A Cheaper, Safer, Faster Technique For Automatic Classification Yard Surveying

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Abstract

An engineering evaluation of a rail yard's performance begins with surveying the physical condition of the track. Obtaining an accurate vertical profile and horizontal alignment is a critical aid for comparing as-built and design grades in order to identify operational problems. Traditionally, the survey of an automatic classification yard requires a survey crew and coordinating safety personnel competing for track-time with yard operations. A class yard is a dangerous environment for a ground crew, and the demands of safety will have a negative impact on yard operations. Productivity disruptions of the magnitude required to insure a safe and accurate survey can only be justified when yard operations are severely degraded to the point that resurfacing has been budgeted and scheduled. Consequently, surveys of yard track are rarely performed, with the consequence that sub-optimal yard performance is accepted and an evaluation of the impact of the physical condition on yard operations is at best, a guess based on anecdotal evidence.

A cost effective, safe, and efficient method has been developed to address yard-surveying deficiencies. The survey methodology uses RTK GPS. A GNSS[1] surveying overview is presented along with a observations of rail operations focusing on the role of the automatic classification yard. These presentations are designed to familiarize the reader with the importance of rail car classification to freight rail transportation and the current state of space-based position determination. Comparisons are made between GNSS, traditional optical, and airborne methodologies. Several hump yard survey case studies are presented to enable an

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[1] GNSS: Global Navigation Satellite System

understanding of the geomatic[2] challenges and opportunities for this innovative method.

[2] Geomatics is the discipline of gathering, storing, processing, and delivering geographic information, or spatially referenced information. It encompasses the fields of geodesy, surveying, photogrammetry, cartography, and geographic information systems.

1 Classification Yard Operations

1.1 Introduction

More than a million and a half rail cars are moving through the United States rail network at any given time (Sanders 2007). To fill shipping orders, a Class I[3] railroad may choose to use it own inventory of rolling stock for many commodities. Bi-lateral agreements enabled by the Staggers Act of 1980 permit interchange of specified car types between rail transportation providers (Armstrong 1998).

Private ownership of rail cars currently exceeds the total number of cars owned by Class I railroads. Privately owned cars are of particular importance to chemical producers and others that ship material that may be adversely affected by chemical cross contamination. Private car ownership also assures availability for fulfilling contracted commodity delivery, such as coal to a power producer.

Regardless of ownership, the first steps in rail movement begin when an industry switching crew brings in or sets out a loaded or empty car. Industry examples include chemical plants, grain silos, coalmines, power plants, automobile manufacturing plants, or scrap yards. The car is added to a train's consist[4], possibly inserted between partially loaded or unloaded cars at a trailing-point or facing point siding. The consist continues en route to its terminus at a classification yard. Upon arrival, the consist is moved off the main haulage line and onto a receiving yard by cutting cars from the consist and reassembling the variously sourced units into blocks headed for their destination.

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[3] The 2005 Association of American Railroads definition of a Class I railroad is having annual operating revenues in excess of $319.3 million.
[4] CON-sist: a list, in sequence, of the specific locomotives and car that comprise a train, and includes train and car length and weight, car type, loaded or empty status, car contents, routing, special handling requirements, and destination Ditmeyer, S. R. (2005). "Network-Centric Railroading Utilizing Intelligent Railroad Systems." 10th International Command and Control Research and Technology Symposium, McLean, Virginia..

In contrast, unit trains consist of a single commodity moving from a single source to a single destination. Unit trains accrue benefit from rapid loading and unloading at facilities constructed to accommodate the entire consist. Long-term contracts, for example between a coalmine and power plant, allow high utilization of rolling stock. Commonly, entire unit trains, including locomotives, are assigned to a specific shipper. Do to the commitment of rolling stock to defined shippers, unit trains are not required to be reclassified through rail yards. Specialized cars such as those used to carry coal from a mine to the power plant, could be owned by the mine, railroad, power producer, or leased.

Specialized designs such as rotary dump coal cars, where the entire car is overturned in a dumper, add to the efficiency of the process. Additional transportation efficiencies maybe negotiated in constructing cars from lighter-weight aluminum alloys. These costly, highly specialized cars are able to carry a few additional tons per car. Additional tonnage compensates for increased capital cost over time, assuring the lowest shipping cost possible.

Units not committed to a dedicated route will be assembled and classified into blocks dependent on their destination. Classification yards fulfill this function. Classification (or simply class) yards are categorized as either flat or automatic yards. As the name suggests, a flat yard has little topographic relief and little influence on the motion of a car in the yard. An automatic class yard, typically referred to as a hump yard due to its characteristic artificial hill at the yard entrance, uses the force of gravity to propel cars through the complex of yard track to the intended destination. Between these two categories, the locomotive and car movements in any class yard are similar. However, the pattern and purpose of the operating scheme maybe quite distinct for an individual yard.

A railroad with a high concentration of chemical producers in a region may commit a flat yard to chemical car operations. The yard operation receives, stores, and assembles tank, polymer, or boxcars into blocks for local delivery or pickup within the region's chemical plants. Flat switching utilizes a few switching engines and attendant crews. Flat-switched yards tend to be smaller than hump yards, and their purpose is to sort blocks of cars headed in the same direction. Manual switches and relatively low throughput characterize a flat yard.

Automatic classification yards use remotely operated electro-mechanical switching, and automated car speed control in conjunction with an elevated inlet. The force of gravity drives a car to its intended position on the receiving tracks or "bowl" end of the yard. Hump yards are particularly efficient when the traffic pattern has cars passing through in different directions. If the incoming freight traffic is considered as individual playing cards, the hump acts as the dealer, gathering the cards of played hands, separating, and dealing new hands in numeric order to the designated departure track.

A hump yard is also a logical point for regulatory or company mandated inspection and maintenance operations. Mandated inspection of every piece of rolling stock entering a yard is a common practice. Attendant light and heavy repair services are familiar part of a hump yard's structure (Nall 2007). Remote or automatically controlled switching, bi-directional arrival and departure, and high throughput are characteristics of a hump yard.

Legacy equipment, methods, and designs left over from the golden age of railroading are constantly reviewed and adapted to keep pace with the modern needs of freight transportation. Railroad engineers incorporate advances like CAD, microprocessor control, remote control engines, and frictionless roller bearings are challenged by yard geometry and grades originally designed for journal bearings designed for a bygone era. (Szwilski et al. 2004).

1.2 Hump Yard Operations

A hump yard is engineered and constructed for the specific purpose of breaking apart a consist and reassigning individual units. A hump yard is designed and constructed with several sub-yards to assist in handling large quantities of freight cars quickly and efficiently. A sub-yard's layout and construction suits a specific purpose and are classified as to its function.

- ☐ Receiving yard – A storage area for incoming units.
- ☐ Engine terminal – An inspection and maintenance facility for locomotives.
- ☐ Inspection – An area dedicated to inspection of rolling stock.
- ☐ Rip track – A small area dedicated to light repairs on active track.
- ☐ Car shop – A facility where a more thorough repair and maintenance can be performed.
- ☐ Interchange yard – A yard dedicated to storing and handling "foreign" cars, those from other railroads.
- ☐ Forwarding yard – A set of tracks dedicated to storing cars to be processed through the hump.
- ☐ Main yard – A set of tracks dedicated to sorting and storage of railcars.
- ☐ Thoroughfare, through, or bypass track – A set of tracks that store cars that are not to be processed over the hump.
- ☐ Departure yard – A set of tracks on the pull-out end of the yard for making up consists; connecting power (locomotives), powering, and inspecting cars in preparation to sending them to their next destination.

There are a number of operations that rail cars are subject to before being processed through the hump. Some operations are to comply with Federal Railroad Administration mandates, while others are specific to the particular railroad or yard. In general, upon arrival at the hump yard car-handling operations progress in the following order.

- ☐ Arrival: Incoming locomotives cut the consist and store the cars for processing.
- ☐ Inbound inspection: Bad-order setout.

- ☐ Hump setup: Cuts of cars are identified and sequenced on the approach to the hump lead.
- ☐ Humping operations: Cars are pushed to the hump and released.
- ☐ Bowl: Cars are assembled and stored.
- ☐ Pull-down: Sorted cuts of cars are removed from the bowl and stored in the departure yard.
- ☐ Outbound inspection and air test: Over-the-road power (one or more locomotives and auxiliaries) are coupled, air lines connected and pressurized.
- ☐ Power-on: Air pressure is applied to the consist with inspection for brake operation and air leaks.
- ☐ Bad order setout – Cars that fail the power-on inspection are cut from the consist.
- ☐ Departure – Assembly, brake airline connect, power-up, EOT installation and inspection.

1.2.1 Arrival

Incoming cars are routed off the mainline to the receiving yard. The receiving yard is a storage area where cars are prepared for movement through the yard. Airlines (the "pipe") connecting the continuous compressed air supply from the locomotive are disconnected. Railcar air brakes are a fail-safe design. In case the air supply to the car is interrupted or fails, the brakes on the car and all those after it are automatically applied. A brief explanation of air brake operation follows.

The WABCO[5] design has been in service on rail cars with little modification since 1920's. The locomotive supplies air pressure at approximately 90 psi to each car in the consist through a series of flexible pressure hoses connecting each car, with hard pipe over the length of the car. Each car is equipped with an air reservoir. The WABCO device automatically activates the brake when the supply pressure

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[5] Westinghouse Air Brake Company

drops below the pressure in the car’s air reservoir. This feature acts to prevent cars that become disconnected from becoming uncontrolled runaways.

During yard operations, in order for the car to be moved without reconnecting to an air pressure source, the reservoir bleed valve is left in the open position, rendering the car’s air brakes inoperable.

1.2.2 Inbound Inspection

An inspection is performed to verify a car’s fitness for service and to insure that the car defects do not contribute to additional maintenance-of-way demands. Wheels are examined for flat spots. Wheel flats dramatically increase the dynamic loading on rail and structures and leads to premature wear or failure. Wheels are also visually inspected for wear. Modernized yards use non-contact methods for measuring wheel profiles.

Trucks are the car’s suspension framework that permits the straight axles to turn as the car negotiates curves. This framework contains bearings supporting the axels. Damaged bearings add energy in the form of heat to the steel axle, weakening the steel and leading to failure.

In addition to the rolling components, couplers are examined for cracks and operation, brake pads are examined for excess wear, and hanging equipment such as ladders or strapping is verified as secure.

1.2.3 Hump Setup

A cut of cars from the receiving yard are pushed toward the hump. Several operations are performed before the cars reach the hump. A car may be precisely weighted (± 0.2%) to fulfill certain billing contracts. This level of precision requires additional handling of the car.

Some modernized yards utilize a system of brushes in an attempt to clean contaminate from the car’s wheels. Contaminates, in particular spent cutting fluids from scrap cars, can drip onto the car’s wheels. The wheels transfer the lubricant to the rail and can contaminate the wheels of the next half dozen cars following the leak. The contaminate acts to lubricate the bottom and side of the wheel which in turn adversely affects the ability of the hump speed control mechanism. The lubricant almost eliminates any friction the speed control can produce, with the result that contaminated cars run over the hump and through the speed control at nearly uncontrolled speeds, which can result in derailment or coupling with excessive impact (Vanwormer 2007).

1.2.4 Humping Operations

Individual or blocks of two to three cars are released from the cars behind them at the top of the hump by the pinpuller. The freed car heads down the hump, accelerating away from the crest due to the force of gravity. The car is weighed just past the crest of the hump by a strain gauge system attached to a section of rail. Car weights are accurate to ± 2%. The car weight is used as an input to the speed control algorithm in calculating grade resistance.

1.2.4.1 Speed Control

A hump yard is designed to allow cars to roll off the hump into the yard and come to a controlled stop, coupling with an existing cut of cars with an impact sufficient to completely couple, but not severe enough to cause damage. The maximum coupling design speed is four miles per hour. (Sanders 2007)

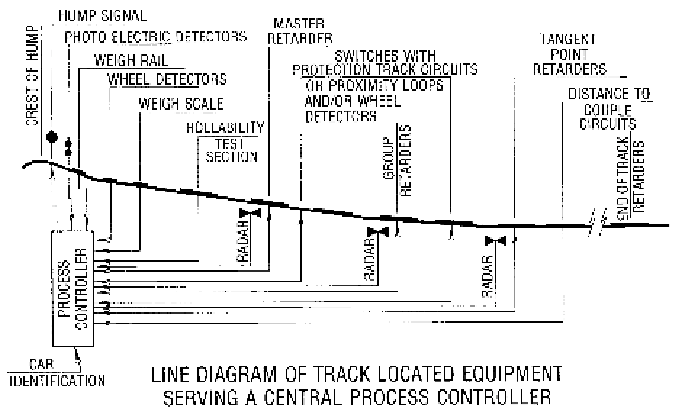

Figure 1-1 Line Diagram of Retarder Control (AREMA)

Rolling from the crest of the hump, a car first crosses the weigh rail providing the hump speed controller with data needed to calculate the coefficient of drag and the rolling resistance for the car. The car next crosses the main retarder. A retarder is a device used to reduce the speed of freight cars. Depending upon the mechanism, each retarder consists of a series of air or hydraulic pistons, or electric motors that operate actuators that apply an external compressive force to car wheels. The friction producing mechanism can be visualized as two long strips of steel clamping the inboard and outboard surfaces of the wheel. The steel on steel compressive force absorbs the kinetic energy turning it into heat and sound, reducing the car's velocity.

An automatic retarder speed controller is a control loop with the retarder acting as the control element, and a microwave speed sensor acting as the control variable sensor. The retarder control applies a variable braking force to the retarder, increasing or decreasing the friction on the wheels as determined by the controller as the car transits the retarder. The controller determines a target exit speed based on car characteristics such as weight and surface area as well as yard characteristics such as destination track length, grade, curve radius and the number of cars already in place in the destination bowl track. PLC[6] based controls use ambient environmental inputs such as temperature, wind speed, and direction to model grade resistance, rolling resistance, curve resistance, wind resistance.

Dependant on the yard configuration, two and sometimes three retarders perform the speed control function. An additional manually controlled retarder maybe used by the pin-puller at the top of the hump to put slack between cars to facilitate the release of the coupling.

The first retarder, referred to as the main or master, is located just below the hump. The main retarder handles every car cut from the top of the hump. Some hump configurations also include an intermediate retarder after the main retarder. A second (third if using a intermediate) retarder makes the final speed adjustment to the car after it has been switched to the destination group but before it is switched to the destination track. Once directed to the destination track, the car is on its own to couple with previously processed cars in the destination track.

1.2.4.2 Factors Influencing Coupling Speed

Car and yard characteristics as well as environmental factors influence the ability of a railcar to successfully transit from the hump to the bowl and couple at the desired speed. Factors that influence speed include physical condition of the rail substructure (sub grade and ballast); the condition of the rail and supporting elements (ties, tie plates, spikes); horizontal and vertical rail alignments; the physical condition, size and shape of the rolling stock; wind speed and direction; ambient temperature; as well the presence of contaminants on the rail. The bulk of these aspects are well defined and can be measured, quantified, and factored into the retarder speed control algorithm. However, other factors may not be easily recognized or quantified.

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[6] Programmable Logic Controller – a ruggedized, special-purpose computer used for controlling a large number of inputs and outputs, including logic for single-variable feedback analog PID (proportional, integral, derivative) control loops.

1.2.4.2.1 Excessive Coupling Speed

Excessive coupling speed increases the opportunity for derailment. Yard grade optimization for roller bearings is a primary mission for resurfacing older yards. Older yard grades were engineered for journal bearings, which have a high friction component compared to modern roller bearings. The resulting optimization contributes to greater yard throughput and reduced wear on rolling stock and retarders.

Cars coupling at speeds greater than four miles per hour will produce undesirable effects on cars and cargo proportional to impact speed. Broken coupling knuckles are common result of over speed coupling, therefore inspection of couplers is a necessary quality-assurance measure at the pullout end of the bowl. Bad order setouts due to coupling or hitch damage add to delays in outbound train makeup.

Cargo with impact restrictions specified by the shipper are shunted to bypass track rather than processed over the hump. These shipments require additional yard resources to identify, cut, and handle. Other sensitive cargo may be equipped with accelerometers that record and/or alarm via cellular, radio, or satellite if the impact exceeds a preset limit (Barnes 2007). Commonly, certain shipments of military cargo, particularly munitions, have accelerometers with automatic alarming to alert the shipper of possible cargo damage.

1.2.4.2.2 Insufficient Coupling Speed

Insufficient speed results in incomplete coupling or a car stalled some distance from the intended block. Uncoupled cars require the service of the trim engine to connect the stragglers before the cut can be pulled from the bowl. This situation is common, with the trim locomotive pushing the cut together as standard procedure before pulling the cut from the bowl.

A car that stalls before clearing the group switch will foul the entire group, blocking access to all the tracks in that group. The next car sequenced for that group will be unable to reach its intended destination. The next car sequenced for that group will have no place to go, shutting down humping operations. Cars destined for the blocked group have to wait until the fouled lead is cleared. Immediate attention of the trim engine is necessary to clear the fouled car to restart humping operations.

In case of a stall past the group but near the track switch, the hump retarder operator is responsible for determining if there is sufficient clearance for cars to pass on adjacent tracks. Clearance between adjacent tracks are determined using a "7 – 11" rule (Vanwormer). This rule provides that eleven feet beyond the point where an initial seven-foot clearance exists between the field side rails of adjacent tracks, adequate clearance exists for the passage of a car on an adjacent track. It is common for this point to be marked in paint on the rail so it is visible to the hump retarder operator from the control tower.

A difficult to quantify friction effect has been observed and measured at a particular yard by Vanwormer. He observed the effect of diurnal heating and cooling of the rail and its influence on car rollability. As a cold rail heats from insolation, it expands both vertically and laterally. Lateral expansion leads to lengthening of the rail, with the most pronounced effect in curves. In certain installations, the lengthening distorts the gauge in the curve, with the effect of closing the gauge. Tight gauge increases friction between the rail and wheels. This factor is unaccounted for by the hump speed control model. The unaccounted friction slows the car through the curve, resulting in a stall (Vanwormer 2007).

1.2.5 Yard description and layout

A hump yard layout can be described by the number of groups and the number of tracks in each group. For example, a 7 by 9 yard describes a 63-track yard of 7 groups having 9 tracks per group. A yard may designate a group or a particular set of tracks for use by local industry, such as chemicals. Shorter yards with bowl tracks less 2,000 feet long pull blocks of cars from several tracks for assembly in a departure yard. Longer yards may be able to use a single track to fully assemble a consist.

2 Classification Yard Surveying

Modern railroad design engineers and track maintenance managers face the specter of legacy equipment, outdated designs, and methods when attempting to integrate modern technological advances into continuing operations. Several survey methods are available for profiling rail track, and before the development of Global Navigation Satellite System (GNSS) surveying[7] in the 1990's, traditional differential and trigonometric leveling are the primary choices for measuring yard profiles. To evaluate the current practical technologies for humpyard surveying, the requirements for speed and accuracy must balance various safety aspects, equipment and mobilization costs, disruption to yard operations, and post survey data processing efforts.

2.1 Engineering Need

Over time, the original grades of a hump yard change as tracks settle and shift. Loading forces from rolling stock degrade track profiles. An occasional limited scale resurfacing aids to maintaining the original grade, however large-scale resurfacing projects are rare.

The first step to evaluate the effectiveness of a large-scale resurfacing project is to survey and evaluate the physical condition, horizontal alignment, and vertical profile of the tracks. The survey data is analyzed using regression analysis and CAD to create track profiles. These profiles are compared with the tracks in the same group and to the original design grade to identify problem track. The results are compared with data from the operations department to confirm and/or identify additional problems. Engineering develops and proposes new grades, a scope of work is outlined, and time and cost estimates developed. The initial surveying

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[7] Survey grade GNSS is defined by the author as an accuracy of a centimeter or less horizontally and two centimeters or less vertically.

phase has traditionally been the most time consuming and costly for the design department, and is the principal driver in examing alternate survey methods for data acquisition.

A traditional yard profile survey can be time consuming, expensive, and hazardous. A survey of the hump and bowl area of a yard may take many weeks to perform in traffic, and cost upwards of $50,000 for just the survey crew labor. The survey crew is constantly in a battle for foul (track)-time with operations, and it is difficult to determine the cost of lost production, and re-routed cars to accommodate the survey. Additionally, the effects of weather with the additional demands on the time of today's scaled-back workforce adds uncertainty to the survey time and cost estimate. Surveying classification yard tracks utilizing laser survey equipment is subject to the same constraints as leveling, and often produces unreliable vertical data (Szwilski et al. 2004). Line of sight is still required and significant planning is necessary in order to survey all the tracks in a yard.

Airborne surveys using LiDAR[8] can be cost prohibitive and is considered overkill in many respects. LiDAR surveys have a typical point density of approximately 2 square feet, resulting in millions of data points collected indiscriminately across the yard. Specialized software is required to extract the features of interest, most notably the theoretical centerline top-of-rail. Since this feature does not physically exist, the actual rail location is observed. However, the rails are generally obscured at the time of observations by cars in process over the hump and stored in the bowl. The location of the rail and its true elevation is estimated between known observations across much of the extracted rail feature. Since LiDAR uses RTK GNSS for determining the position of the aircraft, the error of the LiDAR instrumentation is added to the RTK GNSS positional error producing

[8] Light Detection and Ranging

vertical accuracies no better than 6 centimeters. LiDAR surveying suffers from a lack of ground truth and provides marginal accuracy for resurfacing applications.

The information required by Track Design Engineers is traditional[9] survey data taken in a very specific way. To properly analyze track, points that are more theoretical than physical, such as points of vertical and horizontal curve and tangency, are surveyed to the best approximation while on the ground. Traditional optical surveying methods, where survey collection is slow and point density is kept low in order to increase collection efficiency, office personnel often rely on the field surveyor's best guess. However, a method that takes many points close together (on a 10 to 15 feet spacing) allows for the use of regression analysis to create a more accurate computer model of existing facilities (Tomblin). Acquiring data of this density using traditional surveying would be cost and time prohibitive.

2.2 Safety

All railroad employees, railroads, and railroad contractors performing certain railroad inspection, maintenance, and construction activities are subject to the provisions of 49 CFR Part 214[10]. These regulations are designed to prevent accidents and casualties and present a minimum safety standard. Further, 49 USC 20106 "*preempts any State law, rule, regulation, order, or standard covering the same subject matter, except if directed at an essentially local safety hazard that is not incompatible or is an unreasonable burden on interstate commerce*" (FRA) .

An automatic classification yard is a uniquely dangerous environment. Several factors contribute to the need for focused safety awareness. The noise generated by the braking of rail cars through retarders is a short lived, intense, high frequency squeal. Sound pressure measurements made within fifty feet of a

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[9] Station and elevation or northing, easting, elevation

[10] Title 49 of the Code of Federal Regulations Part 214 Railroad Workplace Safety

retarder will routinely peg the meter at 120 decibels (Vanwormer 2007). Hearing protection is mandatory when working in a humpyard.

Once a car has past the retarder, rolling stock is surprisingly quiet. For the surveyor with full PPE[11] watching for visual clues from the instrument or rod person, a high degree of vigilance is necessary to stay clear of rolling stock on active track. The on-track worker provisions of Part 214 require training for everyone in the survey party, whether employed by the railroad or subcontracted, with an additional requirement for an annual renewal. Additional training beyond on-track worker is required for the watchmen/lookout.

The GNSS survey method described in the later chapters uses a person on the ground only in the event that static, precise measurements of the point-of-switch or retarder inlet and outlet locations as required by the design engineer. Otherwise, these static points are taken from the locomotive along with the thousands of measurements made to determine the track alignment and profile.

2.3 Comparison of Field Survey Methods

2.3.1 Differential Leveling

The principle of differential leveling has been part of the surveyor's repertoire for thousands of years, and with the exception of innovations incorporating the use of a laser rather than a telescope, the principal has remained virtually unchanged for centuries. The basic optical instrument provides a level line of sight through a telescope capable of 360 degree coverage. A level rod is set on a point of known elevation that might be a benchmark, concrete monument, iron stake, or other permanent structure. A backsight is recorded by reading the point on the rod that intersects the telescope cross hairs and determines the height of instrument (HI) above the benchmark. This simple relationship is given by the formula:

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[11] Personal Protective Equipment: steel toe shoes, hardhat, safety glasses, and hearing protection

High of Instrument = Elevation of benchmark + backsight

Unknown elevations are taken as foresights in the same manner, and the unknown elevation is simply the rod reading subtracted from the HI,

Desired elevation = HI – foresight

One limit on baseline length of an observation from a single instrument setup depends on the accuracy required in the finished product. Baselines shorter than 200 feet result in accuracies of a few thousands of a foot and are possible due the observer's ability to interpolate between marks or to use a vernier[12] on the level rod. Longer baselines result in greater uncertainty in reading the rod, and therefore demand more setups. Each setup introduces additional error, degrading the accuracy.

The author feels a conclusion expressed in Szwilski regarding the comparative accuracy of GNSS to traditional differential leveling should be reviewed.

> *"At stations (100 feet intervals) the differences between the two profiles (nearest point to point) were measured. These differences were grouped into four categories: Great (0 to 0.04 feet), Moderate (0.05 to 0.09 feet), Poor (0.1 to 0.19 feet) and Bad (greater that 0.2 feet). The accuracy range of data collected: Great 48%; Moderate 38%; Poor 14% and **Bad 2%."*** {Szwilski et al. 2004)

An examination of GPS elevations collected at 3 foot intervals and differential level points collected at 100 foot intervals reveals that several of the elevation shots designated "Bad" are a result of the surveyor's blunder in incorrectly recording the rod reading, not a deficiency in the GPS technique. The conclusion is that the traditional differential method relies on the human as part of the measurement system, leading to errors that are not easily reconciled back in the office.

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[12] A small movable graduated scale for obtaining fractional parts of subdivisions on a fixed main scale, named after Pierre Vernier (1580–1637), a French mathematician.

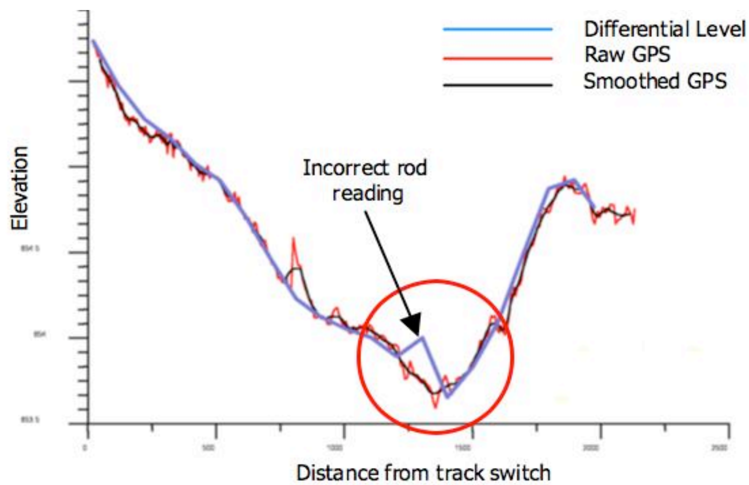

Figure 2-1 Comparison of GPS and differential leveling results from the Norris Yard survey

Table 1 Comparison of various survey methods

Safey, Productivity, & Accuracy Comparison of Survey Technologies				
	Differential Leveling	**Trigonometric Leveling**	**GNSS**	**LiDAR**
Speed	slow	slow	moderate	fast
Safety	poor	poor	good	good
Equipment Cost	low	moderate	moderate	high
Mobilzation Cost	moderate	moderate	low	high
Ground Truth	high	high	moderate	none
Data Density	low	low	moderate	high
Op Disruption	high	high	low	none
Post Processing	high	low	moderate	high
Accuracy definition		high < 0.02m	low > 0.1m	
X accuracy	n/a	high	high	low
Y accuracy	n/a	high	high	low
Z accuracy	high	high	moderate	low

3 Introduction to Global Navigation Satellite System (GNSS) Surveying

A new, exciting, and commercially stimulating era of geodetics was ushered into being on February 22, 1978 with the launch of the first United States Global Positioning System (GPS) space vehicle (SV). The United States initiative, spearheaded by the US Department of Defense (USDoD), could arguably be considered the most successful exploitation by civilians of a military endeavor. The term Global Navigation Satellite System (GNSS) is a generic reference that recognizes that there are several global navigation systems either deployed or undergoing testing and development.

Industrial GPS usage has been widely and eagerly adapted, with new applications appearing often. From applications as diverse as precise time synchronization for multiple seismometers or quickly determining where to drill ventilation and rescue holes to facilitate the rescue of trapped miners, this civilian use of a military navigation system enables industry users to integrate geographic information on an enterprise-wide scale. Management and operations can obtain speed and efficiency in traditional applications as well finding new ways to incorporate innovative products and techniques into their operations.

President Reagan's decision to offer GPS free of charge for civilian aircraft navigation in 1983 was driven by the navigational mishap that led to the Soviet shoot down of Korean Air flight 007. His decision set in motion the beginning of shared military and civilian use of GPS. It wasn't until 1989 that GPS positioning became available for civilian use, and the full civilian capability of the GPS was unleashed in 2000 when selective availability (SA), an intentional falsification of the satellite clock and ephemeris, was turned off by a directive from President Bill Clinton (Leick).

There are two global satellite-based navigation systems available at present, with a third undergoing planning, development, and testing. The United States pioneered the technology with a progression of systems dating from 1958, culminating in the present Global Positioning System. Likewise, the Russian Federation has continued development and modernization of Global'naya Navigatsionnaya Sputnikovaya Sistema (GLONASS). A joint initiative between the European Union, the European Space Agency, and a consortium of private interests are working to develop a non-governmental commercial use system called Galileo.

3.1 Regional Space-Based Satellite Systems

Regional initiatives have produced the Japanese Quasi-Zenith Satellite System (QZSS), (Jun-Ten-Cho in Japanese), which is a constellation of at least three satellites, configured such that one of them is always positioned at a high elevation angle over Japan.

Likewise, Chinese research towards a system has been underway for many years. The satellite component is referred to as the Compass Navigation Satellite Experimental System, or Beidou-1 (Big Dipper). Beidou-1 presently consists of a three-satellite[13] constellation in geosynchronous orbit providing navigation and positioning capabilities to the East Asia region. The system's sponsor is the China Academy of Space Technology (CAST). The claimed system accuracy is 100m, and increases to 20m with the use of ground-based correction stations.

The Chinese system is much different than others in that the system uses two-way communications between the user and SVs. A central control station passing inquiry signals to users initiates a positioning session. The user receives the initial signal from one satellite and responds with a broadcast that is received by both SVs. The central station receives the responding signals sent by the user as relayed from the two SVs. The central station calculates the user's 2D position based on the time difference between receipt of the user's broadcast by the two SVs. The two dimensional position is compared with the central station's digital map to determine the elevation component. The 3D position is encrypted and transmitted to the user via the SVs. The user can use the SVs for transmission of encrypted text messages to the central station.

The BeiDou SVs are in high-altitude geostationary orbits and therefore require a powerful transmitter and associated power storage for field use. BeiDou's user equipment is much larger, heavier, and more expensive than a GPS receiver. The number BeiDou users is limited by the communication capacity of the network. At present, the system capacity is 540,000 users per hour (Chinese Defence Today 2005). Since BeiDou is a closed system, and only supports navigation in the south Asian area.

3.2 Global Space-Based Navigation Systems

There are at present two functional global navigation systems; the United States Global Positioning System and the Russian Federation Global'naya Navigatsionnaya Sputnikovaya Sistema. A third, the European Union's Galileo, has launched two SVs and is at present in the testing and construction phase. Each of the three global space-based navigation systems has individual characteristics that are outlined in this section.

3.2.1 United States - Global Positioning System (GPS)

The satellite based navigation system in the United States is the Global Positioning System or simply GPS. Features of the US GPS are:

- ☐ 24 satellites plus spares in 6 orbital planes; orbital period – 11:58 (½ sidereal[14] day)

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[13] Two operational and one in-orbit spare.
[14] Sidereal day: The time taken for the earth to rotate on its axis relative to the stars, and is almost four minutes shorter than the solar day due to the earth's orbital motion.

☐ MEO[15] - 20,200 km (10,900 nmi) circular, 60° inclination

☐ Provides 24 hour coverage between 80°N and 80°S

☐ Space vehicles transmit downlink signals on several frequencies: L1 (15575.42 Mhz); L2 (1227.6 Mhz); L5 (1176.45 Mhz) – military use; S-Band (2227.5 MHz)

☐ Managed by the USAF NAVSTAR GPS Joint Program Office, Space and Missile Systems Center. Operated by the USAF 50th Space Wing

☐ Civilian use is coordinated by the US Coast Guard.

☐ Ground control segment consist of six monitoring stations: Falcon Air Force Base in Colorado; Cape Canaveral, Florida; Hawaii; Ascension Island in the Atlantic Ocean; Diego Garcia Atoll in the Indian Ocean; and Kwajalein Island in the South Pacific Ocean.

The ground segment monitoring stations check the altitude, position, speed, and health of each SV. These measurements are used to predict SV behavior from movement within its orbit as well as atomic clock changes. Orbital disruptions are due to gravitational interaction with other celestial bodies; the earth, the moon, the sun, and pressure from solar radiation have the greatest influence on a satellite's orbital behavior. The predictions are compiled as an ephemeris[16] and transmitted back to the SV for retransmission to the user's receiver. The receiver stores and uses the latest ephemeris downloaded from the SV to use in determining the user's position. Each station monitors satellites twice a day as they pass by, uploading an updated ephemeris during each pass.

There are two navigational signal types encoded in an SV's transmission; standard positioning service (SPS) and precise positioning service (PPS). The

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[15] MEO – mean earth orbit

[16] A table or data file giving the calculated positions of a celestial object at regular intervals over a period of time.

standard positioning service is available free of charge to anyone in the world and is protected against hostile intent as reflected in a recent policy statement.

> *U.S. Policy Statement Regarding GPS Availability, March 21, 2003*
>
> *The United States Government recognizes that GPS plays a key role around the world as part of the global information infrastructure and takes seriously the responsibility to provide the best possible service to civil and commercial users worldwide. This is as true in times of conflict as it is in times of peace.*
>
> *The U.S. Government also maintains the capability to prevent hostile use of GPS and its augmentations while retaining a military advantage in a theater of operations without disrupting or degrading civilian uses outside the theater of operations.*
>
> *We believe we can ensure that GPS continues to be available as an invaluable global utility at all times, while at the same time, protecting U.S. and coalition security requirements.(U.S. CGNC 2007)*

The US DoD restricts the use of the PPS availability to authorized U.S. and Allied military as well as select federal government users.

3.2.2 Russian Federation – [Global'naya Navigatsionnaya Sputnikovaya Sistema] Global Navigation Satellite Systems (GLONASS)

GLONASS is the Russian Federation's space-based navigation system, comparable in many facets with the GPS. Operation capability was announced in 1995. However, the system is presently operating in a degraded state while undergoing modernization. Older satellites have been deactivated and slowly replaced with newer GLONASS-M SVs. The replacement SVs are designed with upgraded signal characteristics and a longer 7-year design life. The major characteristics of the fully implemented GLONASS are:

- ☐ 24 satellites plus spares in 3 orbital planes, orbital period - 11 hours 15 minutes
- ☐ MEO - 19,100 km (10,313 nmi) circular, 64.8° inclination
- ☐ Each SV operates two downlink frequencies determined by the formula: L1 (1602 MHz + 0.5625 x *j*); L2 (1246 MHz + 0.4375 x *j*),

where *j* represents the channel number assigned to a particular satellite.

- ☐ Managed for the Russian Federation Government by the Russian Space Forces.
- ☐ All ground segment stations are within the borders of the Russian Federation.

The GLONASS system has two types of navigation signals: standard precision navigation signal (SP) and high precision navigation signal (HP). SP positioning and timing services are available to all GLONASS civil users on a continuous, worldwide basis, while the HP signals are reserved for military use.

As of July 2007 the GLONASS constellation consisted of a total of 13 operational satellites.

3.2.3 European Union - Galileo

The Galileo satellite navigation program is a joint initiative between the European Union and the European Space Agency to build and operate a 30-satellite constellation that provides similar capabilities to GPS as a commercially operated, for-profit venture. The system will offer four distinct positioning, navigation, and timing services and one search and rescue service.

An **Open Service** with open access signals that is free of user charges. A **Safety of Life Service** will be a guaranteed service that provides integrity warnings to users when the system fails to meet certain accuracy requirements. A **Commercial Service** that is envisaged to include service guarantees and a limited broadcasting capacity for messages from service centers to users. A **Public Regulated Service** will be a secured (encrypted) service for authorized governmental users (police, fire, emergency response, etc.). A **Search and Rescue Service** will transmit the alert messages received from distress emitting beacons as a contributor to enhancing the performance of the international COSPAS-SARSAT Search and Rescue system.

The United States and Europe agreed to establish interoperability and non-interference between GPS and Europe's planned Galileo satellite navigation system, as well as cooperation on a new civil signal that will be common to both systems. The interoperability is expected to improve service for users by adding another 30 SVs available for observations, provide better satellite availability and constellation geometry at any given time and place than currently possible. Further, safety or production-critical applications would benefit from dual GPS-Galileo receivers making them suitable for cases where reliance on a single system would be considered dangerous. Dual system receivers would also have improved integrity, enabling greater reliance on satellite navigation for computer steering and machine applications. Finally, the orbital inclination of the planned Galileo system will provide greatly increased coverage to users in northern or southern latitudes beyond 80 degrees.

3.3 What GPS Accuracy is Available?

The US GPS a provides standard positioning service using the course acquisition (C/A) code modulated on the L1 carrier. Performance standards set by the DoD guarantee global average positioning domain accuracy to ≤ 13 meter horizontal and ≤ 22 meters vertical error, with worst-case ≤ 36 meters horizontal and ≤ 77 meters vertical. USDoD performance standards are stated with 95% system availability.

There are several methods to augment errors from satellite broadcasts in order to improve the positioning accuracy of code phase GPS. Instrument error sources are introduced from the satellite's atomic clock, variation in signal delay through the ionosphere in addition to the aforementioned orbit variation. These error augmentation methods include both ground and space based systems.

3.3.1 Space Based Augmentation Systems (SBAS)

The United States Federal Aviation Administration (FAA) put a Wide Area Augmentation System (WAAS) into operation in 2003 in order to meet requirements for increased accuracy, availability, and integrity for all phases of flight in the National Airspace System. Although designed primarily for aviation users, WAAS provides corrections to the SPS signal to improve positioning accuracies in North America. WAAS consists of 25 ground reference stations positioned across the US. Two master stations on either coast collect the reference station data and create a GPS correction message. The correction message is relayed to geostationary satellites, which is broadcast in a compatible GPS signal structure. Any WAAS-enabled receiver can read the signal and apply the appropriate corrections to the SPS signal. The FAA's performance goal is to attain a vertical protection limit (VPL) of 12 meters for flight operations.

South American users, although able to receive the WAAS signal, derive no benefit due to the great distance between the users' location and the nearest ground reference station. Other nations have developed SBAS to obtain precisions similar to WAAS. The Japanese are developing the Multi-Functional Satellite Augmentation System (MSAS); the Europeans have the Euro Geostationary Navigation Overlay Service (EGNOS) in place; India uses the GPS in conjunction with their GEO Augmented Navigation (GAGAN); the Chinese have implemented their Satellite Navigation Augmentation Service (SNAS); Brazil and several African countries have expressed a desire to set up their own SBASs.

SBASs have relevance for industry users in nearly worldwide applications that make use of mapping grade accuracies. GPS receivers using SBAS are inexpensive, readily available, with a wide variety of options for mapping and data formats. These receivers are easily incorporated into many basic positioning requirements, from cell phones to receivers integrated with background maps and charts. The

SBAS accuracies, while an improvement on the standard positioning accuracies, are unsuitable for surveying applications.

3.3.2 Ground Based Augmentation Systems

Ground-based augmentation systems are found thought the world, following the international standard ITU-R-M.823. Referred to in the US as the Nationwide Differential Global Positioning Service (NDGPS), this service provides real-time enhancements to the SPS GPS signal. Experimental enhancements and hardware to the NDGPS by the US Coast Guard have demonstrated sub-meter accuracy over the continental U.S. and portions of Alaska. The NDGPS supports a wide range of navigation and positioning requirements at the federal and state levels. NDGPS currently provides single coverage service over 87% of the continental U.S., Alaska, Hawaii, and Puerto Rico, and compatible systems have been installed in more than 40 countries covering all of Japan, most of Europe, most coastal areas, and many inland areas of South America.

The NDGPS performance standard is for positioning accuracies of 2 to 5 meters horizontal, within 250 miles of a reference station. Sub-meter accuracies of 10 to 20 cm are possible with special equipment & software. Using the NDGPS requires a radio receiver capable of receiving and processing corrections broadcast between 285 and 325 KHz.

3.3.3 Real Time Kinematic Methods

Carrier-phase differential GPS (CPDGPS), also referred to as RTK[17] GPS, uses two or more receivers capable of phase-shift measurements to provide positioning accuracies to 1 cm ± 1 ppm horizontal and 2 cm ± 1 ppm vertical. This technique requires that signals from at least five SVs be collected simultaneously by both a fixed location base station and a roving unit throughout the measurement process. Dual frequency receivers, those capable of both L1 and L2 band reception, are best suited for this work. Like DGPS, one fixed position receiver is used for broadcasting corrections to the roving unit. The base station broadcasts typically use a modified FSK[18] modulated VHF[19] or UHF[20] FM[21] signal. A base station connected to the Internet is capable of providing corrections to a roving receiver over the digital cellular telephone network.

A single base station provides coverage for an approximate 40 km radius from its position. Beyond 40 km, initialization times between the base station and roving receiver grow to an unacceptable level. A roving receiver's error increases proportionally with distance from the base station. This error is expressed as an error in parts per million, signifying that for every million parts distant from the base station, the error increases by one part. For example, at a 10 km distance from the base station, an additional 1 cm ($1 \times 10^{-6} * 1 \times 10^{3}$ meters) can be expected in the measurement error.

A network of continuously operating reference stations (CORS) connected to a central server running specialized software provides the basis for creating a virtual reference station (VRS). For small networks of fewer than 25 CORS, a single server may be adequate for communicating with each CORS to collect observations every second, store and convert it to a form useful for the ionospheric modeling, and communications functions.

However, larger networks such as the Ohio Department of Highways Aerial Mapping Division with 58 CORS, split the VRS computing functions between several servers. Individual servers perform the communication, collection, and modeling functions. One server is dedicated to collecting the instantaneous correction data

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[17] RTK: Real Time Kinematic

[18] FSK: Frequency Shift Keying - a form of frequency modulation in which the modulating signal shifts the output frequency between predetermined values.

[19] VHF: Very High Frequency - generally recognized as a band of frequencies covering 30-300 MHz.

[20] UHF: Ultra High Frequency - generally recognized as a band of frequencies covering 300MHz-3GHz.

[21] FM: Frequency Modulation – information represented as variations in the instantaneous frequency of the carrier wave.

from each of the network's CORS. Another server takes care of data conversion and storage while a third runs ionospheric modeling software to create a VRS located near the roving receiver's position.

With a VRS, when the rover's proximity error grows beyond a programmed amount, the rover requests the VRS server to synthesis a new virtual reference station. The roving receiver sees the new virtual base station, initializes with the base, and continues receiving corrections with the proximity error reset to zero. A VRS network is ideal for eliminating growing error sources during long baseline surveys.

Ad hoc, CORS, and VRS reference station are all useful for different aspects of railroad surveys. Ad hoc base stations are quick and easy to set up and use during hump yard surveys, where base lines maybe only several miles long, and the base station and UHF data radio can be located in an elevated position to maximize radio propagation. CORS have been set up in western part of the state of West Virginia and cover a triangular area between Huntington, Charleston, and Ravenswood. These stations provide easy access to high quality observations over a longer rail corridor between Huntington and Point Pleasant.

In addition to their stand alone capabilities, the Huntington (WVHU[22]) and Ravenswood (WVRA) CORS are functional components of the NGS[23] National CORS network. NGS describes the National CORS Network as providing "*Global Positioning System carrier phase and code range measurements in support of 3-dimensional positioning activities throughout the United States and its territories*" (NOAA-NGS 2007).

A partnership between the Rahall Transportation Institute and the Ohio Department of Transportation's Office of Aerial Surveying allows RTI access to

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[22] Access http://www.ngs.noaa.gov/CORS/ and enter WVHU or WVRA

[23] National Geodetic Survey, an office of the US Department of Commerce National Oceanographic & Atmospheric Administration

ODOT's statewide virtual reference system. The Huntington and Ravenswood CORS are integrated into the ODOT VRS and cover southeastern parts of Ohio for ODOT. The partnership has provided RTI with invaluable experience in working with a VRS, and has lead to adopting a section of active CSX mainline track from Huntington to Point Pleasant West Virginia as an "electronic" rail corridor. Numerous experiments in the corridor have provided insights in defining minimum operational, procedural, and functional requirements for safe and efficient long-baseline surveys of surface and subsurface railway infrastructure.

4 Introduction to Humpyard Survey Case Studies

4.1 History

The first attempt at using a locomotive as a survey platform in an automatic classification yard was born out of adaptation and necessity rather than careful planning. The scope of a project to survey the Norfolk Southern Norris Yard was to use the modified Hi-rail, described in initial on-track experiments in Appendix A, as a platform with which to survey the yard. An initial experiment was conducted in nearby departure yard tracks to determine possible detrimental effects of multipath reflections of the GPS signal from boxcars in adjacent rails. The experiment showed no indication of signal problems. However, serious troubles arose during the first attempt at transiting an inerting retarder. The Hi-rail was backed into the retarder at the pullout end of the bowl, and the running gear became firmly wedged in the retarder.

Figure 4-1 Workers attempt to free a Hi-rail wedged in the exit of an air operated inerting retarder. (Dailey 2004c)

Norfolk Southern division engineer, Brad Kerchoff, agreed to attempt the author's suggested to modify the survey equipment for use on a yard locomotive.

The yard managers accepted the plan, and a yard engine was commandeered, and the GPS survey equipment mounted and tested.

The Norris Yard survey was completed in three days. The research team overcame a soaking cold rain, a blown locomotive engine head gasket, and overwhelming the limited capacity of the survey controller to collect 29,000 shots in three and a half days.

The survey controller data was loaded daily into Trimble Geomatic Office software and then exported as an ESRI shape file. The shape file was brought into ESRI ArcMap and rendered with varying elevation quantities mapped to different colors. The resultant map was shared with the yard management before leaving the yard. The elevation map confirmed anecdotal problems wit rollouts on certain tracks. More importantly, the elevation data was used to plan the large-scale resurfacing performed several months later. Norfolk Southern judged the survey to be a success.

The project results were presented at the 2004 AREMA[24] national conference (Szwilski et al. 2004). Several shortcomings with the method were pointed out in the paper and several others are discussed in this report. The presentation was witnessed by a project manager from a transportation systems engineering company, and as a result TranSystems engaged the Rahall Transportation Institute to survey a hump yard in the town of Blue Island, about an hour south of Chicago, Illinois.

The IHB[25] survey was the first automatic class yard survey designed to use a yard locomotive as the survey platform. The survey was an opportunity to address deficiencies and incorporate improvements to the initial ‘paper clip and duct tape’ survey at the Norris Yard.

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[24] American Railway Engineering and Maintenance of Way Association
[25] Indiana Harbor Belt Railroad

The subject of the second case study was conducted at the CSX Boyles Yard during March 2007 to refine the technique and to demonstration to humpyard engineering management that the method is viable, accurate, and repeatable.

The third case study was performed for CSX in May 2007 with two objectives. The primary objective was to survey the fifty year-old yard grade in preparation for a wide-scale resurfacing and control system upgrade. The secondary objective was to survey the outlying yards tracks and other yard assets for entry into a GIS.

4.2 Impediments to acceptance

In describing the technique to industry managers and engineers, a reoccurring objection to acceptance in using a locomotive for a survey platform was expressed by our Norfolk southern coauthors at AREMA. Namely

> *"An engine is a **large piece of machinery that rocks and shakes** and is not designed to operate as a stable surveying platform. This vertical error could be seen in the profiled data sets, especially on tracks surveyed in multiple directions (sometimes the rover made multiple passes along a track). While a best-fit alignment is produced during regression, a tighter data set would produce more accurate results."* (Szwilski et al. 2004)

While the author would agree with his colleague's that a 275,000-pound locomotive is a large piece of equipment, it is the author's contention that the "rock and shake" felt by a human passenger is a result of the reaction to track irregularities, and these irregularities can be measured and quantified. During the Norris Yard survey the author indeed witnessed plenty of shake in the GPS antenna. However the flexure was due to a poorly supported three-meter carbon-fiber rod pole toped by a heavy antenna, not a particular resonance or defect in the locomotive's suspension.

A statement expressed in the conclusion of the AREMA paper expresses the reasons for documenting the result of the next three surveys in an effort to provide a best practices document.

"However, there are several improvements that could be made to the data collection process that would both speed up the office calculation part of the process and inspire even more confidence in the accuracy of the data. Most of these improvements, though, are likely to be from lessons that can only be learned through experience to enhance what promises to be a viable data collection method." (Szwilski et al. 2004)

The following case studies reflect the experience, enhancements, procedures, successes, and failures in developing this technique after the pioneering effort at the Norris Yard.

Table 2 Humpyard Surveying Equipment List

Automatic Classification Yard Survey Equipment List	Item	Description / Note
Ad hoc base station	Trimble 5700 reciever	L1, L2
	Trimble Trimmark 3 (TM3) data radio	460 MHz, 19200 baud
	Trimble Zephyr Geodetic GPS antenna	w/ ground plane, 5/8" x 11 tpi mount
	High gain (+9dB) UHF antenna	NMO x 5/8" x 11 tpi mount
	Fixed height tripod	GPS antenna mount, 5/8" x 11 tpi
	Standard tripod	UHF antenna mount, 5/8" x 11 tpi
	Waterresistant case	Pelican, gasketed, port for cable access
	RG-58 coax cables w/TNC connectors	GPS & UHF antenna connections
	LIMO to LIMO data cable	5700 data to TM3 data radio
	West Mountain Radio fuse block	Anderson Powerpole (APP) connections
	TM3 Power cable, APP	Application specific cable
	5700 Power cable, LIMO to 5mm coax	Application specific cable
	LIMO to LIMO data cable	Initial connection to survey controller
	Trimble TSCe2 survey controller	Initial survey startup
	64 mB Compact Flash data card	Record base station observations
	12VDC deep cycle battery	Application specific cable
Roving reciever-locomotive	Trimble 5700 reciever	2 - NiMH batteries
	Trimble Geodetic antenna	5/8" x 11 tpi mount
	Trimble omni directional UHF antenna	1" range pole mount
	Trimble TSCe2 survey controller	
	Seco magnetic mount	5/8" x 11 tpi mount
	1" range pole	5/8" x 11 tpi mount
	RG-58 coax cables w/TNC connectors	GPS & UHF antenna connections
	LIMO to RS-232 data cable	5700 to TSCe2
Roving reciever	Trimble R8 reciever	1 - NiMH battery, 5/8" x 11 tpi
	Trimble omni directional UHF antenna	"rubber duck" TNC mount
	Trimble TSCe2 survey controller	
	Range pole, 2 meter, 2" carbon fiber	5/8" x 11 tpi mount
	Seco survey control/ range pole clamp	

5 Case Study: The IHB

Survey conducted February 13-15, 2006

Indiana Harbor Belt Railroad, Blue Island Illinois Yard

Configuration: 6 x 7 Automatic Classification Yard, 42 tracks

RTI survey party: Peter Dailey, Alejandro Sanchez

Nominal point density/total data: 10 foot / 9,151 points

5.1 Executive Summary

As a result of a previously published research report (Szwilski et al. 2003), Transystems of Chicago, Illinois contacted the Rahall Transportation Institute with a proposal for surveying the Indiana Harbor Belt Railroad (IHB) Blue Island Yard. The IHB yard, located near Blue Island Illinois, is a 44-track automatic classification yard. The purpose of the survey was to provide centerline top-of-rail elevations to aid in the redesign and resurfacing of the yard. This unpublished case study details survey data collection and processing procedures, incorporating lessons learned from the Norris Yard survey.

5.2 Introduction

Traditional optical survey methods (differential and/or trigonometric leveling) for yard survey work involve a survey crew walking each rail, taking measurements every 100 feet. A typical working crew requires a three-person survey party, and two safety persons, plus coordinated actions of the yardmaster, engineer, and conductor. Previous survey traditional survey work by Norfolk Southern estimated a similar yard would require 4 to 6 weeks of fieldwork (Szwilski et al. 2004), with several additional weeks of office work reducing data and entering it into engineering systems.

This yard survey used several specially modified pieces of equipment and reduced the head count from the Norris Yard survey. The IHB survey was conducted with a 2-person survey crew, an engineer, conductor, and the coordinating efforts of the assistant yard manager. The assistant yardmaster worked to coordinate locomotive movements and humping activities between the hump and retarder control operators.

The IHB survey job was completed during three twelve hour days, resulted in minimal disruptions to yard operations, and at no time exposed the survey crew or support personnel to the hazards of typical hump yard operations.

5.3 Problem Statement

As previously described, a classification or marshalling yard is purpose built to separate, inspect, sort, and group rail cars into outgoing consists. Taking a hump yard out of service, or inactivating a section of the yard for resurfacing has a major impact on movement of revenue producing units. The negative impact on revenues is the major consideration in determining when a yard's productivity has fallen to the point where reengineering and resurfacing are necessary for the future function and efficiency of yard operations.

5.4 Objectives

The objective of the survey was to provide accurate and timely centerline top-of-rail positions and elevations for use in developing engineering estimates for resurfacing the Blue Island yard.

5.5 Data Collection, Processing and Storage

5.5.1 Field Data Collection

The hardware used during the IHB survey are divided into three modules.

Figure 5-1 Ad hoc base station showing GPS antenna placement

1. Ad hoc base station
2. Static survey module
3. Mobile survey module

Ad Hoc GPS Base Station Module. The base station components consisted of the material listed in table. Additional items were incorporated to adapt to site conditions, are visible in illustrations 5.1 and 5.2.

A fixed-height tripod was set up on the roof of the control tower as a support for the base station GPS receiver antenna. A triangular metal tripod support was used under the leg points to protect the rubberized control tower roof from puncture.

After setup, tripod stability difficulties resulting from 30 mph wind gusts required a method of more firmly anchoring the tripod legs to prevent movement during the twelve-hour survey. The fixed height tripod mounting the GPS antenna was lowered from our typical 1.8 to 1.5 meters to improve the stability of the tripod. Additionally, scrap tie plates were duct-taped to the tripod legs to provide sufficient weight to hold the base antenna firmly to the roof of the control tower. Similar modifications were made to the UHF data radio transmitter.

Figure 5-2 Roof protection and wind countermeasures for UHF antenna mount

Static Survey Module. This module is composed of an integrated Trimble R8 dual frequency GPS receiver and antenna, a Trimble Survey Controller model TSCe2, and a 2-meter carbon-fiber range pole with removable bipod.

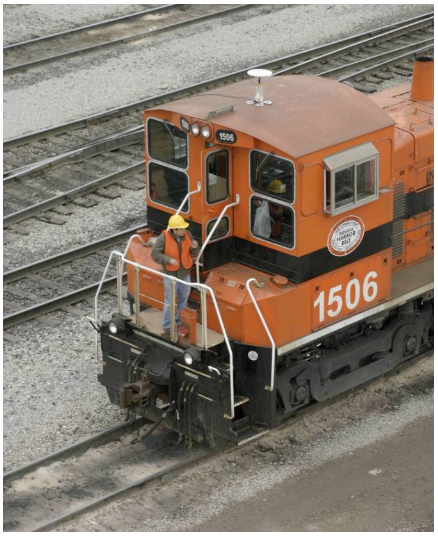

Figure 5-4 GPS and UHF antennas located on yard locomotive

Mobile Survey Module. This module is composed of the item detailed in table 4.2, with several additional items.

- ☐ Purpose built magnetic GPS/UHF antenna mount
- ☐ Long length RG58 50Ω antenna leads
- ☐ 12 VDC AGM battery pack with 120 VAC inverter

5.5.2 Software

A Trimble Survey Controller model TSCe was used for mobile data collection in the locomotive. It uses the Windows Mobile operating system and is capable of controlling data point collection rate and storage of the roving GPS receiver's observations. Data collected in this controller is transferred post-survey using a Trimble-specific adapter and a USB cable connected to a laptop computer running Microsoft Activesync 4.0 or greater. The controller can be programmed to modify the GPS receiver's parameters (survey style, coordinate system, data radio receiver channel) as well as monitoring the status of the data collection process by creating a map display of the data.

The static survey module employed the newest survey controller from Trimble. A model TSCe2 was on loan and used during the survey of points on the ground. This controller is much improved and allowed data transfer to an external USB memory device. Additionally, data can be transferred to a CompactFlash or SecureDigital memory card.

In hindsight, the newer TSCe2 survey controller should have been used rather than the older TSCe. There were periods when the TSCe could not keep up with the data generated by the movement of the locomotive. The data collection slowed, and at several times the controller stalled and had to be reset.

5.6 Methodology

Following a morning safety briefing, a suitable location was scouted for locating the as hoc base station. Previous experience with data radio dropouts at the pullout end of the Norris Yard (Szwilski et al. 2004) indicated that increasing HAAT[26] mounting of the UHF antenna would maximize data coverage across the yard. At the same time, it is necessary to minimizing obstructions between the GPS receiving antenna and satellites. We were fortunate to gain access to the roof of the yard control tower with the promise that we not compromise the integrity of the rubber roof seal.

Wind conditions at the IHB were harsh, with gusts to 30 mph blowing into the yard from across Lake Superior. The countermeasures previously described where sufficient to maintain the base station antennas upright and level.

After setup, leveling, and power up checks, the base station receiver is started by attaching a data cable from the survey controller into port 1 of the receiver. Once the survey software connection is confirmed, the base station startup routine is initialized. As part of the initialization procedure a position for the base station must be entered in one of three ways.

1. A position can be retrieved from a previous survey.
2. Manually entered if known.
3. The autonomous position determined from the receiver's single frequency code phase solution.

An autonomous position using the course acquisition (C/A) phase position plus WAAS[27] provides an initial accuracy of 3 to 5 meters. The initial position is only required to satisfy the base station's gross position check. The base station position is later corrected to centimeter accuracy post survey, with the roving receiver position vectors recomputed to propagate the base station's updated position. This

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[26] Height Above Average Terrain

procedure is described in more detail in the ***Processing and Organization of Data*** section.

After the position for the base is entered, the survey controller starts the base station and the survey controller is disconnected. The base station receiver operating system was previously programmed to record and store observations to a local CompactFlash memory card at a 15-second rate. Recording to the CFcard is activated by a push button on the front panel, with recording activity verified by an indicating LED. Base stations observations are recorded for at least two separate sessions of at least two hours each. In this case the base station observations were recorded during the entire shift. The weather resistant case is secured against ambient conditions.

The base station computes the differential between the measured and entered positions, and sends this differential as a serial stream to the UHF radio. The differentials can be broadcast in several formats, any of which is selectable during the base station configuration phase. As this data is a one-way broadcast, there is no limit to the number of receivers that can receive and process the correctors. There are two data standards available from the Trimble model 5700.

- ☐ RTCM – Radio Technical Commission for Marine Services.
    - o An industry 'standard' with several versions. "Version 2" (RTCM10402.3) is extensively used by most GPS manufacturers. RTCM "Version 3" (RTCM10403.1) addresses the bulky data structure of "Version 2" with an optimized structure for RTK use. (RTCM 2004)
- ☐ CMR / CMR+
    - o A Trimble proprietary format that was developed due to the large data structure of RTCM "Version 2".

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[27] Wide Area Augmentation System

The Trimble Trimmark 3 UHF data radio transmits in the 450 MHz band, with an output power of 25 watts. The starting and ending time and battery voltage are recorded to aid in predicting battery life. We found it possible to get two complete twelve-hour sessions from a commonly available deep-cycle lead-acid battery.

With the base station setup complete, the rover setup on the locomotive was undertaken. The antenna was aligned to the centerline of a straight section of track by first measuring and marking the track centerline on crossties approximately 300 feet apart. While the locomotive was moved another 300 feet away, a theodolite was setup and leveled over the mark nearest the locomotive. A back sight to the centerline mark farthest from the locomotive was observed. The theodolite was turned 180 degrees and a foresight to the roof of the locomotive was made. The centerline was marked on the locomotive rooftop and the magnetic mount centered over the mark. The final magmount position was adjusted by sighting the center of the antenna-mounting rod with the theodolite.

Once the magmount is set, the theodolite is picked up and stored. A watchmen-lookout was a required safety precaution during the alignment procedure for the theodolite operation. The roving UHF and GPS antennas were attached to the mount with the GPS antenna cable threaded behind the UHF antenna to eliminate any interference. A Trimble Zephyr Geodetic antenna was selected for its integral ground plane in an effort to improve rejection of multipath reflections from the radio reflective surfaces of adjacent rolling stock. Additionally, the Zephyr Geodetic was though to minimize the influence of strong magnetic fields generated by the locomotives traction motors. This antenna performed well previously on the Norris Yard survey (Szwilski et al.).

The antenna height above the top of the rail was then determined by measuring the top-of-rail elevations with an antenna attached to a 2-meter range pole. Subtracting the 2-meter pole height, and averaging the elevations from both rails to determine the theoretical centerline top-of-rail elevation. An elevation was measured from the antenna mount on the roof of the locomotive, with the elevation difference between the top-of-rail and locomotive mounted GPS phase center providing the height of the locomotive mounted antenna above the theoretical centerline top-of-rail. This value is subsequently entered as the elevation offset in the survey controller. Observations recorded by the survey controller are then automatically corrected for the height of antenna offset, producing the centerline top-of-rail elevation. After the roving antenna alignment is complete, the locomotive antennas and receiver cables are connected and secured to the locomotive roof. Finally, the survey controller data port is connected to the receiver output, and the roving receiver initialized with the base station.

The yardmaster provides the authority for track movement across the yard. This survey started at the hump, with the locomotive progressing through the main retarder, to the group retarder. The engine was stopped before each track switch in order to configure the survey controller with the point naming convention described later. The survey controller automatically measures, records, stores, and increments data points at a programmable interval. In the case of the IHB survey we used a nominal 10-foot point density. The survey of the track progresses through the group and track switches and into the bowl at the maximum yard speed of 10 mph. Approaching the pullout end of the yard, the locomotive is stopped adjacent to the entrance and exit of the pullout-end inerting retarder and the location marked in the controller. The locomotive clears the exit switch on the ladder and the switches thrown to align the locomotives movement into the next track. The survey progresses as previously describe, with the direction from pullout-end to hump end.

We encouraged the practice of using the yard/survey locomotive to push or pull cars in the bowl on the tracks that were being surveyed. This activity has no discernable effect on the quality of the survey data, and greatly improved the opportunity to run through tracks that were occupied by cars. This small functional capability provides a tremendous advantage in efficiency, and is only available to a locomotive.

5.7 Results

The IHB survey a resulted in the completing of 41 out of 42 track centerline elevations at ten foot intervals, recording some 9,000 shots in two twelve hour shifts. Supplemental data is associated with each point.

- ☐ Point name
- ☐ Feature code
- ☐ Date and time
- ☐ Horizontal accuracy
- ☐ Vertical accuracy
- ☐ Number of satellites visible
- ☐ Position Dilution of Precision (PDOP)

Other point feature names were coded by type and yard reference.

- ☐ Centerline Top-of-rail with feature code "CL"
- ☐ Lead (eg: name prefix 1Lxxx, 2Lxxx, ..., 6Lxxx)
- ☐ Track (eg: prefix with 1/xxx, 2/xxx, ... 44/xxx)
- ☐ Point of switch feature code (POS)
  - o Point name POSxx
- ☐ Point of frog (POF)
  - o Point name POFxx
- ☐ Main and Group retarders, feature code (RET)
  - o Area of retarder outlined by surveying static corners
    - ▪ Point name (eg: name, M = main, G = group + number
    - ▪ Point = a thru d for corners

- ☐ Pullout end retarders, feature code (RET)

Spatial data was collected in projected Cartesian coordinates, referenced to the US State Plane, Illinois East coordinate system. Elevations were referenced to the 1983 North American Datum (NAD83) using the 2003 Geoid model for the continental United States (CONUS). Measurement units of length was US Survey Feet.

A maintenance day with no rolling stock transiting the yard, afforded an opportunity to safely measure point features on the ground without the requirement to spike switches or post a watchman/lookout. The static points of interest include:

- ☐ Point of frog
- ☐ Point of switch
- ☐ Main and group retarder inlet and exit

Benchmarks were placed on both ends and in the middle of the yard to provide position and elevation references for later surveyors. The monument coordinates were determined with a Trimble R8 receiver, 2-meter range pole and survey controller.

A search was conducted to tie existing National Geodetic Survey (NGS) marks with the yard monuments. Of the two possible NGS marks within 5 miles of the yard, both marks were found to have been obliterated by new construction or demolition. Our findings for these marks were reported to the NGS database.

5.7.1 Processing and Organization of the Survey Data

Survey data was downloaded from the Trimble TSCe survey controller using Microsoft ActiveSync and Trimble Data Transfer software. The survey data file was opened with Trimble Geomatics Office (TGO) and the data distributed into different layers for further manipulation.

- ☐ Retarder
- ☐ Centerline
- ☐ Tracks, 1 through 44
- ☐ Control Points

☐ Hump

☐ Leads

☐ Point of Switch

☐ Point of Frog

TGO is programmable to manipulate data in response to a feature code associated with a particular point. This functionality was used with the centerline points to create the centerline artwork. Essentially, TGO 'connects the dots' sequentially between point data to create a line feature. It is possible to code point data for curve features and have the software draw curves between coded segments, however no experiments have been performed during a locomotive survey to develop this feature in practice.

The observations from the base station are retrieved from the storage card and converted from a Trimble proprietary compressed format to a *.dat file. A Trimble conversion utility then converts the *.dat format to a industry standard Receiver INdependant Exchange (RINEX) format. The resultant RINEX data is uploaded to the National Geodetic Survey's Online Position User Service (OPUS)[28]. A minimum of two hours worth of data is suggested by the NGS. The uploaded RINEX file containing the base station observations is processed by the NGS using observations from NGS continuously operating reference stations (CORS) surrounding the survey location. A position report fixing the base station location is emailed to the user. The example NGS OPUS report contained in Appendix B determine the RMS accuracy of the base station control point was determined to 1.5 cm. This position is used to correct the initial base station position. Since the survey data is recorded as vectors from the base station, the point positions are recomputed from the corrected base station position. Point quality data is also collected during the survey and can be mapped as in the ***Vertical Data Analysis*** section.

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[28] http://www.ngs.noaa.gov/OPUS/

The corrected data was then exported as a shape file for import into ESRI[29] ArcMap. The line work was exported as an AutoCAD *.dxf file.

A color code was assigned to survey point elevation, and a color-coded rail elevation map was produced. The track centerlines are superimposed on the point colors to aid in determining track number.

An AutoCAD version of the survey data was also produced using the export function of Trimble Geomatic Office. All the information was copied, and committed to optical media. The media was sent to TranSystems for further engineering and construction estimating.

5.7.2 Data Storage and Dissemination

Several web-based technologies for disseminating engineering information derived from survey data were explored. For this project, the data was exported from Trimble Geomatic Office as series of shapefiles. These files were used to create survey results over layers. ESRI AcrIMS server and ERMapper were integrated to provide a responsive web image and data server. The survey data layers were superimposed over aerial imagery to provide a rich geospatial view of the project results.

These technologies require that specific plug-ins be associated with the target web browser. In this case, the target browser was Microsoft's Internet Explorer version 6. Difficulties arise for industry users that do not have sufficient privileges to install the required browser plug-in. The railroad industry is particularly slow to adapt new technologies, however this characteristics applies to information technology initiatives in a variety of government and industry segments. Most industries have experienced management exhortations to "think outside the box", however education, training, and corporate culture conspire to define the box, its size and shape, and the consequences of working outside its confines. Many times

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[29] Environmental Systems Research Institute, Inc.

experimental technologies are not perceived as adding sufficient value to warrant additional support by the IT department. In this case, the required browser plug-ins were not able to installed by targeted users so the results were not generally available for viewing by those that could use the information.

5.7.3 Vertical Data Analysis

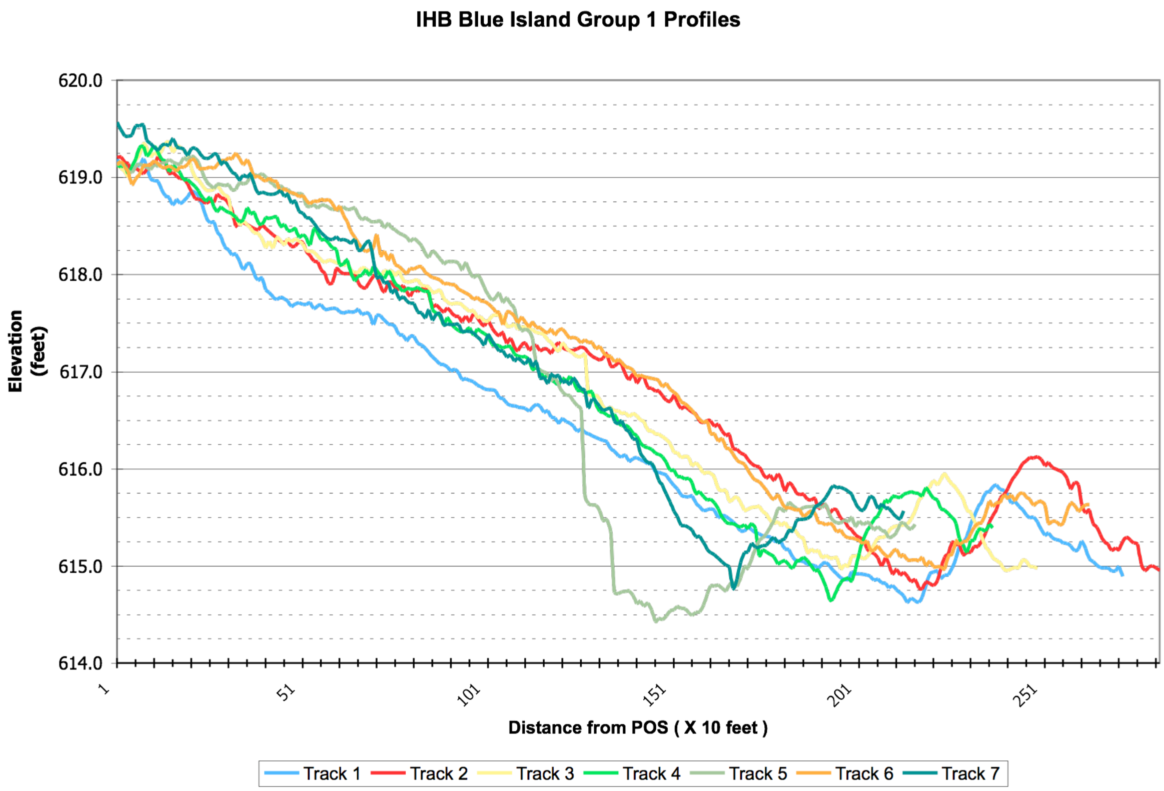

Figure 5-5 Blue Island Yard Profiles

A view of the profile of tracks 1-7 created with Excel Chart illustrates the different track lengths as well as profile variations. The track length starts at the point-of-switch (POS) track entrance and ends at the POS at the track outlet. Relative differences in grade are evident in this simple analysis.

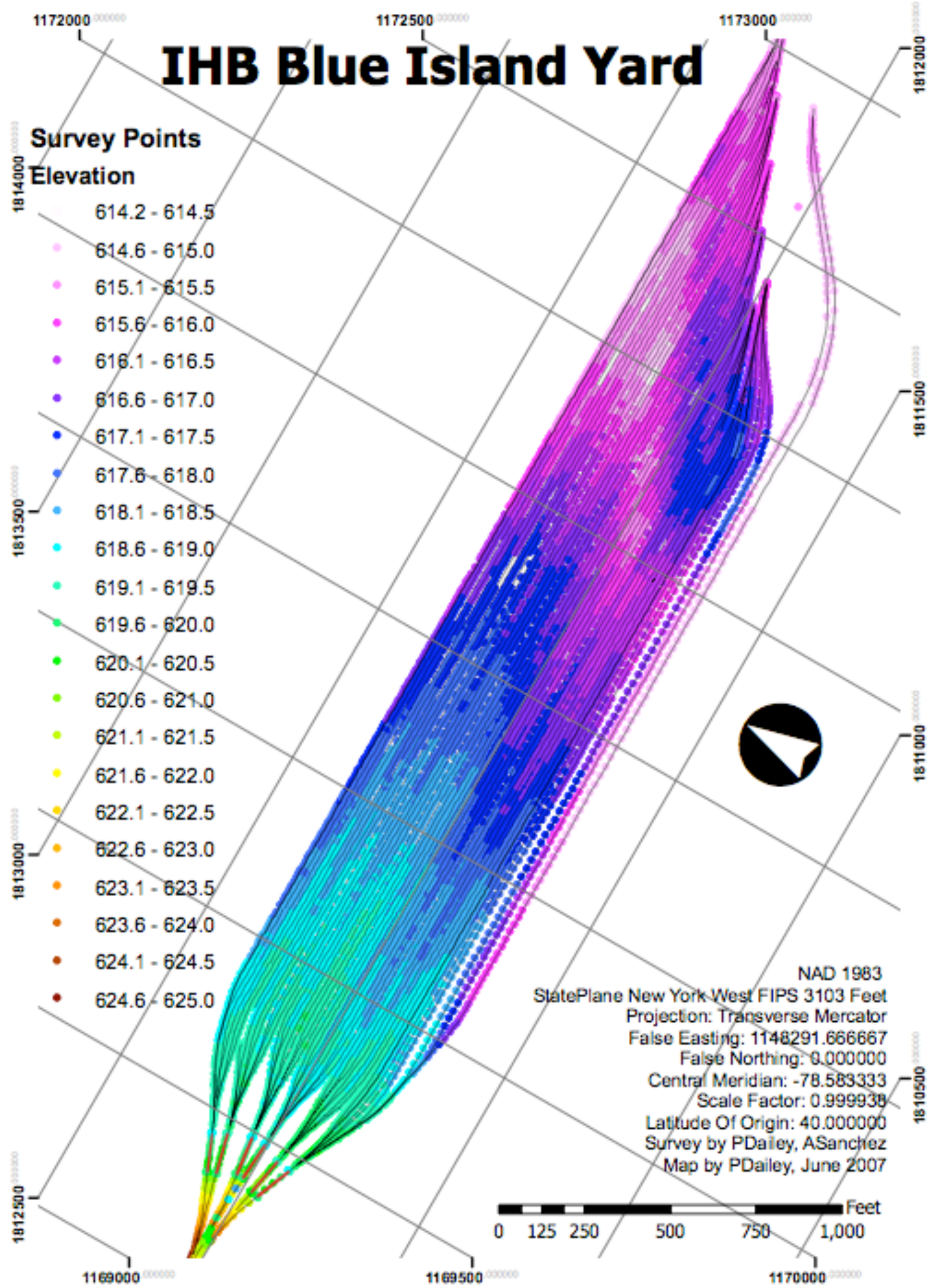

Figure 5-6 Color-coded elevation map of the Blue Island Yard

5.8 Conclusions

The IHB Blue Island Yard survey was completed in three twelve-hour days, and collected some nine thousands data points on a nominal 10-foot spacing. The cooperation extended by management and the train crews of the IHB was a key factor to complete the survey quickly and efficiently. The IHB dedicated a single locomotive to the project and authorized crew overtime to accommodate our twelve hour shifts. A superior finished product offset the additional cost of overtime.

A color-coded elevation map of the uncorrected survey data was produced in the evening after the conclusion of the survey with Trimble Geomatic Office and ESRI ArcMap. An Adobe Acrobat file was produced from the output of ArcMap. During a visit to TranSystems' Chicago office the next day, the elevation map was provided to the company's engineer and output to a D size plotter. The elevation map gave their transportation engineers an immediate preliminary data set for review. It also provided immediate verification of the validity of the novel survey technique.

Office work at the Rahall Transportation Institute consisted of filtered the data for error and creating the centerline artwork. Delivery of derivative information products to TranSystems Company included: track centerlines in dxf (AutoCAD) format; a complete shot list in xls (Excel) and shp (ESRI shape file) format. The ESRI file contained attributes for each point:

- ☐ Northing, easting, elevation
- ☐ Point name
- ☐ Point feature code
- ☐ Date and Time
- ☐ Number of GPS satellites
- ☐ Position Dilution of Precision (PDOP)
- ☐ Horizontal accuracy
- ☐ Vertical accuracy

Transystem reported that the top of rail elevations were used in developing engineering estimates related to resurfacing of the yard.

Distribution of spatial engineering information derived from surveying data over the Internet can provide needed information to a wider audience without traditional paper document control measures. It also provides the opportunity to expand or limit the data available to a particular user or group.

A limited method of information distribution was developed using ESRI ArcIMS and ER Mapper Image Server. ArcIMS provides the over layers containing survey data, derived line work, and provides a user with the ability to calculate grade between any two points on a track on demand. Image Server provides a background of high-resolution aerial imagery quickly and efficiently. This method of distribution is effective, providing the survey and derivative data on demand with a click of the mouse. However, difficulties has risen in organizations where computer users are prevented from installing the needed browser plug-ins.

6 Case Study: CSX Boyles Yard

Survey conduced February 7-9, 2007

CSX Transportation, Boyles Yard, Tarrant Alabama

Configuration: 5 x 8 Automatic Classification Yard, 40 tracks

RTI survey party: Peter Dailey, Alejandro Sanchez

Nominal point density/total data: 10 foot / 6,801 points

6.1 Executive Summary

In 2006, CSX Transportation and the Rahall Transportation Institute (RTI) developed a working relation to leverage FRA funded research performed at RTI for use in rail operations. The Boyles Yard, located north of Birmingham Alabama in the town of Tarrant and commissioned in 1957, is a 40-track hump yard. The purpose of the survey was to provide top-of-rail elevations to aid in defining track profiles and to demonstrate the safety, speed, and accuracy possible by using a locomotive as a survey platform. This unpublished case study details survey data collection and processing procedures incorporating lessons learned from both the Norris and Blue Island Yard surveys.

6.2 Introduction

This effort duplicated the hardware and data collection methodologies of the IHB survey. A more efficient method of aligning the GPS antenna to the locomotive was developed.

6.3 Problem Statement

This survey effort was a demonstration for CSX Humpyard engineering management. Previous discussions over performing a humpyard survey for CSX had stumbled over the efficacy of using a locomotive as a survey platform. However, the benefits seemed too good to ignore, and a research project was undertaken to profile the Boyles Yard north of Birmingham, Alabama.

6.3.1 Data Collection, Processing, Storage, Dissemination

Equipment setup and procedures where almost identical to the IHB survey, except for a change in the antenna location and calibration procedure. Instead of using a theodolite to align the locomotive antenna, a point was chosen on a straight section of rail. The centerline of the rail was measured with a tape, and the center point was measured with the static survey module. Another point several hundred feet away was similarly measured. The locomotive was moved to approximately between the two center points. A line was drawn in the survey controller connecting the two points, creating a centerline for that piece of track. The static survey module was taken to the roof of the locomotive, and maneuvered until the range pole intersected the centerline. The point of intersection was marked on the roof of the locomotive and the magnetic mount centered over the intersection.

Determination of height above the theoretical centerline top-of-rail elevation proceeded as described in the IHB survey.

6.3.2 Data Collection Methodology

Data was collected in the same fashion as the IHB survey. CSX hired a local survey crew to collect the point of switch and retarder elevations, so it was necessary to tie into the control points set by the local surveyors. During the data reconciliation process between our data and theirs, the elevation closed to within a tenth of a foot over the length of the yard.

Figure 6-1 Remote locomotive control unit

Boyles Yard uses remote control locomotives. A remote control locomotive employs two trainmen rather that the traditional engineer and conductor for locomotive control and manual switching functions. With each trainmen is a radio control unit that allows the pair to "pitch and catch" control of the locomotive between them. The remote control allows the trainmen to travel on the ground providing the crew the ability to throw switches, observe coupling distances, and decoupling cars from ground.

Remote control operation of a locomotive allows a railroad to use the lower pay classification as trainmen rather than engineer. A trainmen classification requires only a month or so training on locomotive operations. Trainmen are not permitted to touch the locomotive's controls, and are only permitted to use the radio control unit. Trainmen are generally younger with less experience in locomotive and yard operations.

During our twelve-hour shifts at Boyles, we found that the break between the trainmen's eight-hour shifts created the added burden of explaining and training each crew with what we were doing and how the survey was conducted. To our dismay, we found the younger trainmen unwilling to put any effort into communicating with the yardmaster to move the survey locomotive through the yard. Consequently, there were periods of two or three hours when the locomotive simply did not move. In an effort to take advantage of every opportunity to complete the survey, we stayed on-site enduring a final 21-hour shift. This proved another critical feature of this survey method, namely the ability to survey at night and inclement weather.

6.4 Data Storage and Dissemination

Data point naming convention was similar to the IHB survey. However, after the IHB, we found that Trimble Geomatic office does not recognize non alpha-numeric characters in the point search, with the result that sorting the tracks into individual layers took longer to accomplish than anticipated. The updated naming convention for track points uses a leading alpha character, two digits for the track number, a zero as a pad or to denote different 'runs', with the final three digits a sequential count of data points. For example: T090174 represents track 9 point 174.

The updated numbering scheme enables a rapid way to select entire tracks in the Geomatics software. In the example above, all the points in track 9 are selected by using the point select command and entering the search term "T090*". By separating the track data into layers, individual track data is selected and exported. As described in the IHB survey, a variety of export data types are available. With this naming convention, much of the track separation was performed during the drive back to West Virginia.

Comma separated values and ESRI shape file are the most common file types for downstream engineering users. Alterations to web-based distribution described previously replaced the ERmapper engine and ESRI IMS with a combination of asp and .Net web services along with publicly available lightweight GIS from Yahoo or Google.

6.5 Results

The survey results are represented on the color-coded elevation map in Figure 6-1. Centerlines developed from the survey data point is superimposed over the elevations to aid in visualization. This representation is replicated in the web-based presentation of results.

Additional representations of the quality of the survey are possible using the same graphic. Illustration 6.2 represents the vertical precision of the GPS data in feet. Representing the quality of the elevation profile can aid in making engineering judgments on the value of the data. The vertical precision illustration in 6-2 indicates that survey point precision varies with satellite availability and position, factors that vary with the time of day. This characteristic is evidenced as continuous strips of color. A continuous strip of red indicates low quality precision in the 25 to 30 hundreds of a foot range. The strip indicates the points were collected during a run down a track over a brief period. This diagram is useful for judging the overall quality of the survey results, as well as the quality of individual track profiles.

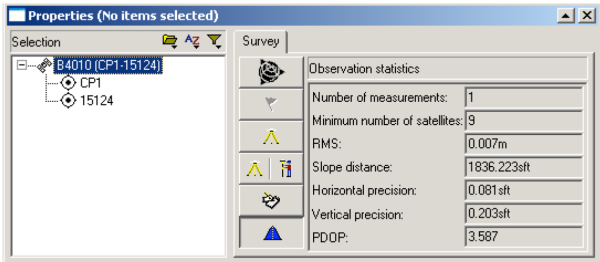

Figure 6-2 Observational statistics

A close examination of an individual low vertical accuracy point can serve to illustrate several elements of GNSS surveying. The occupation detail in Figure 6-3 provides basic information on point 15124. From our numbering sequence, this was point 124 measured on track 15. The measurement was taken on 8 Feb 2007 at 15:10:20, and the antenna height above the centerline top-of-rail was 16.146 feet. Observational statistics in Figure 6-2 indicate that nine satellites were

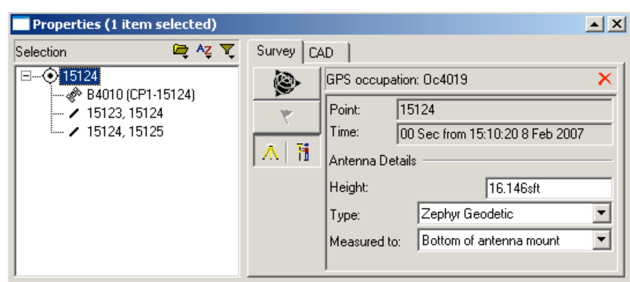

Figure 6-3 Occupation detail

in view, with a PDOP[30] of 3.6. The horizontal precision calculated by the survey controller was 0.081 feet with a vertical precision of 0.203 feet.

In analyzing why the vertical precision decreased for a brief period, the information from the point observation is compared to the PDOP calculated by the Trimble Planning utility. The Planning utility helps plan and schedule GPS field sessions to determine suitable conditions for GPS surveying.

Mission planning is used in the first phase of managing a GPS survey project to define all significant geometric aspects in order to maximize effectiveness and efficiency. Trimble recommends using the Planning utility to insure "*that at least four satellites will be available to gain a known-point initialization, and that five satellites will be available to gain an on-the-fly initialization.*"

Analyzing PDOP values during the anticipated period confirms satellite geometry is suitable for the desired accuracy. However, running the locomotive on available tracks as opportunities permit not leave the surveyor an opportunity to choose the optimal date or time. In the case of point 15124, the dilution of precision predicated for the period suggests that satellite geometry is responsible for lower quality vertical precision for a brief period from 1500 to 1600 hours. A PDOP upper limit of 6 is the upper limit for RTK work. This value is programmed into the survey controller to prevent poor quality data (PDOP > 6) from being recorded. A PDOP value of 3.6 for point 15124 is acceptable for RTK work. As is evident from Figure 6-2, the horizontal precision for this point is excellent.

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[30] Position Dilution of Precision: GPS ranging errors are magnified by the range vector differences between the receiver and the SVs. The volume of the shape described by the unit-vectors from the receiver to the SVs used in a position fix is inversely proportional to PDOP, that is, the greater the volume defined by the range vectors, the more accurate the fix and the lower the PDOP.

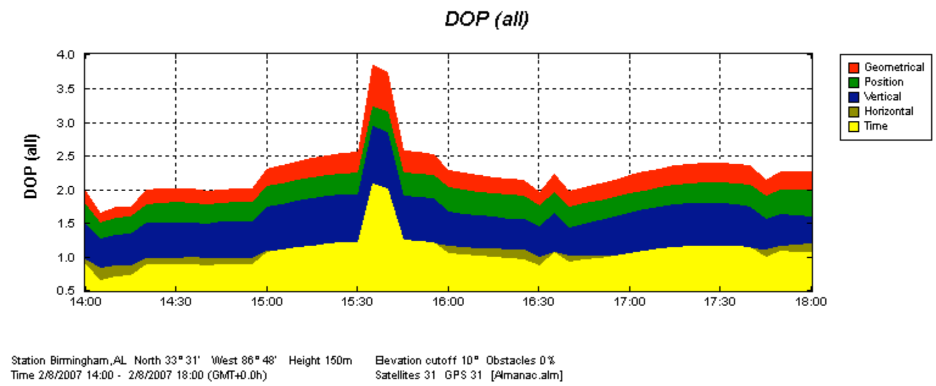

Figure 6-4 Combined Dilution of Precision Chart

The Planning utility can be used pre-survey to visualize and predict satellite availability through tables and graphical representations experiment with satellite selection, almanacs, time zones, site visibility obstructions, and elevation masks determine the best observation periods for a session, given necessary constraints on PDOP and on the hours during which the crew can work.

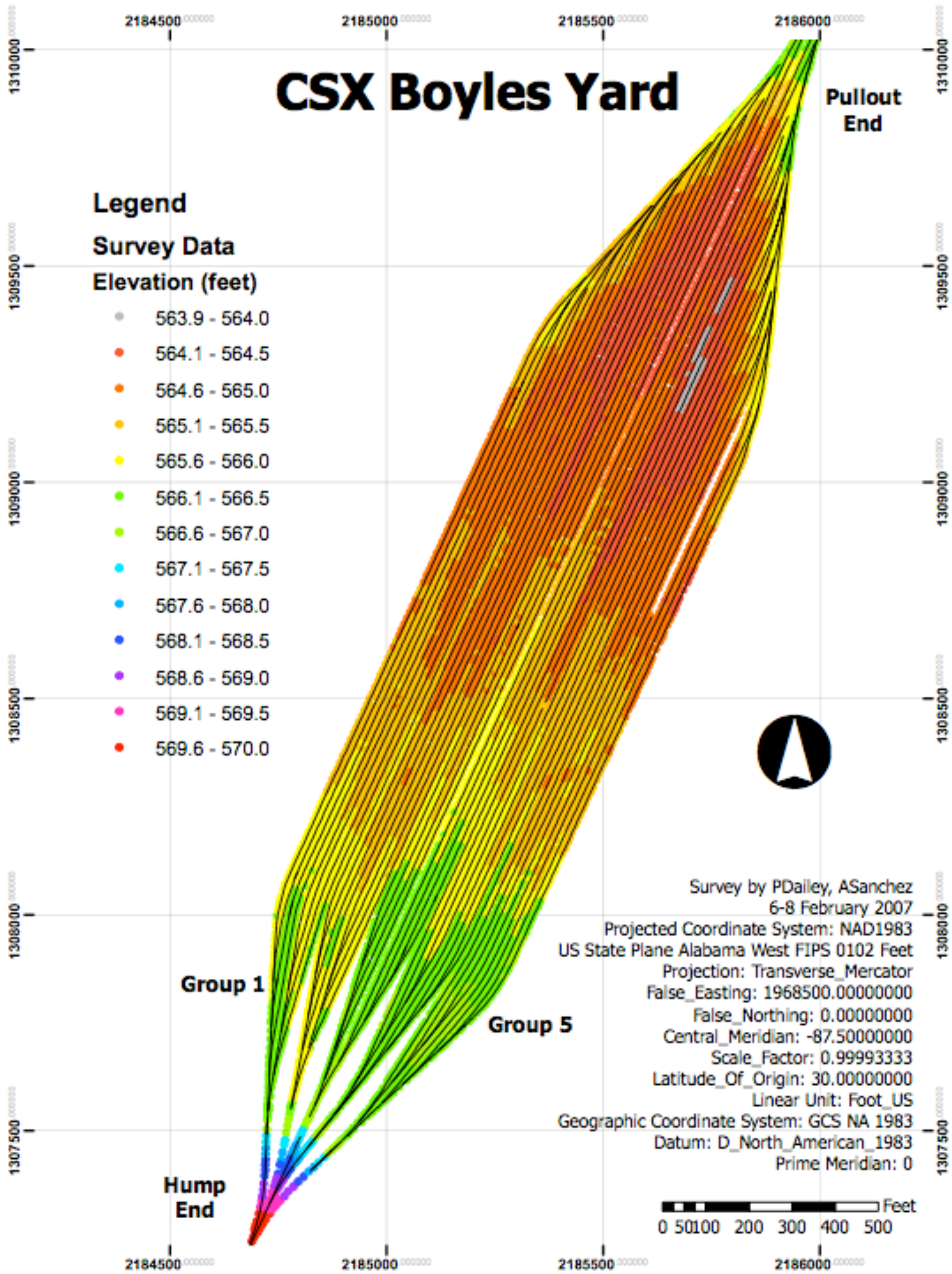

Figure 6-5 Color-coded elevation map of the Boyles Yard with centerline overlay

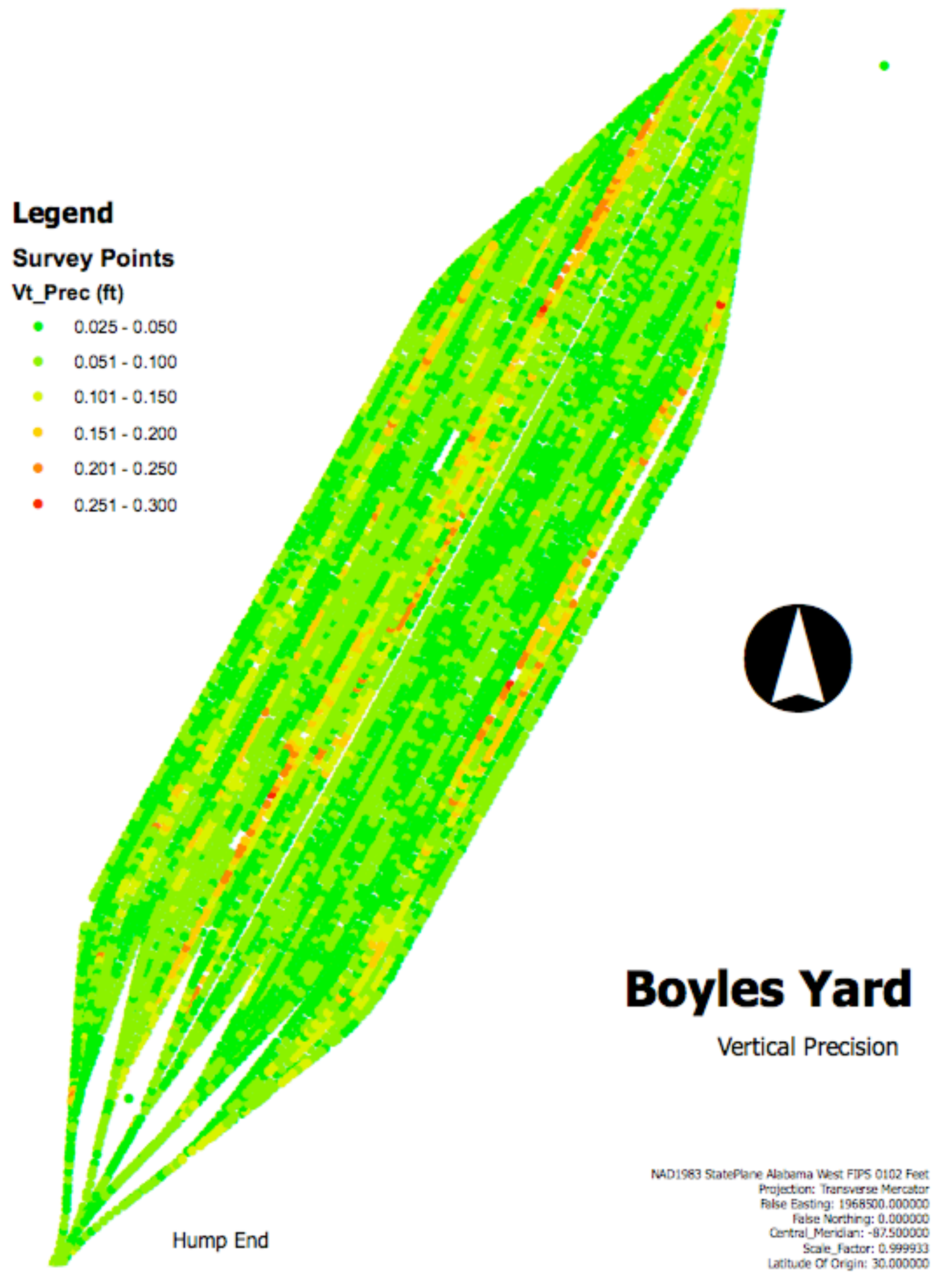

Figure 6-6 Color-coded map of survey point vertical precisions

7 Case Study: CSX Frontier Yard

Survey conduced May 15-18, 2007

CSX Transportation Frontier Yard, Buffalo New York

Configuration: 7 x 9 Automatic Classification Yard, 63 tracks

RTI survey party: Peter Dailey, Zhibin Sheng

Nominal point density/total data: 10 foot / 32,652 points

7.1 Executive Summary

The purpose of the survey was to provide top-of-rail elevations to aid in defining track profiles using a locomotive as a survey platform. This unpublished case study details survey data collection and processing procedures incorporating lessons learned from the Norris, Blue Island, and Boyles Yard surveys.

This survey used a slightly modified equipment configuration and data collection procedures than described in previous surveys.

7.2 Introduction

The Frontier Yard, located on the eastern boundary the city of Buffalo New York, is a 63-track automatic classification yard. Designed and constructed in 1956, the Frontier Yard was put into service in 1957 and featuring the first "automatic" control system in North America. The control system incorporates relays for logic and vacuum tube analog circuits for speed control. Remarkably, due to the meticulous maintenance and spares foresight attributable to maintainer Ron Szymanek, this yard continues to operate with almost exactly the same control system as originally installed in 1956. The only difference between the initial installation and current practice has been the replacement of H-band radar with X-band speed sensors (Szymanek). The control system is completely constructed with discrete circuit elements. It is a remarkable achievement that no transistors or silicone control devices of any kind have been grafted into the control scheme in fifty years of continuous operation.

With a still functioning but antiquated control system, CSX has chosen this yard for a complete overhaul, from resurfacing to hump control.

7.3 Data Collection, Processing, Storage, Dissemination

This project differed in significant ways from previous efforts. The most evident was the expanded scope from previous efforts. The Frontier Yard is a 7 x 9 configuration with tracks to 5,000 feet in length. The primary survey objective was to profile the bowl area, but a secondary objective was to survey all the yards track and assets. The secondary objective provides data for a detailed GIS with derivative products such as topographic mapping to provide information for use in environmental management incidents, such as hazardous spill containment planning.

A survey of the primary objective produced 22,371 data points. The secondary objective added 10,222 points for a total of 32,593 shots for the 3-1/2 day effort. The nominal spacing between points was maintained as in previous humpyard surveys at ten feet. The increase in the volume of data coupled with an active disregard for the established naming convention by one of the attendant surveyors added significant post-processing time to the dataset, delaying data availability for railroad design engineers.

Figure 7-1 GPS and UHF antenna on commercial magnetic mount.

A subtle but significant change in hardware was made to the locomotive survey antenna. The high-end Trimble Zephyr Geodetic antenna with integral ground plane was replaced by a standard Trimble Geodetic. The Zephyr Geodetic was originally chosen to counteract perceived GPS reception problems due to intense magnetic fields identified surrounding a diesel-electric locomotive (Bertran and Delgado-Penin). The Zephyr is lighter and therefore less susceptible to the continuous vibration present on a locomotive. It is also less costly. In this application there were no perceived differences between the standard antenna and the high-end model.

7.3.1 Data Collection

The Trimble TSCe2 survey controller was used for data collection. This updated survey collector replaced the TSCe used in the Norris and IHB surveys. The faster processing speed and external memory capabilities overcomes the limitations of the TSCe experienced in the IHB survey.

Data collection during the IHB was interrupted or 'stalled' with several thousand data points in memory. Preceding the stall, data point collection stalled, indicated by a change in the frequency of the sound generated after the collector stored a point. Further, the older TSCe runs the Windows CE operating system, has a shorter batter life, and requires a specialized computer interface adapter in order to download data. The newer TSCe2 eliminated those problems with a faster processor and an interface to standard external memory devices such as Compact Flash, USB, and Secure Digital memory cards. The TSCe2 also incorporates a higher capacity, easily replaceable battery pack for extended.

The human interface to data collection hindered the post-survey processing. The first day of the survey was spent aligning the locomotive antenna and surveying the outlying tracks in the north arrival/departure yard. The area outside the bowl was part of an asset management survey to develop topographic maps for understanding the yard drainage. This information could be used to develop a response in case of a hazardous materials spill.

The few tracks surveyed on the first day were named and numbered according to the previously described collection plan. Unfortunately, the surveyor assigned to the locomotive during the next four days was asked repeatedly but refused to follow the naming and numbering convention due to a lack of understanding of the down stream use of the data and believing a numbering scheme was not useful. As a result, post processing the data – separating tracks into layers in preparation for export – turned into a tedious, labor-intensive process consuming an additional 60 to 80 person-hours of office work. If the naming convention had been in place, the separation process would only have required six to eight hours.

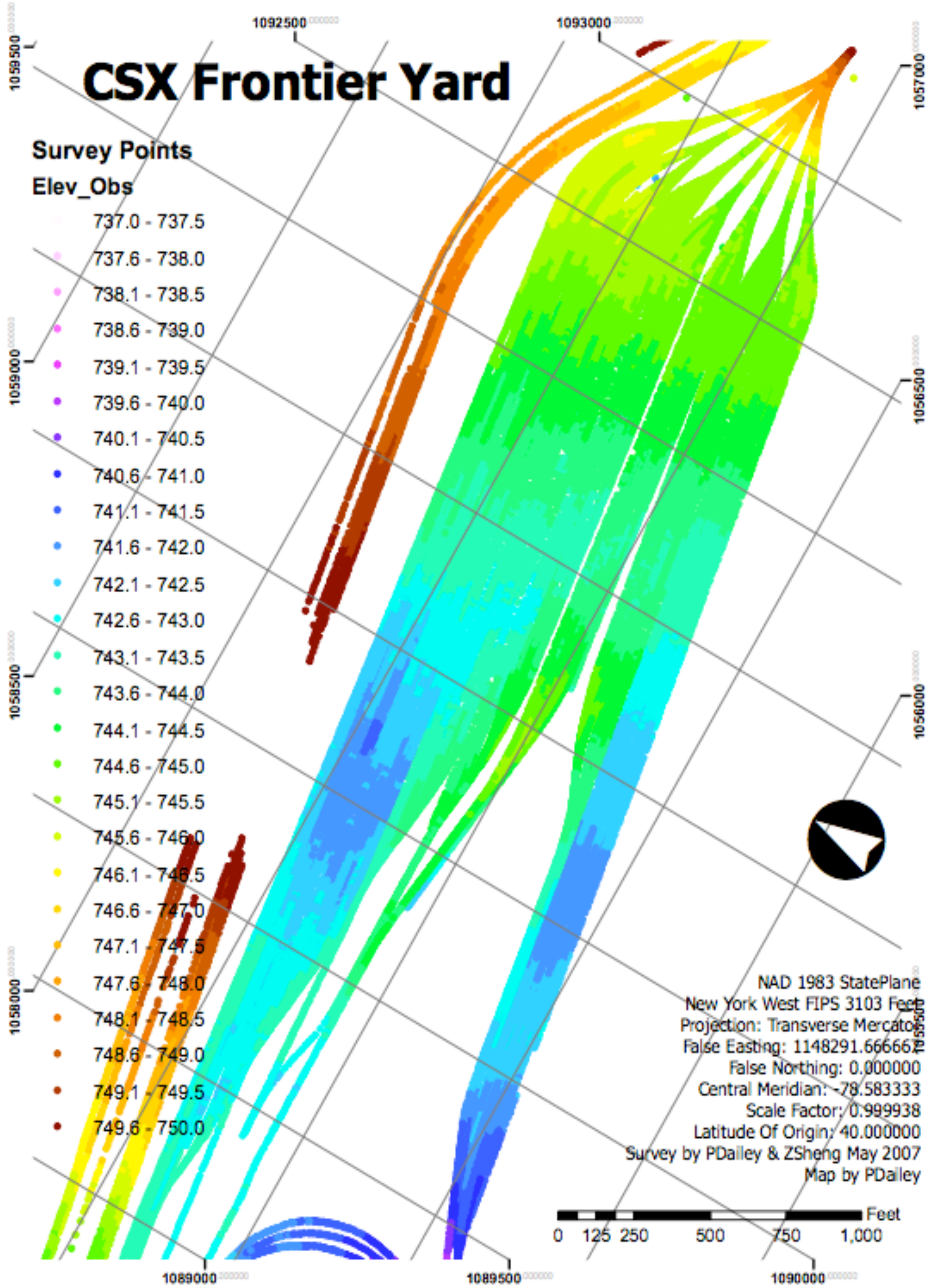

Figure 7-2 Frontier Yard Color-coded elevation map

8 Conclusions

The method described has proved to be an effective process in providing a safe, efficient, and relatively inexpensive method for measuring grades and mapping rail centerlines in humpyards.

Further, a typical locomotive weighs 14 tons and provides a gravity load to the rail without the need to simulate rail loading as required in 49CFR Part 213.110 "Gage Restraint Measurement Systems". A loaded rail measurement provides insight to the track substructure condition, a measurement not as effectively simulated.

Further refinements would integrate the use of a two-axis inclinometer for incorporating grade and cross-level (pitch and roll) measurements increasing the positioning precision as well as providing a more detailed track geometry.

Further research initiatives would examine using regression for developing a "track roughness index" for comparing the magnitude and frequently of rail deviation. A combined analysis of track irregularity and analysis of dynamic response of rolling stock to the irregularity provides a method for determining the friction effects of track. Track friction is directly related to horsepower consumption of the locomotive.

Additionally, the use of a locomotive to survey line-of-road by employing a network of CORS[31]. A network of CORS offers the opportunity for long baseline surveys by providing continuous corrections to a roving receiver mounted on a locomotive in either of two ways:

- Using corrections from the nearest stations. Stations are automatically changed as the rover moves away from a station and closer to the next.

[31] Continuously Operating Reference Stations

- Integrating a Virtual Reference Network composed of CORS connected to a central server running modeling software capable of creating virtual reference stations in reaction to error growth (ppm error).

Additional opportunities in developing a complete inventory of mainline assets could incorporate infrastructure management methods from highways:

- ☐ Integrate cameras for asset management along rights-o-way.
- ☐ Integrate other geophysical inspection tools such as ground penetrating radar or electromagnetic inductance with the locomotive.
- ☐ Developing a high-precision reference map for line-of-road segments providing the initial step in the location accuracy needed in implementation of automated train control.

9 Appendix A: Evaluating a Remotely Mounted GPS Antenna to Measure Rail Track Irregularities

9.1 Problem Statement

Traditional rail surveying is time consuming and dangerous. A surveyor competes for track time with production equipment, resulting in relatively few opportunities for clear track access. Dangers appear from many sources requiring personal protective. Further, on-track work of any kind is regulated by the "Railroad Workplace Safety" provisions of 49 CFR part 241.

A piece of rolling stock as a survey platform, combined with suitable GNSS survey system may offer a significant advantage for safely and quickly surveying rail.

9.2 Objective

The experiment was performed to compare the response of a survey grade GNSS antenna attached to a Hi-rail with an antenna mounted in direct contact with the rail. Two mounting methods are compared; 1) an antenna in direct contact with the top of rail using a conical roller to center the mount, and 2) an antenna mounted to a roof rail of a Hi-rail using modified running gear.

The survey grade GNSS total station used in this experiment has a manufacturer's claimed horizontal accuracy of ± 1 cm and a vertical accuracy of ± 2 cm. Comparison of an antenna mount in direct contact with the rail to a remote location fixed to a rail vehicle provides a method to quantify the response of a remotely mounted antenna in measuring track irregularities.

Experimental results provide and indication of whether a Hi-rail equipped vehicle or a locomotive may be capable of acting as a track survey platform.

9.3 Date and Location

10 August 2004, Operating Rule 704 authority number 32020 employee in charge J.E. Cullen held by CSX Roadmaster Rodney VanPelt to access Bluejay to Lesage block of CSX mainline track from 11:47 to 14:30, near Guyendotte West Virginia, CSX mile marker 208.

9.4 Hardware

A Chevrolet Suburban with Fontain Hi-rail gear was modified by a certified inspection shop. The modification objective was to force the starboard side wheels to maintain contact with the gage side rail. The port side rear flange was determined to be the most advantageous contact area to minimize the opportunity for derailing the Hi-rail. The starboard side wheels were aligned with no offset. The port side rear wheel had 1/8" toe-in applied to force continuous contact between the starboard wheel flange and rail.

Welding a tube to accommodate a clamp mount for the GPS antenna modified an arm manufactured by Portec Rail Products, Incorporated[32]. The Portec arm employs a roller in constant contact with the top of rail. Conical ends of the Portec roller keep the assembly centered on the rail. The design of the roller and arm assembly allows transiting track structures such as switches and frogs without danger of roller derailment. The Portec arm and GPS antenna mount is illustrated in Figure 9-1. The modified Portec device provided a convenient solution for maintaining continuous rail contact during a long baseline survey. Other less satisfactory methods of mechanically maintaining rail contact are discussed in the author's previous experimental results (Szwilski, et al.).

The Portec arm although convenient, is less than ideal for HADGPS rail surveys, as the low mounting position (49.5 cm from top-of-rail) impedes a clear

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[32] A supplier of railway friction management systems based in Huntington, West Virginia

view of SVs when the Hi-rail is positioned between the antenna and one or more SVs. To address possible satellite dropouts, a section of mainline tangent track was identified that allowed a clear presentation of SVs to the Portec mount.

A Trimble Geodetic antenna mounted to a tubular rack on a Hi-rail as illustrated in Figure 9-2 provided the remote mounting configuration. The antenna was positioned over the gage side of the starboard rail using a transit at an elevation of 2.354 cm above the top-of-rail. Alignment was accomplished by setting up a transit over the gage side edge of the starboard rail. A back sight to a point on the gage side edge of the rail was observed several hundred feet away. A foresight to the GPS antenna aligned the antenna phase center with the gage side of the starboard rail. The antenna position was adjusted by moving the antenna along the instrument rack. This alignment provided a physical point of reference between the antenna and rail.

An ad hoc GPS base station, model 5700 receiver with a Zephyr Geodetic antenna, was configured and set up. Corrections were transmitted through a Trimble Trimmark III data radio to the roving receiver in the Hi-rail.

A Trimble TSCe survey controller was used to record in continuous topographic mode as described in ***Data Collection and Processing***.

9.5 Illustrations/Photos

Figure 9-2 Hi-rail GPS and UHF Antenna Roof Mount (Dailey 2004a)

Figure 9-1 Portec GPS Antenna Mount (Dailey 2004c)

Figure 9-3 GPS Antenna Alignment (Dailey 2004b)

9.6 Data Collection and Processing

Two runs on a 1500 meters section of mainline tangent track were performed for each antenna position. A Trimble TSCe survey controller recorded position data. The controller was programmed to collect a topographic point every meter. The Hi-rail was driven at a constant 6.7 m/sec (15 mph). The data were downloaded from the survey controller into the Trimble Geomatic Office (TGO) software.

The controller was programmed to record natively using the Universal Transverse Mercator zone 17N projected coordinate system and included the use of Geod03, CONtinental United States (CONUS). Unit collection was meters. Vertical datum was North American Datum 1983. The position observations (point name, Northing, Easting, Elevation) were exported from TGO as comma delimited files and imported to Excel for analysis.

Common starting and ending points were selected from each of the data sets. A least squares linear regression of northing vs. distance was performed for each data set. A plot of residuals for each point was constructed, with the result as shown in Figure 9-4.

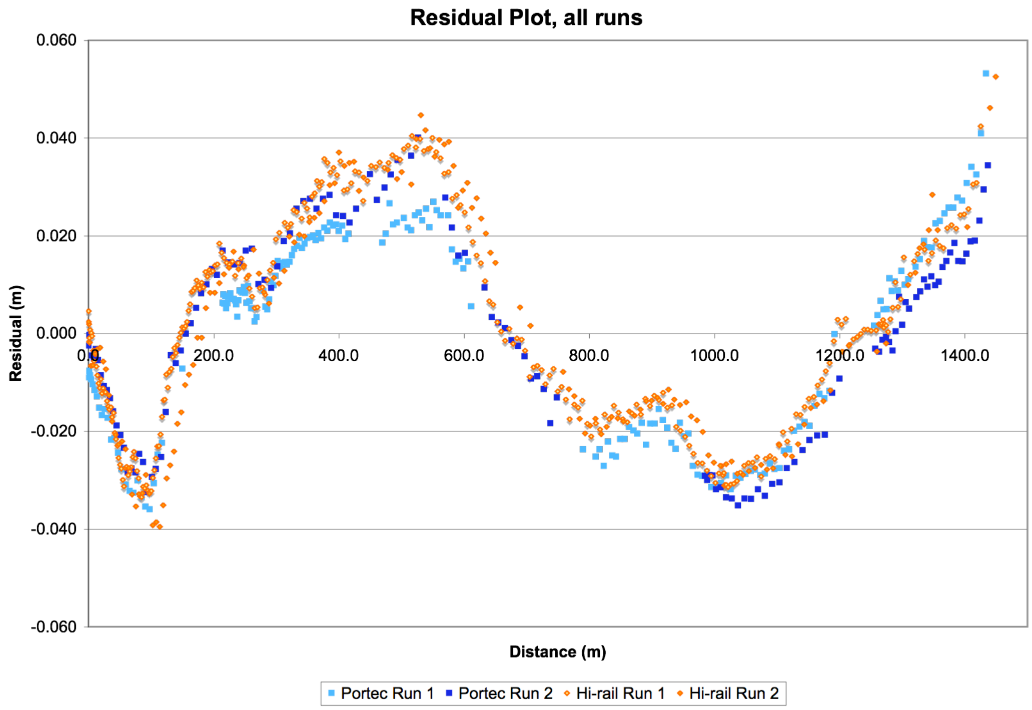

Figure 9-4 Residual plot of track measurements (Dailey 2004)

9.7 Results

A least-squares regression analysis was performed on the four data sets. A plot of the regression residuals graphically represents deviation from a theoretical straight track. Clearly, the four data sets exhibit a close correlation, indicating the extent and magnitude of track irregularities over the 1500-meter section of track. The correlation between the direct measurement from the top of rail (Portec) and those from a roof-mounted antenna are in all cases 2 centimeters or less.

The manufacturer quantifies instrument error as ± 1cm horizontal plus 1 ppm due the base station proximity. In this study, the maximum distance from the base to the receiver was 2 km. The proximity error component contributed 1 ppm in 2 km ($1 \times 10^{-6} * 2 \times 10^{3}$ meters = 2×10^{-3} cm or 0.2 cm).

The measurement error is determined from both the instrument and proximity error, with the root mean square value providing the total horizontal error.

$$\varepsilon = \sqrt{(1^2 + 0.2^2)}$$

$\varepsilon_{horizontal}$= 1.02 cm

The majority of the position differences between direct rail contact observations and the roof mount is within the manufacture's specified 1 cm horizontal error of the HADGPS.

Modifications to the Hi-rail running gear generate concerns about wheel wear contributing to a possible derail while taking rail measurements on active mainline track. A Hi-rail contributes little to the railroad's productivity. Breaking a wheel while on the mainline resulting in a derail fouls the track. A fouled track impedes train movement, as the locomotive must wait for the fouled equipment to be safely removed. In the extreme, a derail on a bridge would imperil the lives of the Hi-rail passengers.

The Rahall Transportation Institute's Chevrolet Suburban has logged several hundred track-miles with running gear modifications without a derailment. Hi-rail movements have been both forward and reverse with no adverse effect. However, wear to the starboard side outboard wheel flanges was evident after a couple hundred track-miles. The wear was determined to be excessive and the port and starboard wheel sets were exchanged, exposing a fresh wearing surface to flange/rail contact.

9.8 Conclusions

The use of a Hi-rail with a roof mounted GPS antenna provides a fast and accurate method for surveying rail location. The four runs over a 1.5 kilometer stretch of CSX mainline track collected slightly less than 1000 points in less than three hours.

Several error sources from an out-of-plumb antenna, from grade and cross-level track elevation differences are not accounted for in this study. Integration of a two-axis inclinometer with the data collector, and applying the necessary algorithms, would provide corrected position locations. The grade and cross-level errors are the same effect as holding a range pole with a prism out-of-plumb while taking a shot with a Total Station instrument. Correction for grade and cross-level allows comparison of the same location between survey platforms with antennas mounted at different heights. With the configuration used in this experiment, comparison of track geometry can be made only with an identical height of the antenna above top-of-rail.

To correct for grade and cross-level errors, certain software used in hydrographic surveys could be adapted to rail surveying. In a hydrographic survey, sonar is used to determine water depth. The pitch and roll of a ship cause the sonar to make out-of-plumb measurements. Pitch and roll measurements from a two-axis inclinometer are simultaneously fed to specialized software integrating RTK GPS measurements and producing a corrected three-axis location. This same software would provide both corrections to the observations, but would also provide a richer set of track data. Cross-level and grade provided a more detailed view of the track geometry, and if incorporated into a locomotive, has the advantage of determining the geometry under actual, not simulated, loaded conditions.

The results of this experiment indicate that rapid, repeatable measurements of rail location can be performed with a Hi-rail with modified running gear equipped with a survey grade GNSS antenna and receiver. This technique could be transferred to any piece of rolling stock. Of particular interest would be an installation of the RTK GPS equipment on a locomotive.

Further derivative research might include mounting a survey antenna to the centerline of a locomotive in order to survey a humpyard. The locomotive would be able to work 'in traffic' with minimal disruption to yard operations. Further, no survey personnel would have to work outside of the locomotive as on-track workers. Limiting the exposure of the surveyor to hazardous environments has proven to be a positive safety and cost benefit in mining and road construction.

10 Appendix B: National Geodetic Survey Online Position User Service (OPUS) Report

```
FILE: 89690384.07o 000075155

                              NGS OPUS SOLUTION REPORT
                              ========================

      USER: dailey29@marshall.edu                       DATE: February 09, 2007
RINEX FILE: 8969038p.07o                                TIME: 15:08:12 UTC


  SOFTWARE: page5  0612.06 master10.pl                START: 2007/02/07  15:33:00
 EPHEMERIS: igr14133.eph [rapid]                       STOP: 2007/02/07  23:58:30
  NAV FILE: brdc0380.07n                           OBS USED: 19755 / 20379   :  97%
  ANT NAME: TRM41249.00     NONE                # FIXED AMB:    95 /    95   : 100%
ARP HEIGHT: 2.0                                 OVERALL RMS: 0.015(m)


 REF FRAME: NAD_83(CORS96)(EPOCH:2002.0000)           ITRF00 (EPOCH:2007.1037)

         X:       297857.233(m)   0.014(m)           297856.546(m)   0.014(m)
         Y:     -5310151.430(m)   0.010(m)         -5310149.964(m)   0.010(m)
         Z:      3508995.209(m)   0.015(m)          3508995.043(m)   0.015(m)

       LAT:   33 35 34.20956      0.007(m)        33 35 34.23205      0.007(m)
     E LON:  273 12 37.70277      0.014(m)       273 12 37.67935      0.014(m)
     W LON:   86 47 22.29723      0.014(m)        86 47 22.32065      0.014(m)
    EL HGT:          143.049(m)   0.016(m)               141.706(m)   0.016(m)
 ORTHO HGT:          172.163(m)   0.030(m) [Geoid03 NAVD88]

                        UTM COORDINATES    STATE PLANE COORDINATES
                         UTM (Zone 16)         SPC (0102 AL W)
Northing (Y) [meters]     3717031.779          398585.600
Easting (X)  [meters]      519528.986          665944.663
Convergence  [degrees]     0.11645242          0.39310993
Point Scale                0.99960470          0.99998693
Combined Factor            0.99958225          0.99996447

US NATIONAL GRID DESIGNATOR: 16SEC1952917032(NAD 83)



                              BASE STATIONS USED
PID       DESIGNATION                        LATITUDE    LONGITUDE DISTANCE(m)
DI1696 MSMR MERIDIAN CORS ARP              N322203.022 W0884356.779  226810.3
DF5876 HAC1 HACKELBURG 1 CORS ARP          N341649.966 W0875121.382  124658.2
AF9571 MLF1 MILLERS FERRY 1 CORS ARP       N320524.917 W0872330.504  175915.2

                 NEAREST NGS PUBLISHED CONTROL POINT
DH1101      Y 164                          N333507.    W0864723.        841.6

This position and the above vector components were computed without any
knowledge by the National Geodetic Survey regarding the equipment or
field operating procedures used.
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11 Glossary of Railroad Related Terms

Absolute Block

A length of track in which no train or engine is permitted to enter while it is occupied by another train or engine.

Absolute Permissive Block (APB)

A designated section of track or tracks within which the movement of trains will be governed by block signals, whose indications supersede the superiority of trains. The block signals may be controlled manually or automatically.

Absolute Signal

A block or interlocking signal designated by an "A" market or the absence of a number plate.

Add, to

Couple car(s) to a train

Air Brake System

All of the devices and parts included in making an air brake for controlling the speed and stopping a locomotive or train. It is made up of the operating devices, the pipes, fittings, and foundation brake gear.

Alley

A clear track in a switching yard.

Angle Cock

An appliance used for the purpose of opening or closing brake pipe on ends of cars, rear ends of tenders, and front ends of switch engines so equipped. Provision is made for supporting hose at proper angle. Application Consists of all of the operations from the time the brake pipe reduction is started until the brake is released.

Approach Signal

A signal that governs the approach to another signal.

Automated Classification Yard, Hump Yard

An efficient mechanism for sorting rail cars and making up blocks of cars for outbound destinations.

Automatic Block Signal System (ABS)

A series of consecutive blocks governed by block signals, cab signals or both, actuated by a train, engine or by certain conditions affecting the use of a block.

Automatic Cab Signal System (ACS)

A system which provides for the automatic operation of the cab signals and cab warning whistle.

Automatic Train Stop System (ATS)

A system actuated by wayside inductors, so arranged that its operation will automatically result in the application of the brakes until the train has been brought to a stop.

Bad-Order

A unit of rolling stock that needs repair.

Bail

By moving the independent brake handle sideways, the engineer can release locomotive brake cylinder pressure due to an automatic brake application as from a brake pipe pressure reduction. The bail has no effect on brake cylinder pressure due to an independent brake application.

BIE

Brakes In Emergency; application of the emergency braking system.

Block

A length of track between consecutive block signals or from a block signal to the end of block system limits, governed by block signals, cab signals or both.

Block Occupancy Indicator

An indicator used to convey information regarding block occupancy. A common BOI sensor is a loop detector.

Block Signal

A fixed signal at the entrance of a block to govern trains and engines entering the block.

Block System

A block or series of consecutive blocks within APB, ABS, ACS, CTC or interlocking limits.

Blue Flag

An important safety signal, originally a blue flag but may be a locally agreed upon signal that is placed on or associated with a car or locomotive when workers are around or under it. A blue-flagged car or locomotive must not be coupled to or moved in any manner by anyone. To assure safe operations, the only person allowed to remove a blue flag is the one responsible for its initiation.

Bogie

A chassis or framework carrying wheels, attached to a vehicle. It can be fixed in place, as on a cargo truck, mounted on a swivel, as on a train carriage or locomotive, or sprung as in the suspension of a caterpillar tracked vehicle.

Bowl

The destination tracks in an automatic classification yard. This area gets its name from the bowl shape of the track vertical profile.

Brake Beam

A cross-piece in the foundation brake gear for a pair of wheels to which the leverage delivers its force to be transmitted through the attached brake head and brake shoes to the tread of the wheels.

Brake Cylinder

A cast metal cylinder with a piston that is forced outward by compressed air in applying the brakes and returned by a release spring to release the brakes.

Brake Pipe

Also commonly called a train line, it comprised the piping, hose, connections, angle cocks, cut-out cocks, and fittings connecting the locomotive and all cars from the locomotive to the last car in a train for the passage of air to charge and control the brakes.

Brake Rigging

A common term for foundation brake gear.

Brakes, Automatic

Automatic brakes are the brake controls in the locomotive that regulate the pressure of the brake pipe and apply or release the brakes for the entire train including the locomotives

Brakes, Independent

Independent brakes are the brake controls in the locomotive that apply the brakes on the locomotives only. The air hose marked ACT or BR CYL enables the lead unit to control the trailing units brakes

Branch

A portion of a division designated by a timetable. Rules and instructions pertaining to subdivisions apply on branches.

Branch Line

A secondary line of a railroad, not the main line.

Cab Signal

A signal located in engineer's compartment or cab, indicating a condition affecting the movement of a train or engine and used in conjunction with interlocking signals and in conjunction with or in lieu of block signals.

Centralized Traffic Control (CTC)

A remotely controlled block signal system under which train movements are authorized by block signals whose indicators supersede the superiority of trains.

Classification Yard, Class Yard, Marshalling Yard

An organizational system for receiving, inspecting, storing, and separating incoming rail cars for reassembly or onto tracks outgoing for delivery to receiving destinations. There are two general types of classification yards: flat yards and hump yards.

Clear Block

A block not occupied. Sometimes used to denote a clear signal indication.

COFC

Container on flat car. Referred to in intermodal traffic.

Color Light Signal

A fixed signal in which the indications are given by the color of a light only.

Color-Position Light Signal

A fixed signal in which the indications are given by color and position of two or more lights.

Conductor

A person in charge of all aspects of a train except the power.

Consist (pronounced CON-sist)

A list in sequence, of the specific locomotives and car that comprise a train, and includes train and car length and weight, car type, loaded or empty status, car contents, routing, special handling requirements, and destination.

Controlled Point
A location designated by number where signals and/or switches of a CTC system are controlled by a control operator.

Controlled Siding
A siding within CTC or interlocking limits, the authorization for use of which is governed by signal indication or control operator.

Controlled Signal
An absolute signal, the aspect of which, is controlled by a control operator.

COT&S
Clean, Oil, Test & Stencil. Applies to air brake rework.

Crossing
A length of track that carries one track across another.

Cross Level
The difference in elevation between points perpendicular to the centerline on the top of each rail of the same track.

Crossover
A connection between two adjacent tracks.

Current of Traffic
The movement of trains on a main track, in one direction, specified by the rules.

Cut, to
To separate a car from a train. Also used as a reference to a group or block of cars.

Dark Territory
Sections of track where no radio communication with the train is possible.

Derail (verb)
The unintended action of rolling stock running off the rails.

Derail (noun)
A track device for intentionally running rolling stock off the rails in an emergency, or placed purposefully to protect sections of track or workers from rolling stock incursions.

Distant Signal
A fixed signal outside of a block system, used to govern the approach to a block signal, interlocking signal or switch point indicator.

Division
A portion of the railroad designated by timetable.

Double Track (DT)
Two main tracks, on one of which the current of traffic is in a specified direction, and on the other in the opposite direction.

Drawbar Horsepower
The total horsepower of a locomotive less the amount of horsepower that it takes to move the locomotive itself, the balance being available to pull the load.

Drill Track
A track connecting with the ladder track, over which locomotives and cars move back and forth in switching.

Dump the Air
Emergency application of the air brakes causing a train to stop abruptly, usually causing damage to the merchandise being carried, to the train equipment, or rail infrastructure.

Dynamic Braking
A method of train braking where the kinetic energy from the train movement generates current at the locomotive traction motors, and is dissipated in a resistor grid on the locomotive. This braking method is preferred by management as it reduces wear on car brakes and reduces fuel consumption, but disliked by train crews because the process takes up the slack between cars with the resulting jolts transferred to the locomotive crew.

Dynamite
Initiating the application of emergency brakes.

Dynamiter
A term commonly given to a brake operating valve that goes into quick-action emergency when it should not. Also called a Kicker.

Electric Switch Lock
An electrically controlled lock device affixed to a hand operated switch or derail to control its use.

EMD

Electro-Motive Diesel, Inc. (formerly General Motors Electro-Motive Division) currently the world's second largest builder of railroad locomotives in terms of overall sales. EMD has built the overwhelming majority of locomotives in service in North America. EMD can lay claim to being the company that ended the dominion of the steam locomotive on the world's railroads, by both producing high-quality, reliable locomotives, and knowing how to sell them.

Emergency Application

An application resulting from an emergency rate of brake pipe reduction which causes the brakes to apply quickly and with maximum braking force for the shortest practical stopping distance.

Engine

A unit propelled by any form of energy, or a combination of such units operated from a single control, used in train or yard service. Also referred to as power.

Engineer

The person in charge of and responsible for the locomotive(s). He or she is in command of the mechanical operation of the train; preparing equipment for service, checking paperwork, and the condition of the locomotive(s); controlling the train's acceleration, braking, and running speed; handling of the train while underway. An engineer must know the physical characteristics of the railway; the grades along the route, the right-of-way, speed limits, and slow orders.

EOT

End Of Train unit (see also Caboose). An EOT transmits brake pipe pressure to the lead unit (head end locomotive), while a two way EOT is also capable of receiving a transmission from the lead unit to open the brake pipe and put the train into emergency stop.

Facing Point Lock

A locking device which automatically locks the switch points of a spring switch in normal position.

Field-side Rail

The side of the railhead facing away from the opposite rail.

Flagman

When used in relation to roadway worker safety means an employee designated by the railroad to direct or restrict the movement of trains past a point on a track to provide on-track safety for roadway workers, while engaged solely in performing that function.

Foul Time

A method of establishing working limits on controlled track in which a roadway worker is notified by the train dispatcher of control operator that no trains will operate within a specific segment of controlled track until the roadway worker reports clear of the track, as prescribed in CFR49 Part 214.323.

Fouling a Track

The placement of an individual or item of equipment is such proximity to a track that the individual or equipment could be struck by a moving train or on-track equipment, or in any case is within four feet of the field side of the near running rail.

FRED

Flashing Rear End Device; an End Of Train telemetry device. See EOT.

Frog

The intersection of two rails opposite the point of switch.

Full Service Application

Corresponds to a handle position for the automatic brake actuator. In the FSA position the brake pipe pressure is reduced from 90 to 62 psig. When applied to the automatic brakes, the equalizing reservoir pressure drops in proportion to the actuator handle movement. The automatic brake valve vents pipe pressure at a service rate until the reservoir and brake pipe pressures are equal, as measured at the locomotive. After a 6 psig drop to 84 psig, the automatic brake valve actuator is linear to zero pressure.

Gandy Dancer

A railroad track worker. The term originated from the Gandy Manufacturing Company, a producer of track tools in the 19th century.

Gateway

See Interchange Point.

Gauge

As measured in the US, the distance between interior sides (gauge side) of the railhead, 5/8” down from the top of rail to account for metal extrusion from the railhead, causing an incorrect gauge measurement.

Gage Standard	SI Units	US Customary Units
Broad gauge (Spain)	1674 mm	5' 5 9/10th"
Broad gauge (Portugal)	1665 mm	5' 5 11/20th"
Broad gauge (Ireland)	1600 mm	5' 3"
Broad gauge (Finland)	1524 mm	5' exactly
Broad gauge (former USSR)	1520 mm	5'
Standard gauge	1435 mm	4' 8-1/2"
Narrow gauge (Cape gauge)	1067 mm	3' 6"
Narrow gauge (meter gauge)	1000 mm	3' 3-37/100"
Narrow gauge (US narrow)	914 mm	3' 0"

Gauge Side

The side of the railhead nearest the opposite rail.

Gladhand

The metal attachments to which train line air hoses connect

Grade Resistance

Resistance that results from the energy you must put into a train to lift it vertically. The energy is returned without loss when the train comes back down again.

Highball

A signal given to proceed at maximum permissible speed. Derived from the days of hoisting a red signal ball to the top of a pole indicating clear track with yard switches thrown in the direction of travel.

Horsepower per Trailing Ton

The total horsepower of all working locomotives divided by the total trailing weight of the train in tons.

Hot Box

On friction bearings, an overheated journal bearing.

Hot Box Detector

A sensor that reads the temperature of rail car bearings. Overheated bearings due to inadequate bearing lubrication or mechanical flaws causes a significant increase in bearing friction which, in turn, causes the wheel bearing temperature to increase. When the bearing temperature rises to an abnormally high level, bearing failure results. Such failures are a major cause of derailments. (CN) A hot box detector counts the number of passing car axles and passes the count, together with a hot box alert (if any) of the axle number via a synthesized voice radio communication to the locomotive crew. A conductor can use the HBD axel count as a secondary method of checking the number of cars in the consist when departing a yard.

House Track
A track entering, or along side a freight house. Cars are spotted for loading or unloading.

Hi-rail, Hy-rail, HiRail
A roadway maintenance machine manufactured to meet Federal Motor Vehicle Safety Standards and is equipped with a retractable flanged wheels to facilitate travel over a highway or on railroad tracks. The Mitchell Equipment Corporation has manufactured a wide variety of rail gear products under the name Hy-rail since 1978.

Inerter, Inerting retarder
A device that stops rail cars at the pullout end of a humpyard. It may be mechanical, air, or hydraulically operated.

Initial Station
The first station on each subdivision from which a train is authorized to occupy the main track.

Interchange Point
The point at which two or more railroads join. Traffic is passed from one railroad to another at interchange points.

Interlocking
An arrangement of signal appliances so interconnected that their movements must succeed each other in proper sequence. It may be operated manually or automatically.

Interlocking Limits
The tracks between the outer opposing absolute signals of an interlocking.

Interlocking Signals
The fixed signals of an interlocking, governing trains using interlocking limits.

Intermodal
Freight traffic that refers to containerization of freight for easy transloading to different modes of transportation. See TOFC, COFC, Piggyback.

Joint Facilities
Any facilities owned by two or more railroads.

Kicker
An expression for an emergency brake application which occurs when a service brake application is intended or when no application is intended.

Ladder
A series of turnouts providing access to any of several parallel yard tracks.

Line Haul Road
A railroad that handles freight over a medium to long distance.

Locomotive
Locomotives are units propelled by any form of energy, or a combination of such units operated from a single control station, used in train or yard service

Main Track, Main Line
A track extending through yards and between stations which must not be occupied without authority or protection.

Maintenance of Way, M of Way, MOW, MW
Maintenance of way refers to the maintenance of railroad rights of way. It can include procedures from the initial grading of the right of way to its general upkeep and eventual dismantling.

Manual Block System
A series of consecutive blocks, governed by block signals operated manually, upon information by radio, cellular phone, telegraph, telephone, or other means of communication.

Marker
See EOT device.

Marshalling Yard
See classification yard.

Multiple Main Tracks
Two or more main tracks, the use of which is designated in the timetable.

MU
Multiple Unit. A lead locomotive followed by one or more locomotives.

On-track Safety

A state of freedom from the danger of being struck by a moving railroad train or other railroad equipment provided by operating and safety rules that govern track occupancy by personnel, trains, and on-track equipment.

Originating Line Haul Road

The railroad where any freight shipment starts.

Originating Station

The first station on each subdivision from which a train is authorized to occupy the main track.

Overhead Line Haul Road

Any railroad or railroads between the originating line haul road and the terminating line haul road. Also known as a bridge line haul road.

Overlap Sign

A sign marking the limit of control of a block signal.

Paired Track

When two railroads own single track lines, they may reach an agreement whereby one railroads track services both roads in one direction, while the other railroads track services both roads in the other direction.

Partial Service Application

Reducing the brake pipe pressure at a service rate but not enough to cause the reservoir and cylinder pressure to equalize.

Piggyback

TOFC or trailer on a flat car. Originally used when truck trailers were loaded onto flat cars for shipment by rail.

Pilot

An employee assigned to a train when the engineer or conductor is not acquainted with the rules or portion of a railroad over which the train is to be moved.

Pinning a Switch

Placing a stop on a "push button" yard switch control panel to prevent movement of the switch actuator. An electro-mechanical version of "spiking a switch".

Pinpuller

An automatic classification yard worker positioned at the top of the hump to uncouple cars for processing through the hump control.

Pocket
Portion of track within a terminal on which a train may stand for a period of time.

Position Light Signal
A fixed signal in which the indications are given by the position of two or more lights.

Power
See locomotive.

Prime Mover
A V-type diesel with 8 to 20 cylinders rated at about 125 hp per cylinder if normally aspirated or 250 hp per cylinder if turbo charged.

Push-Button Yard
An automatic classification yard, named for the electro-mechanical operation of the switches.

Railroad
All forms of non-highway ground transportation that run on rails or electro-magnetic guideways, including 1) commuter of other short-haul rail passenger service in a metropolitan or suburban area, and 2) high-speed ground transportation systems that connect metropolitan areas, without regards to whether they use new technologies not associated with traditional railroads. Such term does not include rapid transit operations within an urban area that are not connected to the general railroad system of transportation.

Rail Weight
Sizing of different rail construction designs, using the weight in pounds per yard. Rail weight defines the bearing capacity, with heavier weight rail capable of supporting heavier loads. Currently, rail is produced in weights between 112 to 145 pounds per yard.

Regular Train
A train authorized by a timetable schedule.

Repeater Signal
Signal placed on the opposite side of the track from the controlling signal. It repeats the aspect of the controlling signal for a greater range of vision.

Restricted Speed
A speed that will permit stopping within one half the range of vision; short of train, engine, railroad car, stop signal, derail or switch not properly lined, looking out for broken rail, not exceeding 20 MPH.

Retarder

A device at the hump end of an automatic classification used to reduce or retard the speed of cars in order to produce the desired coupling speed.

Rip Track

A car repair facility, often a single track in a yard. Name derived from "Repair, Inspect, and Paint", or "Repair In Place".

Roadmaster

A railroad employee responsible for coordinating the inspection and maintenance of a particular segment of track.

Rolling Resistance

Resistance that is made up of wheel friction, journal friction, and wind resistance. It is non recoverable.

Ruling Grade

The particular point on the run at which the combination of grade and curve resistance makes the train pull hardest and therefore, "rules" how heavy a load can be given to the locomotive.

SBU

Sense and Brake Unit.

Schedule

That part of a timetable, which prescribes class, direction, number, and movement for a regular train.

Section

One of two or more trains running on the same schedule, displaying signals or for which signals are displayed.

Shock

The effect of a sudden change in speed of a car, locomotive or train, or part of a train.

Side Track

A track auxiliary to the main track.

Siding

A track auxiliary to the main track for meeting or passing trains.

Signal Aspect

The appearance of a fixed signal conveying an indication as viewed from the direction of an approaching train; or the appearance of a cab signal conveying an indication as viewed by an observer in the cab.

Signal Indication

The information conveyed by the signal aspect.

Single-Car Test Device

Is used to test the air brake equipment on car that is sent to a repair track

Single Track

A main track upon which trains are operated in both directions.

Skate

A device that rests on top of a rail and used to stop and hold a rail car.

Slack

The motion, forward or back, that one or more cars, locomotives, or parts of a train has without moving other coupled cars, locomotives, or parts of the train. Loose slack is the free movement or lost motion between parts of a train. Spring slack is the movement beyond the free or lost motion brought about through compressing the draft gear springs. Slack is necessary so as to start one car at a time and so that the train may be operated around curves and over high and low places.

Slack Action

Movement of part of a coupled train at a different speed than another part of the same train.

Slug

A small, ballasted, four or six-axle unit, that does not have a prime mover has traction motors. Generally semi-permanently coupled to a locomotive used in yard duty where the switcher has enough horsepower, but not enough tractive force to push long strings of cars up the hump.

Spiking a switch

Driving a spike beside the switch mechanism in order to prevent its unintended operation. Used as a safety measure when working on a section of track, usually in conjunction with a derail.

Spotting, to spot a car

A term used to denote placement and securing of a railcar for loading, unloading, or storage.

Spring Switch

A switch equipped with a spring mechanism to restore the switch points to original position after having been trailed through.

Staggers Act of 1980

This act significantly deregulating the railroad industry, replacing the regulatory structure that had existed since the passage of the 1887 Interstate Commerce Act. Railroads were permitted to determine where they ran trains and how much to charge. The act was signed into law by President Jimmy Carter on October 14, 1980, and followed the Airline Deregulation Act of 1978.

The act was named for Congressman Harley Staggers (D-WV), who chaired the House Interstate and Foreign Commerce Committee.

Stall

A car that does not transit the bowl area of a hump yard and couple as intended.

Stub Track

A form of side track connected to a running track at one only and protected at the other end by a bumping post or other obstruction.

Subdivision

A portion of a division designated by timetable.

Superior Train

A train having precedence over another train.

Tangent Track

Straight track.

Tare Weight

The weight of an empty car.

Team Track

A track on which rail cars are placed for the use of the public in loading or unloading freight.

Terminating line haul road

The last railroad over which any shipment travels.

Terminating Station

The last station on each subdivision to which a train is authorized to occupy the main track.

Timetable

The authority for the movement of regular trains subject to the rules. It may contain classified schedules and includes special instructions.

TOFC

Trailer On a Flat Car. See intermodal.

Tons per Operative Brake

Gross trailing tonnage of the train divided by the total number of cars having operative brakes. (not including locomotives)

Track Bulletin

A notice containing information as to track conditions or other conditions, necessary for the safe operation of trains or engines.

Track Circuit

An electrical circuit that uses the rails as an active element. The track circuit is the basis of signaling systems.

Track Gauge

The distance between the inner faces of the railheads measured 5/8" down from the top of the head. Nominally, 4'-8 1/2".

Track Head

The top of the rail on which the wheels roll.

Track Permit

A form used to authorize occupancy of main track where designated by special instructions.

Track Side Warning Detector

Wayside detectors which are provided at various locations as shown in the timetable which detect such conditions as overheated journals, dragging equipment, excess dimensions, shifted loads, high water and slides.

Track Warrant Control (TWC)

A method of authorizing movements of trains or engines or protecting men or machines on a main track within specified limits in territory designated by special instructions or general order.

Track Web

The thin section of metal between the base and the head of a section of rail.

Trackage Rights

An agreement between two railroads in which one railroad buys the right to run its trains on the tracks of the other, paying a toll for the privilege. The toll is called a “wheelage” charge.

Tractive Effort, TE

The pulling force exerted by a locomotive, though the term could also be used for anything else that pulls a load. It is normally understood to be the actual force on the locomotive's drawbar or rear coupler. When a bare figure for tractive effort is quoted without a speed qualification, this is normally for starting tractive effort, i.e. at a dead start with the wheels not turning.

Train

An engine or more than one engine coupled with, or without cars, displaying a marker and authorized to operate on a main track.

Train Approach Warning

A method of establishing on-track safety by warning roadway workers of the approach of trains in ample time for them to move to or remain in a place of safety in accordance with the requirements of CFR 49 Part 214.

Train Brake

The combined brakes on locomotive and cars that provides the means of controlling the speed and stopping of the entire train.

Train Coordination

A method of establishing working limits on track upon which a train holds exclusive authority to move whereby the crew of that train yields that authority to a roadway worker.

Train Line

See Brake Pipe.

Train Set

A group of rolling stock that is permanently or semi-permanently coupled together to form a unified set of equipment, most often applied to passenger train configurations.

Train Order Signal

Fixed signal near the entrance to a river tube, bridge or at stations with moving platforms. Two lunar white mean Proceed without orders according to rules, two red mean Stop, stay and call for orders.

Triple Valve

An operating valve for charging the reservoir, applying the brake, and releasing the brake.

Truck

A structure underneath a unit of rolling stock to which wheel axles are attached through bearings. There are usually two for each car, connecting the chassis and forward and rear bogie. The connection of the bogie to the car allows rotational movement around the vertical axis of the bogie.

Truck Hunting

Rapid oscillation of an empty car truck at high speeds, where the wheel flanges tend to ride up on the head of the rail.

Watchman/Lookout

An employee who has been annually trained and qualified to provide warning to roadway workers of approaching trains or on-track equipment. A watchmen/lookout's sole duty is to look out for approaching trains/on-track equipment and provide at lease fifteen seconds advanced warning to employees before arrival of trains/on-track equipment.

Wheel Pull

Caused by the friction between the brake shoe and the wheel and transmitted to the rail.

Wheel Rolling

A wheel rotating on its axle with no motion existing between the wheel and the rail at the area of contact.

Wheel Slipping

A wheel rotating on its axle with motion existing between the wheel and rail at the area of contact.

Wheel Sliding

A wheel not rotating on its axle with motion existing between the wheel and rail at the area of contact.

Working limits

A segment of track with definite boundaries established in accordance with CFR 49 Part 214 upon which trains and engines may move only as authorized by the roadway worker having control over that defined segment of track. Working limits may be established through “exclusive track occupancy”, “inaccessible track”, “foul time”, or “train coordination” as defined in CFR 49 Part 214.

Wye

A track shaped like the letter "Y", but with a connector between the two arms of the "Y".

Yard

A system of tracks, other than main tracks and sidings, used for making up trains, storing of cars and for other purposes.

Yard Limits

A portion of main track designated by yard limit signs and by timetable, train order Form T or track bulletin, which trains and engines may use as prescribed by Rule 93.

Yard Engine

An engine assigned to yard service.

Yardmaster

A railroad employee superintending the safe and efficient movement of rolling stock in a yard.

(CN 1999; FRA 2005; Nall 2007; Sanders 2007; Vanwormer 2007; Zinoviev and Veltman 2002)

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