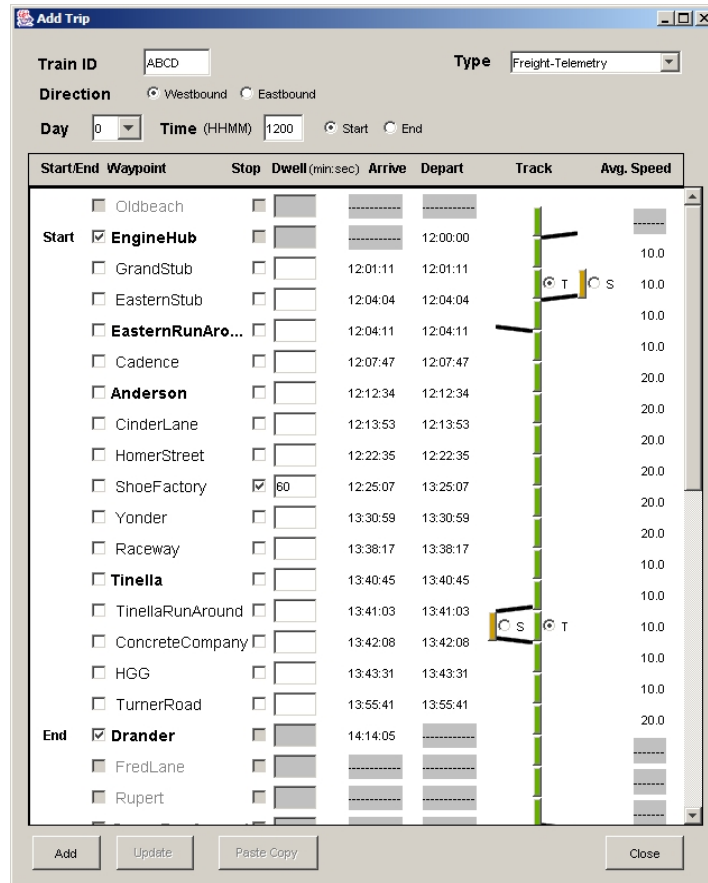
- Train ID:** ABCD
- Type:** Freight-Telemetry
- Direction:** Westbound (selected)
- Day:** 0
- Time (HHMM):** 1200
- Start/End:** Start (selected)

Start/End	Waypoint	Stop	Dwell (min:sec)	Arrive	Depart
Start	<input checked="" type="checkbox"/> EngineHub	<input type="checkbox"/>		-----	12:00:00
	<input type="checkbox"/> EasternRunAro...	<input type="checkbox"/>		12:04:11	12:04:11
	<input type="checkbox"/> Anderson	<input type="checkbox"/>		12:12:34	12:12:34
	<input type="checkbox"/> Tinella	<input checked="" type="checkbox"/>	30	12:40:45	13:10:45
	<input type="checkbox"/> Drander	<input type="checkbox"/>		13:44:23	13:44:23
	<input type="checkbox"/> GreenRunAround	<input type="checkbox"/>		13:54:13	13:54:13
	<input type="checkbox"/> Addie	<input type="checkbox"/>		14:00:38	14:00:38
End	<input checked="" type="checkbox"/> Oakville	<input type="checkbox"/>		14:28:32	-----
	<input type="checkbox"/> Asinboro	<input type="checkbox"/>		-----	-----
	<input type="checkbox"/> MillArea	<input type="checkbox"/>		-----	-----
	<input type="checkbox"/> WestTreeYard	<input type="checkbox"/>		-----	-----
	<input type="checkbox"/> Umbrellino	<input type="checkbox"/>		-----	-----
	<input type="checkbox"/> Littlepark	<input type="checkbox"/>		-----	-----

Buttons at the bottom: Add, Update, Paste Copy, Close

Figure 5. Condensed Add Trip window

The *Condensed Add Trip* window only lists the primary waypoint names. If users want to work with the secondary waypoints or specify which tracks the train will use, they can use the *Extended* version of the *Add Trip* window (Figure 6).



**Figure 6. Extended *Add Trip* window**

After a string has been added to the *String View Area*, the user can display its times and average speeds, as shown in Figure 7.



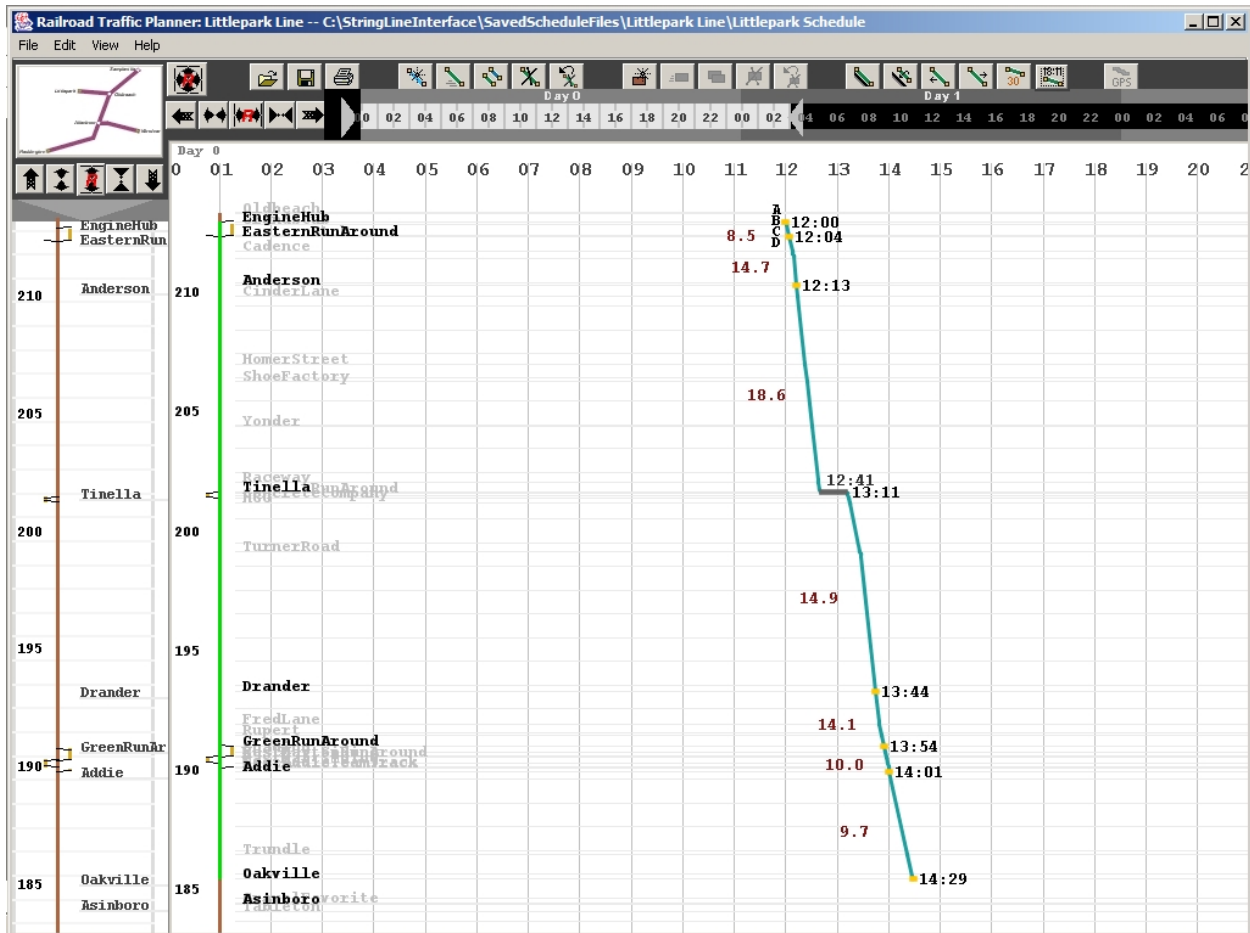


Figure 7. String with speeds and times displayed

### 2.2.3 Adjusting Strings

There are several ways to adjust strings. For example, users can click on the strings in the *String View Area* and drag them. To adjust all of the times for a string, users can click and drag the beginning of the string. To slow down or speed up a segment of a string, users can click and drag the end of the segment. To increase the dwell time, users can hold the Shift key on the keyboard and drag the part of the string where they want to adjust the dwell. Users can also adjust the times and dwells by accessing the *Update Trip* windows (which are similar to the *Add Trip* windows) and typing in the changes. Other functions are also available to adjust the strings by 1-minute intervals.

If a user would like to try some changes without committing to them, he/she can set a baseline for the strings. When a string with a baseline is moved, the baseline stays in the original position to show where the string was when the baseline was set. If the planner decides that the proposed changes are undesirable, the planner can restore the string to the baseline values. When the user is satisfied with the changes, he or she can set the baseline to the new position.

## 2.2.4 Track Restrictions

In addition to the strings, users can add track restrictions to the *String View Area*. Track restrictions are rectangles that indicate where and when a track will be out of service or have a restricted speed. Adding a track restriction is similar to adding a string. To do it, users bring up the *Add Track Restriction* window (Figure 8) and enter the type, speeds (if it is a speed restriction), start time, end time, beginning waypoint, ending waypoint, and tracks.

**Add Track Restriction**

Type

Track Out of Service

Speed Restriction

Freight Speed  MPH

Passenger Speed  MPH

Start Day  Time  (HHMM)

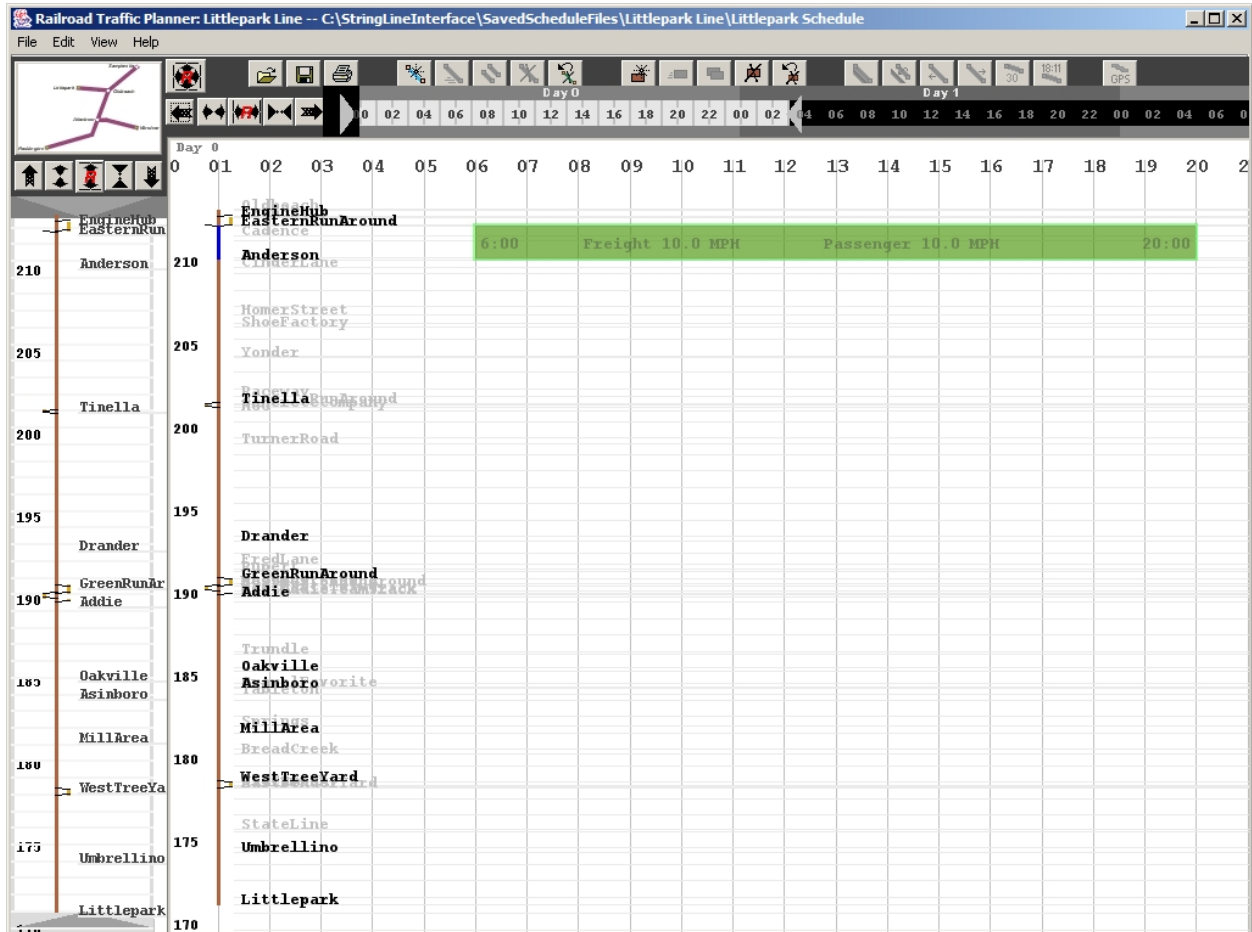
End Day  Time  (HHMM)

Start/End	Mile/Waypoint	Track
	Oldbeach	
	<b>EngineHub</b>	
	GrandStub	
	EasternStub	
Start	<input checked="" type="checkbox"/> EasternRunAro...	
	Cadence	
End	<input checked="" type="checkbox"/> <b>Anderson</b>	
	CinderLane	
	HomerStreet	
	ShoeFactory	
	Yonder	
	Raceway	
	<b>Tinella</b>	
	TinellaRunAround	
	ConcreteCompany	
	HGG	
	TurnerRoad	
	<b>Drander</b>	

Add Close

Figure 8. *Add Track Restriction* window

When the user presses the *Add* button on the *Add Track Restriction* window, the track restriction is placed in the *String View Area*. To select the track restriction, users place the cursor over it and press the right mouse button. When the track restriction is selected, the display shows details about that restriction, as shown in Figure 9.



**Figure 9. Selected track restriction**

If the user adds a string on top of a speed restriction or a speed restriction on top of a string, the system adjusts the string to conform to the restricted speed if it is lower than the speed in the file for that train type.

### 2.2.5 Timetables

The planner can export the timetable (which shows when the trains are scheduled to arrive and depart from each primary waypoint) to a file that can be opened in a spreadsheet application (see Figure 10). This makes it easy to view schedule documents in a tabular format and share them with other people who do not have access to the *Railroad Traffic Planner*.

OUTBOUND		ABCD		IJKL	
READDOWN		Arrive	Depart	Arrive	Depart
Brow	x		800	x	1421
DannyWest		823	823	1444	1444
Rugby		924	1124	1546	1606
OldBeach		1138	1138	1620	1620
Searance		1144	1144	1626	1626
Graydon		1212	1312	1652	1652
Larry		1324	1324	1704	1749
DennisCourt		1341	1341	1806	1806
CPF-LO		1351	1351	1816	1816
CPF-NC		1405	1405	1830	1830
AdventureTown		1433	1433	1858	1858
Grenfell		1456	1456	1922	2017
Gardentown		1525	1525	2048	2048
Reddington		1551	x	2114	x
INBOUND		EFGH		LMNO	
READDOWN		Arrive	Depart	Arrive	Depart
Reddington	x		1827	x	729
Gardentown		1853	1853	755	755
Grenfell		1924	2039	824	824
AdventureTown		2102	2102	846	846
CPF-NC		2129	2129	913	913
CPF-LO		2139	2139	923	923
DennisCourt		2149	2149	933	933
Larry		2206	2206	951	1531
Graydon		2217	2217	1542	1542
Searance		2243	2243	1608	1608
OldBeach		2251	2811	1615	1615
Rugby		2825	2825	1627	1627
DannyWest		2920	2920	1722	1722
Brow		2943	x	1745	x

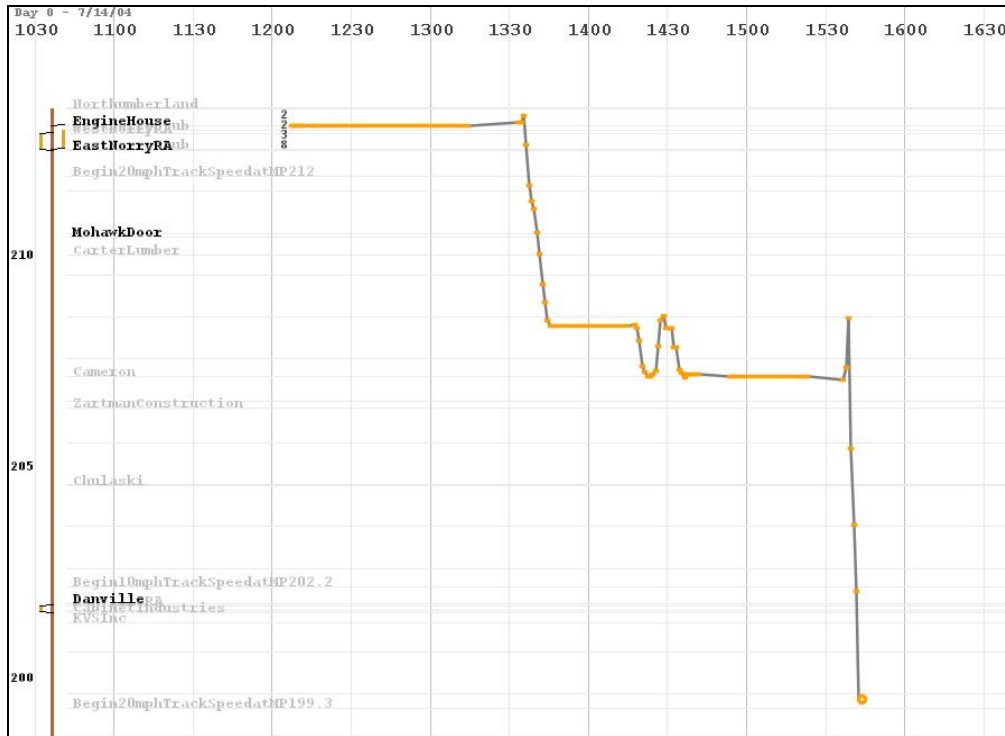
**Figure 10. Sample timetable**

## 2.3 GPS Tracking

Although the software was initially developed as a planning tool, individuals who saw early prototypes suggested incorporating actual train positions. For example, potential users from one of the railroads did not want to take the time to enter strings manually into the system, so they proposed that a low-cost GPS device mounted on the locomotives could provide the string information throughout the day. They explained that since their volume of traffic was low, minimal scheduling was required, so a tracking tool could be more valuable than a planning tool. They wanted to monitor maintenance and inspection vehicles that use the tracks in addition to locomotives. As a result of this feedback, the development team chose to incorporate a GPS tracking system.

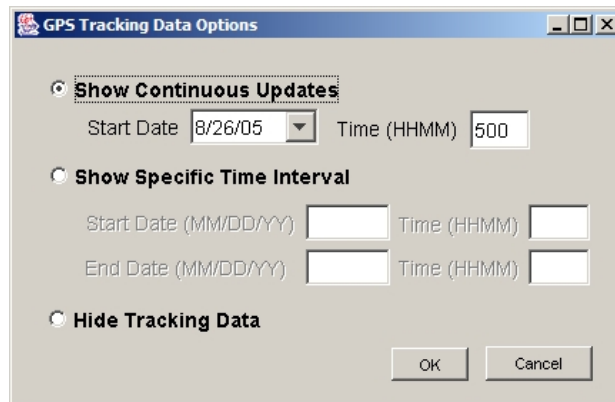
### 2.3.1 Railroad Traffic Planner Tracking Display

Figure 11 shows GPS data displayed in the *Railroad Traffic Planner*. The GPS system provides a location approximately every minute, so when the crew is switching, some of the forward and backward motion is evident on the display. (When creating strings for schedules, it is generally not necessary to plan each switching movement, so the motion is always either forward or stopped.) Because the GPS tracking devices have been mounted on maintenance and inspection vehicles that travel on both tracks and roads, a symbol was incorporated in the string line display to show when a vehicle leaves the tracks. This is the open circle shown at the end of the GPS string in Figure 11.



**Figure 11. GPS data in string line display**

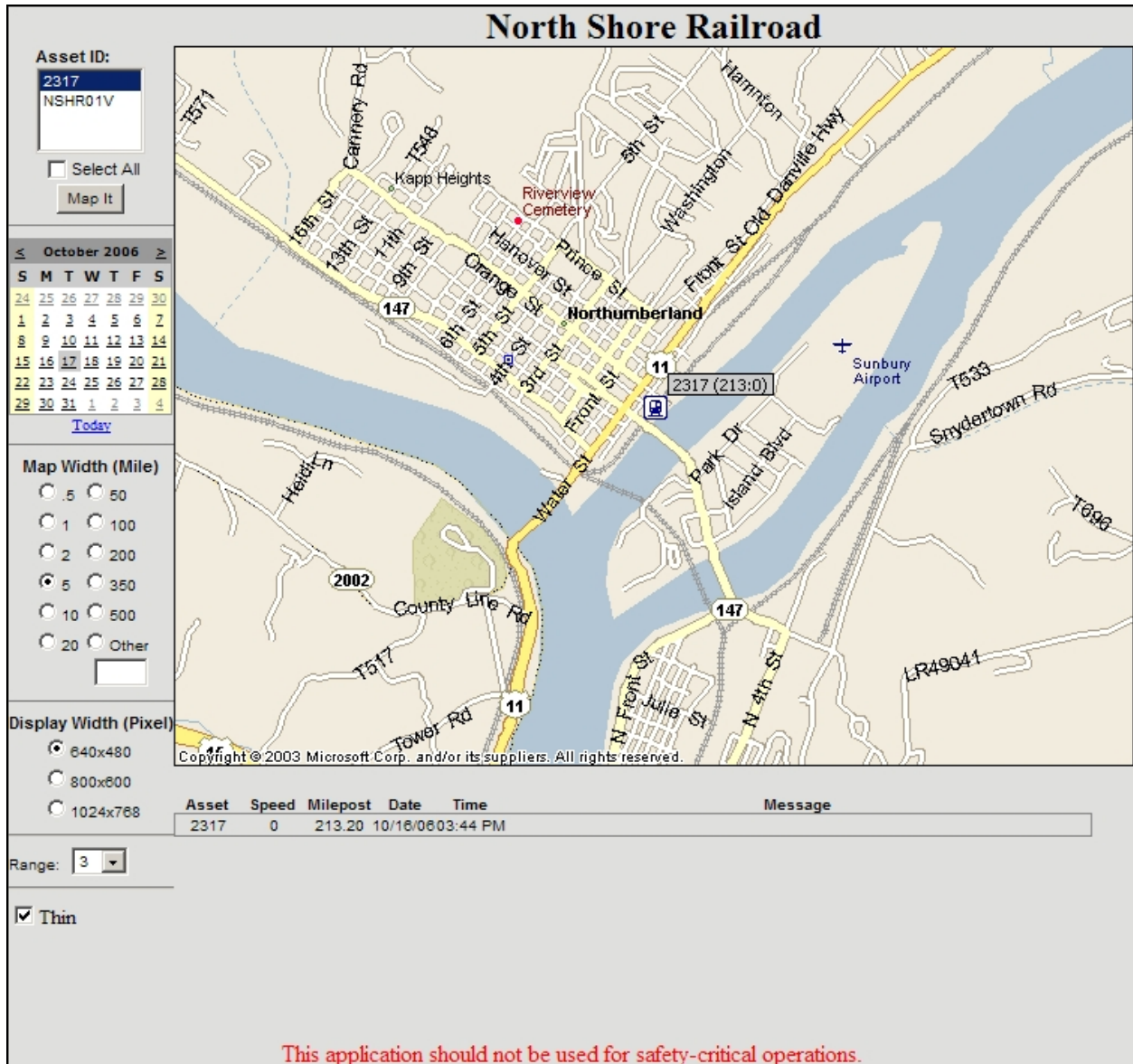
The *GPS Tracking Data Options* window (Figure 12) allows users to specify which GPS data will display in the *String View Area*. If they choose to show continuous updates, the application will request data from the database every minute. Users can also pick specific time intervals to display (up to three days at once), or they can hide the tracking data altogether.



**Figure 12. GPS Tracking Data Options window**

### 2.3.2 Web-Based Geographical Map Display

As part of the technology transfer, Fulcrum also developed a Web-based geographical map display of the tracking information (Figure 13) that is separate from the *Railroad Traffic Planner* software. This enables the railroads to view the location of vehicles that are not traveling on the tracks. It also includes speed information.



**Figure 13. Geographical map display of tracking data**

Because the cellular phones provide a relatively inexpensive two-way communication channel, Fulcrum also helped the railroads use it for other purposes, such as transmitting readings from temperature sensors in the locomotive to computers in the main office.

## 3. Challenges

This section describes some of the major challenges encountered during this project.

### 3.1 Software Development

Due to limited programming resources, not all of the features that the development team wanted to include could be added to the *Railroad Traffic Planner*. Below are some of the elements the team might have improved if additional resources were available.

#### 3.1.1 Desired Usability Enhancements

As part of the user-centered design process, the development team worked with the planners to design displays that would facilitate their understanding and ease of use. As the software evolved over time, planners indicated that there were major improvements that made the tool less cumbersome and more user-friendly. People who tried the demonstration software and saw it at conferences also indicated that the tool was “intuitive and easy to handle” (e.g., J. Pachl, personal communication, April 2, 2005). For example, one individual who tried the software wrote, “I would like to pinpoint the fact that the user interface is user friendly (dynamic windows, simplified and exact terminology, traffic concepts well-categorized in the appropriate forms). I needed less than an hour to get familiar with the process of building a trip, and adding the appropriate track restrictions” (G. Kalafatas, personal communication, February 20, 2005). In spite of the positive feedback, some of the usability improvements that the development team wanted to incorporate were left out due to limitations in programming resources. Below are some of the team’s usability concerns:

- There are no standard confirmation and error messages, such as the one that asks if you would like to save your changes before closing the application.
- Users cannot “undo” changes (*Undelete* functions were included, which allow users to bring back a string or track restriction that was accidentally deleted, but there are no other undo options available to reverse other changes).
- The use of colors could be improved. For example, strings with baselines are red if unselected and going in one direction, blue if unselected and going in the other direction, and green if selected (regardless of direction). Strings without baselines are cyan in both directions, with a darker shade when they are selected than unselected. This color-coding scheme is difficult to remember because it is inconsistent. Additionally, the display looks more cluttered than necessary and people with poor color vision may have difficulty recognizing some of the features.
- The process for defining the railroad-specific track and speed information currently uses tab delimited text files that require the user to recognize which cells are labels and which are settings. A better database structure with a more user-friendly front end could make it much easier for railroads to enter and update their settings.
- Because the GPS tracking system was only installed on one train and one vehicle in two demonstration sites, it was not possible to determine how effective it would be when monitoring sites with more train traffic. Even with only two devices per site, some people



expressed concern about difficulty differentiating the GPS strings when the vehicles were close together.

### **3.1.2 Integration of Planning and Tracking Features**

When GPS tracking was added to the planning system, several people suggested that the GPS data should move the planned strings so that users could see how the actual performance might influence future meets and passes. This functionality was never added, but it could have proven useful. Showing where and when actual train performance has deviated from the schedules could indicate where there are opportunities to improve the schedules, which could lead to the development of better schedules.

### **3.1.3 Known Bugs**

The software is a prototype designed to research the effectiveness of using computerized string line visualization tools in the railroad industry. It still has a number of known bugs, which are described in the *Railroad Traffic Planner User Guide* available on the Volpe Center Web site at <http://www.volpe.dot.gov/hf/railroad/rtp.html>.

## **3.2 Tracking System Development**

Incorporating the GPS tracking and keeping it operating also introduced some challenges to the project, which are described below.

### **3.2.1 Selecting the GPS Tracking System**

Several possible GPS systems were considered for this project. Some of them were satellite-based, which would be helpful in areas with poor cellular coverage, but they offered fewer data transmissions (once per hour or once per day) at a much higher price. Some satellite-based tracking systems were \$2,500 to \$10,000 or more plus a monthly charge, whereas the initial price for the cellular phones was around \$200 plus \$50 per month. Also some of the larger tracking system companies were not interested in this demonstration project because only a few units were to be purchased. Another issue with some of the other tracking systems was that the companies did not want to de-bundle their existing software from their GPS tracking devices so the *Railroad Traffic Planner* displays could be used instead. In addition to considering preconfigured systems, the team contemplated combining various hardware components, such as an external GPS device, an analog modem, and a cheaper cellular phone. Ultimately, the development team chose the Motorola i730 cellular phone option because so many of the desired features were already bundled together in a cost-effective package. (Nextel phones had already been used for asset tracking in other industries, such as trucking and snowplowing.) Before finalizing the decision, development team members rode on trains at NHR and PAL to test the cellular and GPS coverage there. The Nextel cellular coverage was good at NHR, which was not a surprise that since the railroad had already been using Nextel phones for communicating with train crews there. The GPS tracking signal was also sufficient in that area. The cellular and GPS coverage were also deemed adequate for PAL.



### **3.2.2 Keeping the GPS Tracking System Operating**

Keeping the equipment on the trains operating was also challenging. Before the *Railroad Traffic Planner* team collaborated with NSHR, someone there installed a GPS device on a locomotive and it stopped working within 6 months. Keeping the GPS tracking systems running during this project at NSHR and PAL was a challenge as well. Some of the problems were relatively easy to overcome, but others were not so easily solved. For example, the project team originally plugged the tracking system battery pack into the 12-volt lighter outlet in the locomotive cab that the crews used to charge their own cell phones, so it was frequently unplugged. To address this issue, the mechanic at NSHR wired the system behind the panel, so the train crews could not unplug it. Another problem was that the wire connecting the phone to the battery became disconnected inside the enclosure mounted on the train. Epoxy was used to better secure it in place, and information about the battery level was added to the messages transmitted from the phone so that the development team would know about battery issues sooner. One limitation of the cellular phones was that there was no good way to remotely turn the phones back on when they powered down. This made it crucial to identify problems before the phones shut down. Also, when the phone was in the enclosure, it was much harder to operate the power button. Therefore, a magnetic switch was added so that someone could turn on the phone by waving a magnet over the outside of the enclosure. This usually worked well, but one time the magnet was held up to the enclosure for too long, so the phone went into “airplane mode” in which no data are sent (this happens if the power button is held for 5 seconds). Since the phone was inside the enclosure, no visual or auditory feedback indicated that the phone was powered up, so it took a while for the team to recognize the change in operating mode.

Some problems were outside the control of the project team. For example, within a week of the initial deployment at NSHR a major bug in the Motorola/Nextel firmware caused phones using the GPS feature to continually reboot. On other occasions flooding at NSHR and a power outage at Fulcrum interfered with the proper operation of the system.

### **3.3 Technology Transfer**

In addition, challenges, related to the technology transfer, existed. Levin and Kappel (1998), who studied the process of transferring technology from research and development to a business unit in a company, found that several elements contribute to successful technology transfer. These elements include: personal relationships, coordination of the handoffs and adaptations, expertise transfer, the ability to adopt the technology, and buy-in to the process from both the receiver and transferor. While each of these elements occurred to some extent during the *Railroad Traffic Planner* technology transfer, some challenges were associated with each one as well.

#### **3.3.1 Personal Relationships**

Fulcrum had prior relationships with NSHR and PAL on previous successful projects. This definitely supported the technology transfer, but may have hindered it somewhat as well. Because of their relationships with Fulcrum both railroads offered to serve as demonstration sites for the *Railroad Traffic Planner* even though the initial version was not well-suited to their needs.

### **3.3.2 Coordination of the Handoffs and Adaptations**

One of the most challenging aspects of the technology transfer in this project was the coordination of handoffs and adaptations. Since the small railroads were less interested in the planning capabilities of the *Railroad Traffic Planner* than low-cost tracking, which was not in the original product design, the development team incorporated the new tracking component to facilitate the technology transfer. The railroads possibly would have adopted some of the string line features more, if additional effort had gone into adapting them to meet the needs of small railroads. For example, based on feedback from NSHR, the development team considered adding functionality in the *Railroad Traffic Planner* to show times and speeds along the GPS strings on the string line display, but this was not built because of limited programming resources.

### **3.3.3 Expertise Transfer**

Regarding expertise transfer, the development team provided some training at each site and documentation. Further focus on expertise transfer might have increased the usage level at each site.

### **3.3.4 Ability to Adopt the Technology**

Another element identified by Levin and Kappel is the ability to adopt new technology, which considers both technical and organizational skills. Although the *Railroad Traffic Planner* development team used the user-centered design process to focus on features most desirable for the target users, the participating railroads struggled to incorporate this new tool into their work process. Some of the railroads saw little need for the planning tool, but even those that could benefit most from it rarely used it in place of their other planning practices. A threshold of effort seems to exist, which must be exceeded for a given planning task for the tool to provide a real clear value that inspires people to use it. This is partly because many small railroads do not have dedicated planning staff, so their planners also have many other responsibilities, such as crew scheduling, business operations, finances, and supervising dispatchers. They are often too busy to learn new software and keep the data current. One of the planners involved in this project had tried other planning programs in the past and concluded that they had too many features for him to use quickly. He also thought they were too expensive and too difficult to keep up-to-date. He thought that the *Railroad Traffic Planner* would save him time because it was interactive, enabling him to quickly visualize the schedules and make changes based on moving things around. In spite of his confidence in the *Railroad Traffic Planner*'s potential and the development team's efforts to make it as easy as possible to set up, learn, and use, this planner experienced difficulty finding enough time to use it effectively. Other planners involved in the project also found that they were unable to use it as much as they wanted, because other aspects of the job competed for their time. Perhaps if the tool supported other parts of their job, the planners would have fewer obstacles preventing them from using it for the planning tasks for which it was developed. (On the other hand, expanding the application to support other activities might increase its complexity too much, making the planners less likely to use it.)

### **3.3.5 Buy-In from the Receiver and Transferor**

The level of buy-in from the railroads was probably influenced by how easy it was for them to incorporate the tools into their business and how much perceived value they gained from them.

The buy-in of the transferors also played a role in how this technology transfer was carried out. The results of this project suggest that companies are more reluctant to perform technology transfer of a product they did not create, as there is less incentive for them to promote something to which they do not have licensing rights. When the technology transfer effort began, Fulcrum hoped that railroads would be interested in paying them for services related to the software, such as installation, training, setting up the databases, and providing help desk support. As the project progressed, Fulcrum found that smaller railroads did not seem to need the tool and were not accustomed to paying for planning support. Fulcrum instead decided to focus on creating features they could sell that were separate from those created by MIT, such as the geographical map display of the GPS tracking data and techniques for passing data from temperature sensors through the cellular phones used for GPS tracking. Although each of these new developments provided features desirable to the railroads, they did not necessarily constitute technology transfer of the original *Railroad Traffic Planner* software.

## 4. Benefits

The project team identified many potential benefits for people using tools like the *Railroad Traffic Planner* including those listed below.

### 4.1 Planning

The value of string line diagrams has been demonstrated many times in this project and others.

#### 4.1.1 Updating Schedules

With string line software, less time is needed to perform calculations, draw strings, and make modifications compared to doing these activities with paper-based planning techniques. One planner involved in this project demonstrated that he could modify schedules more accurately and efficiently with the *Railroad Traffic Planner* than when using his typical paper-based approach. First he showed his typical approach, which involved writing out all the stops on a piece of paper and then looking at the paper version of the existing schedule to identify a potential starting time for the new train that seemed like it would not interfere with any existing trains. Next, he calculated for each stop a time based on travel times of other trains in the paper schedule. For each station he checked the trains going in the opposite direction to see if they would conflict, using a paper track diagram to see if the track configuration would accommodate the trains. In an area where many lines converged, he had to look at the schedules for all of the lines to find out which times were bad for inserting a new train. He also had to check the equipment and crews to ensure that they would be available for the new train.

To add a train to the schedule with the *Railroad Traffic Planner*, the planner selected the proper line, and then zoomed in to the area where he wanted to add it. Since the software showed the other trains, as well as the tracks, stations, and interlockings, he did not need other documents. He opened the window to add a trip, and selected the locations where the train should stop. (When doing this, he realized that he had forgotten to include one of the stops on his paper version.) He added the string and found very quickly that the times were pretty close to his expectations. One benefit of the string line display was that it showed exactly where the trains would pass each other, whereas with the paper version, the meets could only be approximated on the basis of the schedule times at the stations. With the *Railroad Traffic Planner*, the planner could grab a string and drag it to a time when all of the meets would occur in appropriate places, and the software would update the times for each station simultaneously. When the modifications were complete, he could display the *Railroad Traffic Planner* schedule in an electronic document that he could easily share with other people. This planner emphasized that the *Railroad Traffic Planner* is a usable, flexible tool for this type of activity.

#### 4.1.2 Considering Alternatives

With scheduling software planners can rapidly evaluate a variety of schedules, a task that is more time consuming without a computer. Modifications can be made without recreating the entire schedule, leaving more time available to consider alternatives and identify the best ones. For example, one planner needed to determine the impact of accommodating a request from another railroad to limit the disembarkment of passengers to a certain track at certain stations. When he first got the request, he spent an hour or more creating rough hand-drawn string diagrams based

on three points along the line for each train throughout the day (the line has about 17 stations and handles approximately 40 trains per day). He then used the *Railroad Traffic Planner* software to check the accuracy of his hand-drawn strings and to see what would happen if he made adjustments to the schedules. Both string line diagrams helped him see approximately where the trains would meet, but the software was more precise. With the *Railroad Traffic Planner* he could drag the strings around to assess the impact of potential changes (doing “what if” scenarios). He found that revising the meets so that the trains would stop on the desired track at those stations would cause a series of lengthy delays. The rail network had a limited number of locations where trains could meet, and a seemingly simple change had ripple effects throughout the schedule, causing other trains that shared the same equipment to also be delayed. The strings helped the planner determine that accommodating the request to only stop on a certain track would not be feasible without eliminating trains or incurring excessive delays on other trains.

#### **4.1.3 Calculating Effects of Speed Changes**

Train speeds in the *Railroad Traffic Planner* can be adjusted quickly by updating the speed files. One railroad used this approach when evaluating a request from another railroad to allow increased train speeds along certain sections of track. As with their other spreadsheet-based technique for calculating the effects of speed changes, the planners found that for a ride more than 2 hours, the trip duration would be decreased by less than 15 minutes. Both approaches for calculating the impact of the speed change helped them reach the same conclusion, but the *Railroad Traffic Planner* let them do it more efficiently.

#### **4.1.4 Evaluating Effects of Taking Tracks Out of Service**

Another activity that the *Railroad Traffic Planner* supports is deciding when to take a track out of service. One planner demonstrated his old paper-based procedure, which required looking at the train schedule and the track diagram. His first step was to write out all of the stops with train times below, calculating times for the places where the train did not stop. He drew the tracks and went through train by train looking for conflicts during the time span he was considering. To take a track out of service with the *Railroad Traffic Planner* was easier because the track and schedule information were already integrated. With the software he did not have to calculate the times to see the conflicts. In a few minutes he could do what took a few hours to do by hand. He said that with the software he could respond to a request for a track outage, while the requestor was still on the phone, rather than saying that he would need to call back after the analysis was complete.

#### **4.1.5 Communicating Proposed Schedule Changes**

Because string lines have been used in the railroad industry for so many years, many planners are already familiar with how to use them for schedule visualization. The learning curve for using this software should be much less than if a novel type of display were created. Examples related to the display are provided below. It is common for several people to work together on activities like resolving track outages, deploying extra trains for events, and adjusting dwell times. The visual representation of trains over time in the *Railroad Traffic Planner* helps planners quickly show each other potential problems and solutions, which help them more efficiently communicate their ideas for how to resolve issues. String line schedules can also be converted to a tabular format and shared with people who are not familiar with strings. Two of

the railroads involved with this project suggested that the visual evidence provided by the string line display could help them better communicate with other railroads about proposed schedule changes.

## **4.2 Tracking**

Some of the demonstration railroads indicated that they were considering purchasing additional tracking system units based on their experiences with the system. They indicated that the monthly charge (roughly \$50 per unit) seemed reasonable considering the potential benefits the system could provide. Some potential benefits of the tracking system are provided below.

### **4.2.1 Monitoring Progress**

Real-time train location information could help railroad personnel better monitor progress throughout the day. This could provide crucial safety benefits if it helped them identify potential collisions early enough to prevent them. It could also help with monitoring the movement of hazardous materials, improving arrival time estimates for customers, and predicting crew change times. A mechanic who helped install the tracking equipment indicated that the tool helped him predict when the locomotives would return for maintenance. Including tracking data in the string line display also enabled people to look at historical data, which is beneficial for identifying trends in the traffic patterns when analyzing fuel usage.

### **4.2.2 Tracking Speeds**

Another benefit of the GPS tracking system is that it could be used to monitor locomotive speeds. Speeding was a major concern at one of the railroads that received community complaints about train speeds. They appreciated being able to view the speeds remotely, and even indicated that they might ask FRA if they could use the tracking data rather than radar guns to check the train speeds, since the data are potentially more continuous and enforceable.

### **4.2.3 Two-Way Communication of Information**

Because the GPS-enabled cellular phones provide a two-way communication channel, some of the railroad participants suggested incorporating sensors to monitor the temperature of locomotive engine and installing a security system for the locomotive cab. Other participants suggested attaching the system to printers in the locomotives for delivering printed information to the crews. Another suggestion was to integrate the information gathered by the tracking system with other computerized systems at the railroads.

## **4.3 Training**

Many individuals indicated that the *Railroad Traffic Planner* could be useful for training planners and dispatchers. Several professors of transportation courses who received the demonstration software for this project expressed interest in using it in their classes. Some potential benefits of using the *Railroad Traffic Planner* for training are described in the following sections.

### **4.3.1 Demonstrating the Impact of Decisions**

Many people said that the *Railroad Traffic Planner* could help the students learn to recognize potential traffic conflicts and how decisions they make about one train can affect others. One planner explained that experienced planners and dispatchers remember problems they encountered in the past and ways to avoid them, but because novices lack this knowledge, providing visualization tools to support their training before they start the actual job could be helpful. He mentioned that even people with more experience can benefit from visualization support tools since they tend to remember the major mistakes that they vowed not to do again, but they might never have recognized suboptimal decisions that had less severe consequences.

### **4.3.2 Fostering Key Dispatcher Skills**

The dispatcher is the focal point of a territory, and has to help resolve any problems that arise, including track problems, mechanical issues, and operating delays. Poor decisions can make dispatching even more difficult. Reinach, Gertler and Kuehn (1998) analyzed dispatcher training requirements, and listed many training objectives that a tool like the *Railroad Traffic Planner* could help novice dispatchers better understand, such as judging train and track priorities, managing unplanned and emergency events, and defining temporary speed restrictions. Roth, Malsch, and Multer (2001) listed several cognitive skills that dispatchers need to develop, including strategies that help them maintain broad awareness, anticipate problems, and plan contingencies. Using a tool like the *Railroad Traffic Planner* in dispatcher training could help promote these skills.

### **4.3.3 Providing Visual Representations**

People learn and understand things in different ways, and for those who are visually oriented, string line tools could greatly increase their understanding of important concepts fundamental to railroad operations. Training on how to use string line diagrams could also be beneficial for people who are less graphically oriented. One planner explained that some people who are accustomed to a column of numbers on a train sheet say, “What is all that spaghetti?” when they see string line diagrams. Perhaps if they were exposed to string line diagrams earlier in their careers, they would more comfortable utilizing them in their work, and would benefit from the advantages these types of tools provide.

## **4.4 Security**

Even small railroads worry about security, since they carry hazardous cargo. People from several railroads have indicated that they want tools to help them address their security concerns, but they have limited funds available to spend on them.

### **4.4.1 Supporting Rapid Response**

During a crisis, effective planning systems are especially important to help planners move people and materials in or out as quickly as possible, handle hazardous cargo, and address bottlenecks. The paper-based planning methods used in many railroads are not well suited to rapid response when schedule changes are urgently needed. The *Railroad Traffic Planner* can support railroad security by assisting in activities such as the development of contingency plans, the revision of schedules during an emergency, and the work needed to return operations to normal after a

disruptive event. Planners can quickly assess the consequences of delays by adjusting the strings to reflect the delays, and minimize the negative impact. Also, the GPS tracking system provides near-real-time data, which can help people in remote locations monitor the traffic and figure out how to address the problems. The *Railroad Traffic Planner* can operate on laptop computers, making it portable for first responders who need to make decisions in the field. When multiple railroad companies operate over the same track, it is essential that they communicate in a timely fashion to coordinate their activities. Because people from many railroads are familiar with string line diagrams, the *Railroad Traffic Planner* charts provide an excellent communication tool that can help them work together to assess the situation and the options available for resolving issues. The software also provides arrival and departure times in a tabular format that is beneficial for those who are not familiar with string lines.

#### **4.4.2 Supporting Ongoing Monitoring**

The tool can also be of value for day-to-day security-related operations. For example, Fulcrum has used some of the tracking capabilities developed during this project for a hazardous tank car security program sponsored by FRA and a container security program for the Office of Naval Research.



## 5. Recommendations

This section includes recommendations for people interested in developing, distributing, and using systems like the *Railroad Traffic Planner*.

### 5.1 Planning

Railroads should seek tools that effectively support their planning efforts. Below are some suggestions for railroads and companies that develop railroad software.

#### 5.1.1 *Determine Which Tools Best Meet the Particular Organization's Needs*

As explained above, many potential benefits of using string line tools exist, and there are also many potential challenges associated with using them. The *Railroad Traffic Planner* may be helpful for some railroads with limited resources, but others would probably benefit more from other commercial software applications with more sophisticated features.

One consideration is the complexity of the calculations. Planning system calculations should be accurate enough to meet the needs of those who will be using them. A common question when people saw the *Railroad Traffic Planner* was whether schedule optimization tools were incorporated, since several other planning tools with sophisticated train performance calculators already exist. The goal for this project was to require as little data entry as possible while providing numbers that were at least as accurate as those determined through the other methods the planners used. This approach was supported in the literature, which indicated that instead of focusing on the maximum efficiency from a mathematical perspective, planners often try to limit changes to minor adjustments to minimize the impact on their railroads and the connecting ones. Planners tend to aim for “a credible production planning approach rather than optimality” (MacCarthy and Wilson, 2001). If the operations are satisfactory for the railroad and their customers, they might not want to upset the status quo, even if other changes would be mathematically superior. For small-scale operations, the potential benefits of optimized schedules are not as great as for larger railroads. On the other hand, optimization tools can help identify significant budget savings and improvements in operational efficiency and effectiveness (G. Kalafatas, personal communication, February 20, 2005), so railroads that have the resources for such tools should incorporate them into their planning processes.

#### 5.1.2 *Support for Human Decision Making*

Planning systems should support, rather than replace a human scheduler's decision making, since people have additional information and knowledge about the current situation, perceptions about the future, and a range of pressures and demands (MacCarthy & Wilson, 2001). Although the *Railroad Traffic Planner* has been designed to incorporate a large amount of railroad information, the developers always expected that creating the best schedules possible would require the knowledge of a skilled planner. Planners have specialized knowledge about the trains, crews, and railroad operations, which has not been incorporated into the *Railroad Traffic Planner*. For example, planners know that trains should not be operated at certain speeds due to a phenomenon known as harmonic rock, which can cause derailments. Planners also need to recognize if there are bad meets where two trains are scheduled to arrive at the same time and place on a single track, so they can make the necessary adjustments.

### **5.1.3 Offer Better Integration with Existing Systems**

One reason the GPS tracking system was added to the *Railroad Traffic Planner* was to make the software less dependent on manual data entry. Development to integrate the application with other computerized systems at the railroads could have also decreased the need for manual data entry. For example, one of the railroads participating on this project has more than one hundred speed restrictions on their main line, with some restrictions changing every day. Since their speed restriction data are stored electronically, a process could have been added to directly input the speed restrictions into the *Railroad Traffic Planner*, which would make it simpler for the planners to use the system.

## **5.2 Tracking**

### **5.2.1 Consider Other Forms of Tracking Data**

Although the cellular phone approach was effective at NSHR, a wider range of options for including near-real-time data should be considered to take advantage of existing systems at other railroads. For example, Guilford planners talked about wanting the *Railroad Traffic Planner* to help them compare actual and scheduled train positions. They suggested linking it to a database they already have containing train position information. In railroads like Guilford, where position data are already available, the expense and time associated with installing new tracking systems may not be justified.

### **5.2.2 Integrate Tracking Data with Other Systems**

Potentially large financial and safety advantages can occur increasing the ability of the railroads to work with the data that are collected by their GPS tracking systems. People expressed interest in using this data in other ways, such as analyzing the data to find out if people are habitually speeding, and linking the GPS information (location, time, etc.) to other computerized systems for things such as dispatcher train sheets and car tracking for customers. The data stored in the GPS tracking system database at Fulcrum are currently only available to the railroads through visual displays—the string line display and the geographical map display. Enabling the railroads to import the data into other systems could be very helpful.

### **5.2.3 Communicate with Everyone Impacted by the System**

When deploying a tracking system, it is helpful to ensure that the people who will be impacted by it understand its purpose. In the deployment of a GPS system for bus drivers in 1996, the drivers felt that the new system was added to give managers “more control over the operators” and that “big brother” was watching them (Stearns, Sussman, and Belcher, 1999). It is possible that the train crews had similar feelings about the GPS system installed for this project. Educating the train crews about the device and getting their buy-in could be very helpful since they are the ones who are closest to the tracking hardware, and could be valuable allies in resolving the issues that arise with it. Incorporating features that help them with their work is one way to improve their impressions about the system.

### **5.3 Technology Transfer**

As mentioned above, several factors contribute to successful technology transfer, including personal relationships, coordination of the handoffs and adaptations, expertise transfer, the ability to adopt, and buy-in to the process from both the receiver and transferor (Levin and Kappel, 1998). Support should be provided to ensure that all parties involved have the capabilities and motivation required to succeed. Some suggestions related to this based on *Railroad Traffic Planner* project experiences are included in the next sections.

#### **5.3.1 Encourage Adaptation of Technologies to Meet the Recipients' Needs**

This project demonstrated that sometimes even if the technology is not a perfect match, it can be adapted as it is being implemented. This was demonstrated through the implementations at the participating railroads, and also through Fulcrum's implementations of the technology in other settings both in and out of the railroad industry. In fact, although the *Railroad Traffic Planner* was developed for the railroad industry, people from other industries such as military, maritime, and transit have expressed interest in it. For example, someone from the Coast Guard indicated that *The Railroad Traffic Planner* could be helpful for planning and monitoring vessel traffic since the vessels follow specific paths through the water with distinct points along them. U.S. Army representatives mentioned that this type of tool could be used for logistical support. Other people suggested using the tracking system to monitor the status of delivery vehicles, fire trucks, and police cars. Future work could involve adaptation of the existing technology to meet the needs of other groups such as these.

#### **5.3.2 Broadly Disseminate Results**

This project demonstrated that sharing ideas about technology can be beneficial, even if the actual hardware and software is not complete. The *Railroad Traffic Planner* team created a Web page devoted to the project (<http://www.volpe.dot.gov/hf/railroad/rtp.html>), presented the software at several conferences, and distributed more than 60 copies of the demonstration software to individuals who indicated that they would like to try it and provide feedback. Several university professors expressed interest in using the *Railroad Traffic Planner* in their courses, since it provides an opportunity to share the value of string line diagrams with students. The project team also encouraged other software companies to incorporate ideas from this project into their own software. These outreach efforts reached hundreds, if not thousands, of individuals, and helped promote dialog about the value of string line and tracking tools. Although the exact impact of these interactions has not been measured, they certainly increased the overall impact of this project beyond the four railroads officially involved in the technology transfer effort.

## 6. Conclusions

The *Railroad Traffic Planner* application is demonstration software that supports planning activities using string line diagrams that show train positions over time. It also includes near-real-time position information for trains and maintenance vehicles with associated GPS tracking devices installed. The results of the development have been widely disseminated through a number of technology transfer efforts including installation at four railroads, demonstrations at conferences, distribution of more than 60 copies of the demonstration software, and a Web page devoted to the topic. The *Railroad Traffic Planner* is imperfect prototype software, but the overall project has reached out to a wide range of people in the railroad industry to learn more about and to promote the use of visualization tools to improve safety and productivity. Many people have had an opportunity to learn from this project, and some of the knowledge gained has already been applied in other settings.

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