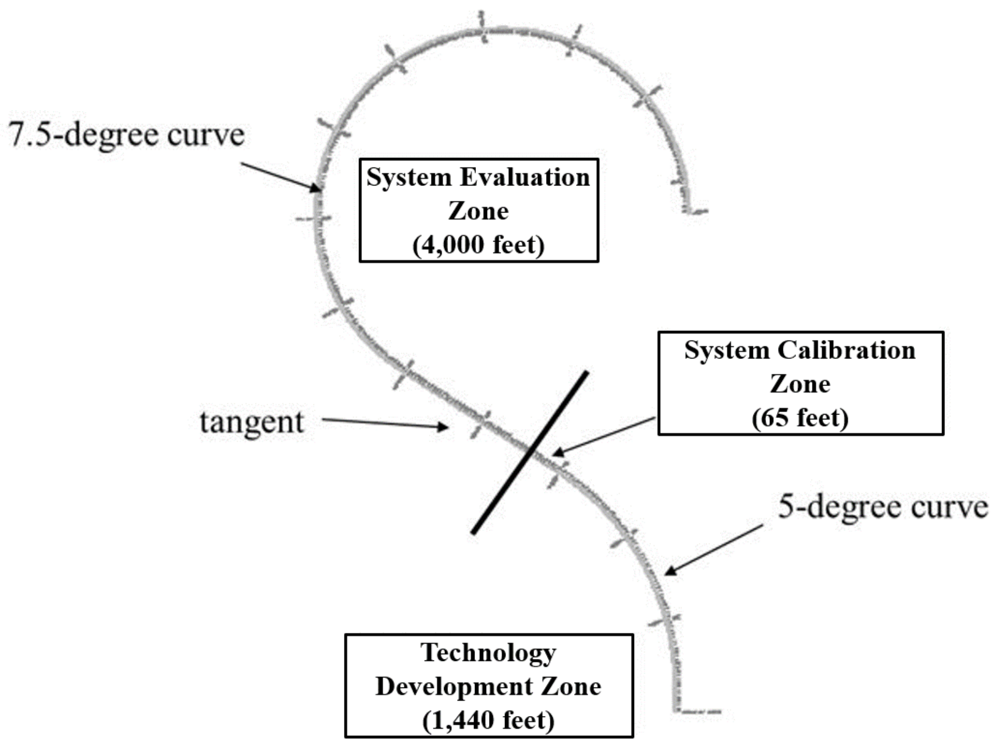
U.S. Department of Transportation

Federal Railroad Administration

Recharacterization of the Rail Defect Test Facility at the Transportation Technology Center

Office of Research, Development and Technology
Washington, DC 20590



DOT/FRA/ORD-18/12

Final Report
April 2018

REPORT DOCUMENTATION PAGE				*Form Approved* *OMB No. 0704-0188*

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE April 2018	3. REPORT TYPE AND DATES COVERED Technical Report

4. TITLE AND SUBTITLE Recharacterization of Rail Defect Test Facility at the Transportation Technology Center	5. FUNDING NUMBERS DTFR53-11-D-00008 Task Order 375
6. AUTHOR(S) Ryan Sheehan	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Transportation Technology Center, Inc., 55500 DOT Road Pueblo, CO 81001	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Department of Transportation Federal Railroad Administration Office of Railroad Policy and Development Office of Research, Development and Technology Washington, DC 20590	10. SPONSORING/MONITORING AGENCY REPORT NUMBER DOT/FRA/ORD-18/12
11. SUPPLEMENTARY NOTES COR: Luis Maal	
12a. DISTRIBUTION/AVAILABILITY STATEMENT This document is available to the public through the FRA Web site at http://www.fra.dot.gov.	12b. DISTRIBUTION CODE

13. ABSTRACT (Maximum 200 words)

Transportation Technology Center, Inc. (TTCI) performed work sponsored by the Federal Railroad Administration to recharacterize and redevelop the Rail Defect Test Facility (RDTF) at the Transportation Technology Center (TTC). FRA also contributed funding to test the rail flaw detection system developed by the University of California at San Diego. The recharacterization and redevelopment provides TTC and the rail industry an improved test facility that accurately represents conditions found during revenue-service operations, and moving forward, can better support the evaluation of rail flaw detection systems.

14. SUBJECT TERMS Rail flaw detection systems, Rail Defect Test Facility, RDTF, nondestructive testing, NDT	15. NUMBER OF PAGES 21
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

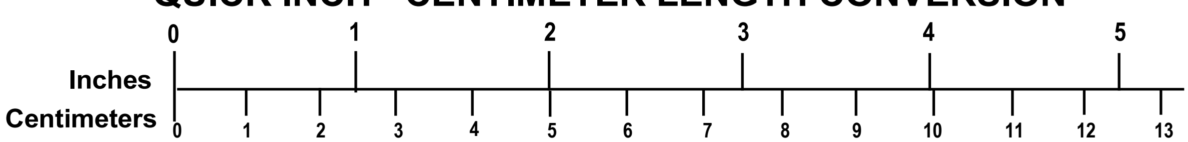
NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
298-102

METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC			METRIC TO ENGLISH		
LENGTH (APPROXIMATE)			**LENGTH** (APPROXIMATE)		
1 inch (in)	=	2.5 centimeters (cm)	1 millimeter (mm)	=	0.04 inch (in)
1 foot (ft)	=	30 centimeters (cm)	1 centimeter (cm)	=	0.4 inch (in)
1 yard (yd)	=	0.9 meter (m)	1 meter (m)	=	3.3 feet (ft)
1 mile (mi)	=	1.6 kilometers (km)	1 meter (m)	=	1.1 yards (yd)
			1 kilometer (km)	=	0.6 mile (mi)
AREA (APPROXIMATE)			**AREA** (APPROXIMATE)		
1 square inch (sq in, in^2)	=	6.5 square centimeters (cm^2)	1 square centimeter (cm^2)	=	0.16 square inch (sq in, in^2)
1 square foot (sq ft, ft^2)	=	0.09 square meter (m^2)	1 square meter (m^2)	=	1.2 square yards (sq yd, yd^2)
1 square yard (sq yd, yd^2)	=	0.8 square meter (m^2)	1 square kilometer (km^2)	=	0.4 square mile (sq mi, mi^2)
1 square mile (sq mi, mi^2)	=	2.6 square kilometers (km^2)	10,000 square meters (m^2)	=	1 hectare (ha) = 2.5 acres
1 acre = 0.4 hectare (he)	=	4,000 square meters (m^2)			
MASS - WEIGHT (APPROXIMATE)			**MASS - WEIGHT** (APPROXIMATE)		
1 ounce (oz)	=	28 grams (gm)	1 gram (gm)	=	0.036 ounce (oz)
1 pound (lb)	=	0.45 kilogram (kg)	1 kilogram (kg)	=	2.2 pounds (lb)
1 short ton = 2,000 pounds (lb)	=	0.9 tonne (t)	1 tonne (t)	=	1,000 kilograms (kg)
				=	1.1 short tons
VOLUME (APPROXIMATE)			**VOLUME** (APPROXIMATE)		
1 teaspoon (tsp)	=	5 milliliters (ml)	1 milliliter (ml)	=	0.03 fluid ounce (fl oz)
1 tablespoon (tbsp)	=	15 milliliters (ml)	1 liter (l)	=	2.1 pints (pt)
1 fluid ounce (fl oz)	=	30 milliliters (ml)	1 liter (l)	=	1.06 quarts (qt)
1 cup (c)	=	0.24 liter (l)	1 liter (l)	=	0.26 gallon (gal)
1 pint (pt)	=	0.47 liter (l)			
1 quart (qt)	=	0.96 liter (l)			
1 gallon (gal)	=	3.8 liters (l)			
1 cubic foot (cu ft, ft^3)	=	0.03 cubic meter (m^3)	1 cubic meter (m^3)	=	36 cubic feet (cu ft, ft^3)
1 cubic yard (cu yd, yd^3)	=	0.76 cubic meter (m^3)	1 cubic meter (m^3)	=	1.3 cubic yards (cu yd, yd^3)
TEMPERATURE (EXACT)			**TEMPERATURE** (EXACT)		
[(x-32)(5/9)] °F	=	y °C	[(9/5) y + 32] °C	=	x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSIO

°F	-40°	-22°	-4°	14°	32°	50°	68°	86°	104°	122°	140°	158°	176°	194°	212°
°C	-40°	-30°	-20°	-10°	0°	10°	20°	30°	40°	50°	60°	70°	80°	90°	100°

For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price $2.50 SD Catalog No. C13 10286

Updated 6/17/98

Contents

Illustrations

Tables

Executive Summary

From May 2015 to December 2015, Transportation Technology Center, Inc. (TTCI) conducted work sponsored by the Federal Railroad Administration (FRA) to recharacterize and redevelop the Rail Defect Test Facility (RDTF) at the Transportation Technology Center (TTC). FRA also contributed funding to evaluate the rail flaw detection system developed by the University of California at San Diego (UCSD).

The RDTF is a unique state-of-the-art test track where known rail defects are intentionally installed in track and provides a rail flaw detection tool to developers for calibrating and testing their technologies. A recharacterization of the System Calibration Zone, Technology Development Zone, and System Evaluation Zone regarding defect type, size, classification, and description was necessary to promote the development of rail inspection equipment and provide accurate information of defects within the RDTF to developers.

The recharacterization provided a standardized flaw dataset that improves the accuracy and reliability of system analysis during performance testing on the RDTF. The dataset improved the necessary defect characterizations—such as type, size, classification, and description as well as linear distance measurements referencing the inside rail, center line of the track, and outside rail for welds, joint bars, and defects. Also, rail defects were reinstalled to more accurately represent revenue service conditions and expand upon existing track markers to efficiently locate defects while testing.

The outcomes of this project provided TTC and the rail industry with an improved test facility that accurately represents conditions found during revenue-service operations, and moving forward, can better support the evaluation of rail flaw detection systems.

1. Introduction

The Federal Railroad Administration (FRA) provided funding to Transportation Technology Center, Inc. (TTCI) to undertake recharacterization and redevelopment efforts of the Rail Defect Test Facility (RDTF) located at the Transportation Technology Center (TTC) in Pueblo, CO. This report describes the project objectives, the work performed from May 2015 to December 2015, and the results of this effort. The results include what was characterized with each defect, how the defect was recorded, and what process was involved to redevelop the RDTF.

1.1 Background

The RDTF is a unique state-of-the-art test track where known rail defects are intentionally installed in track. The facility is approximately 1 mile long and resides alongside the balloon loop track at TTC. The rail flaws represent a mixture of service and machined defects that are mapped according to their location, size, and type. The facility was developed in the late 1990s in response to a need for improving rail flaw detection technologies. It provides a tool for rail flaw detection to developers for calibrating and testing their technologies.

Currently, the RDTF has a System Calibration Zone, a Technology Development Zone, and a System Evaluation Zone (Figure 1). For short, the zones will be referred to as follows:

- Technology Development Zone – Development Zone
- System Calibration Zone – Calibration Zone
- System Evaluation Zone – Evaluation Zone

The ground truth defect configuration is known for each zone, but is only revealed to the operators in the Calibration and Development Zones. The System Evaluation Zone is for blind testing.

Over the years, several shortcomings have been identified with the RDTF. The System Calibration Zone has a high concentration of rail defects placed into a short segment of track. This results in an unrealistic concentration of defects. This configuration creates artificial conditions that confound the capability of some detection technologies. Additionally, some of the rail defect vendors have traversed the facility so many times that the defect arrangement at the facility is largely known to them. A recharacterization of the facility regarding defect type, size, classification, and description improves the development of rail inspection equipment by providing more accurate defect information than what was previously available.

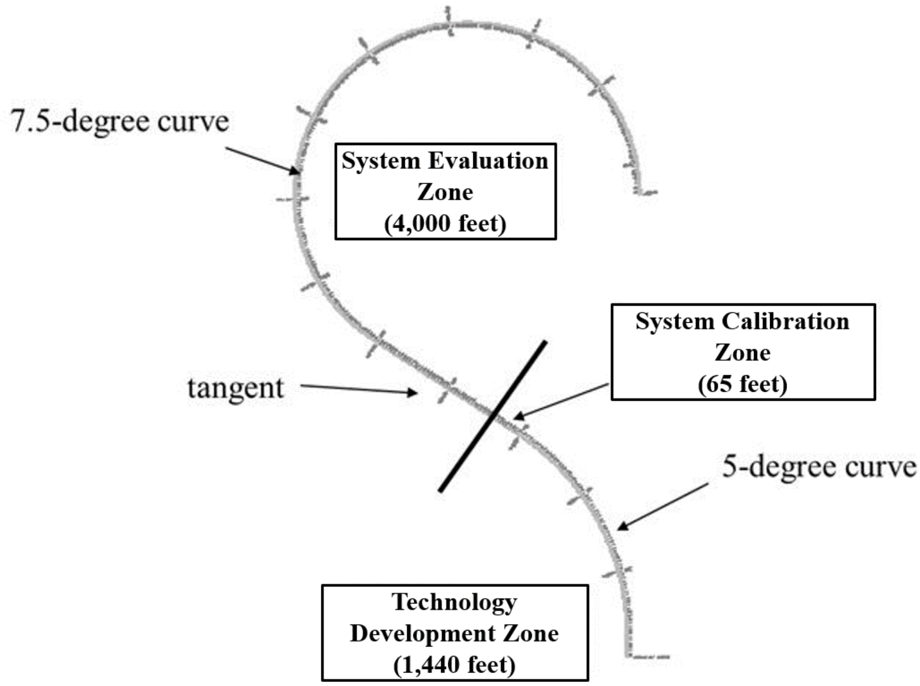


Figure 1. RDTF Zones

1.2 Objectives

TTCI had two objectives. The first was to recharacterize the RDTF to ensure more accurate and reliable results while performing rail defect detection tests on the RDTF. TTCI was also tasked with providing engineering support for the University of California at San Diego (UCSD) during evaluation of UCSD's rail flaw detection systems on the recharacterized RDTF.

1.3 Overall Approach

TTCI separated the work in this project into three tasks: (1) Recharacterization and Development Plan, (2) RDTF Redevelopment and Flaw Mapping, and (3) UCSD Testing Support. The following sections describe each of the tasks in detail.

1.3.1 Phase I – Recharacterization and Development Plan

TTCI analyzed and characterized the population of defects within the RDTF's Calibration, Development, and Evaluation Zones using visual inspection and ultrasonic nondestructive testing (NDT). A dataset detailing the characteristics of each defect was reviewed with stakeholders to create a Test Implementation Plan (TIP). The TIP defined the efforts to rearrange and redevelop the rail defects within the Evaluation (Blind) Zone in the RDTF. TTCI optimized the following issues within the TIP with input from FRA and the John A. Volpe National Transportation Systems Center (Volpe):

- Common and uncommon defect types in revenue service
- More accurate defect characterizations

- Trackside distance and defect markers

1.3.2 Phase II – RDTF Redevelopment and Flaw Mapping

TTCI implemented the TIP developed in Phase 1 for the System Evaluation Zone on the RDTF. Additionally, all defects within the Calibration, Development, and Evaluation Zones were characterized and recorded in a database and computer-aided design (CAD) file. The database references the CAD file and includes the defects according to the following parameters:

- Location
- Type
- Orientation
- Severity
- Size

1.3.3 Phase III – UCSD Testing Support

UCSD coordinated with ENSCO, Inc. and TTCI for system evaluations on the RDTF. TTCI supported the testing for 5 days under the direction of FRA and Volpe. UCSD conducted the testing.

1.4 Scope

This project focused on the recharacterization of defects contained within the RDTF to more accurately define defect characteristics using NDT techniques, and standardized RDTF defect reporting into a singular database. Additionally, the orientation and characteristics of defects within the System Evaluation Zone were modified by removing and installing additional defect samples into the RDTF to more accurately reflect defects found in revenue-service operation. Reporting the characteristics and location of defects within the RDTF was outside the scope of this project to maintain confidentiality associated with the System Evaluation Zone. Reporting details regarding UCSD testing and results was also outside the scope of this project to maintain confidentiality.

1.5 Organization of the Report

This report is organized in three major sections. Section 1 presents the introduction, which includes the three-phase approach taken to complete the objectives of the project. Section 2 describes the work that was carried out to recharacterize and redevelop the RDTF. Section 3 provides conclusions from this work.

2. RDTF Recharacterization

The following details the work that was completed to meet the project deliverables defined in the overall approach.

2.1 Phase I – Recharacterization and Development Plan

TTCI separated Phase I into three subtasks:

- Characterization of RDTF and Laydown Yard rail defects
- Stakeholder discussion over revenue service rail defects
- TIP for System Evaluation Zone

Each defect was characterized by employing visual inspections and handheld ultrasonic NDT equipment consisting of three components: the Olympus Epoch 650, the Harisonic 2.25 Mhz 0.25-inch round probe, and the Harisonic 70 degree 0.5-inch by 1.0-inch wedge. Figure 2 shows the equipment measuring a defect's severity by analyzing the location and magnitude of the returning sound waves in the rail.

Figure 2. Ultrasonic NDT Equipment

Defects were categorized by flaw type, weld type (if applicable), flaw location, and flaw size, as shown in Table 1.

Table 1. Recharacterized Flaw Location

Rail Flaw	Weld	Flaw Description (HxW)	Flaw Location	Flaw Size
Detail Fracture	Electric Flash Butt Weld (EFBW)	0.55" by 0.8" Depth 0.75"-1.3" Start of Gage Corner	Gage	7.5%

The information in Table 1 is an example from the RDTF's Technology Development Zone and provides an illustration of the revised format used to increase consistency in characterizing the varying defects within the RDTF. The height, width, and depth of the detail fracture are illustrated in Figure 3 and can be used to quickly determine if a defect is within a system's operating range. This capability allows TTCI to more effectively analyze a system's competency in identifying different defects.

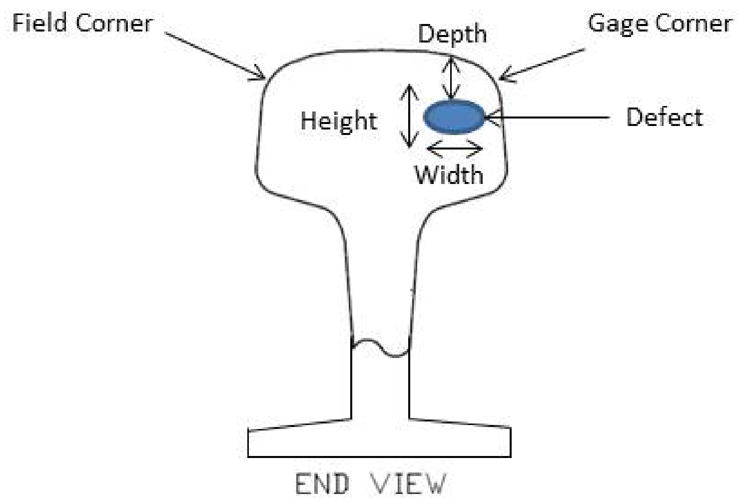


Figure 3. Recharacterized Flaw Location

TTCI reviewed the recharacterized defects and discussed potential improvements with project stakeholders including representatives from railroads and rail flaw detection companies. Input from stakeholders provided TTCI a list of defects found in revenue service that, if added, would benefit the RDTF's ability to accurately evaluate rail flaw detection systems. The recommended defects were gathered from TTCI's Laydown Yard populated by onsite heavy axle load fatigue testing and donated revenue service samples.

A TIP was created to define the required information needed to install the additional defects within the RDTF. This included identifying sections of track that accurately represented defect spacing within the System Evaluation Zone and methods to join the rail samples to existing track. Table 2 shows the header information for the TIP.

Table 2. TIP Header Example

Rail Sample	Sample Length	Defect Type	Defect Location in Sample	Start Tie	Weld/Jbar	End Tie	Weld/Jbar
N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Information is not populated in the table to preserve the proprietary data reserved for Evaluation Zone system analysis. Examples of installed defects include, but are not limited to, transverse defects, transverse defects underneath shelling and/or crushed heads, vertical split heads, and web defects. The defects also vary in severity and flaw location.

2.2 Phase II – RDTF Redevelopment and Flaw Mapping

Phase II was separated into the three subtasks as follows:

- RDTF Evaluation Zone Redevelopment
- RDTF Calibration Zone Configuration
- Updated Flaw Database and Track Marking

TTCI focused on two objectives during the RDTF System Evaluation Zone redevelopment that were identified by project stakeholders. The first was to include defects found in revenue service that were not installed in the System Evaluation Zone. This was addressed by implementing the TIP described in Section 2.1. The second was to improve ride quality on the RDTF. This was accomplished by smoothing transitions between dissimilar rails with height-compensating joint bars and grinding at transitions through the System Evaluation Zone.

The System Calibration Zone within the RDTF is configured according to the description in American Railway Engineering and Maintenance-of-Way Association (AREMA) Volume 1, Chapter 4, Section 4.6, "Recommended Calibration Rails for Rail Flaw Detection System" [1]. This document defines the spacing and orientation of machined defects. The engineering drawings provided by AREMA were used for proper installation of the RDTF System Calibration Zone.

The third subtask standardized the flaw database format for the Calibration, Development, and Evaluation Zones. Using input from AREMA Volume 1, Chapter 4, Section 4.5.6, "Recommended Procedures for Operator Performing Ultrasonic Testing of Rail or Track Components" [1]. The following information was included in the database:

- Tie Number
- Test Zone
- Rail Identification (rail weight, make, length)
- Inside or Outside Rail
- Rail Flaw
- Weld
- Flaw Description
- Flaw Location

- Flaw Size
- Linear Distance Along Track (referencing inside rail, outside rail, and center line)
- Notes
- GPS Information

Due to the curvature in the RDTF, an accurate linear distance is dependent on the rail referenced by a positioning sensor during testing. The linear distances of flaws, welds, and joint bars were calculated by surveying the RDTF using Trimble's Global Positioning System (GPS) equipment. The survey was imported into AutoCAD to create a track profile for the inside rail, outside rail, and center line of track. Figure 4 provides a high-level relationship of the RDTF using the GPS points compared to the TTCI RDTF Map.

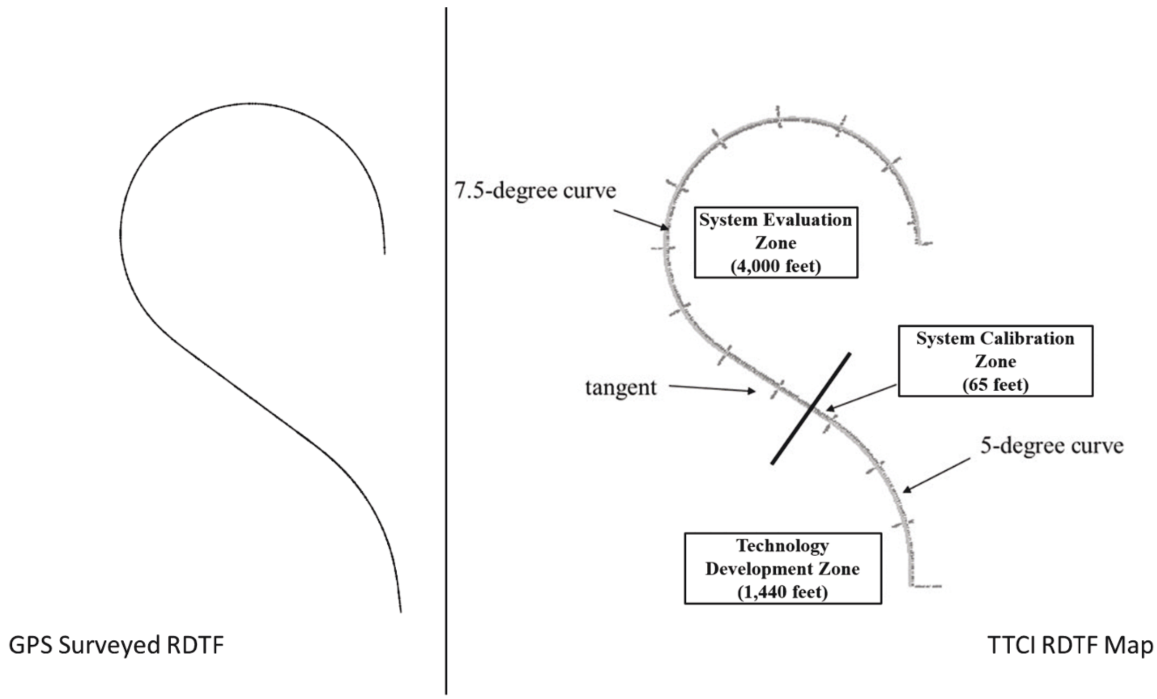


Figure 4. RDTF Track Profile from Survey

A perpendicular to track reference was created on the GPS points representing each flaw, weld, and joint bar in the track profile, to provide an accurate distance calculation from the start of the RDTF. Figure 5 shows an example of the perpendicular reference for linear calculation method. The pink lines represent the inside and outside rail of the RDTF and demonstrate the change in distance (in feet) through a curve. The four dashed lines represent the access road along the track.

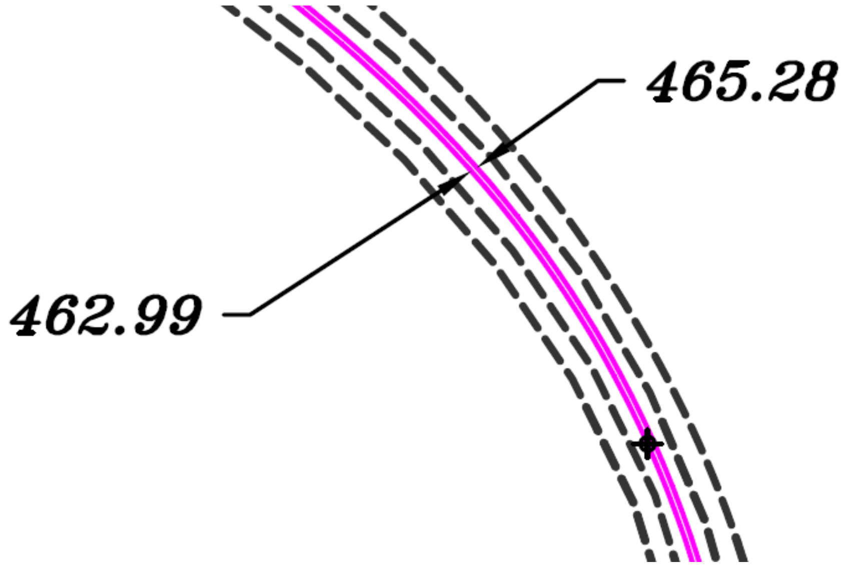


Figure 5. Perpendicular Reference for Linear Calculation

Once the linear distances were calculated with the GPS points, a measuring wheel was used to verify and correct any discrepancies found in the RDTF. The corrections made from the measuring wheel updated the linear distances to more accurately reflect the distances traversed while testing. However, there is still considerable error in measurements made with a measuring wheel, while measurement accuracy decreases as the distance measured increases. For future development, referencing welds, joint bars, and defects to installed Automatic Location Determination (ALD) markers would increase the accuracy and precision of the linear distance measurements for welds, joint bars, and defects. ALD markers would also reduce potential cumulative errors in a measuring system. The result would be more accurate evaluation of rail flaw inspection systems tested at TTC.

In conjunction with updating the flaw database, TTCI improved track references on the RDTF. These improvements will support customer needs during rail flaw detection system performance testing. Track references include tie markings on the outside of the web every 10 ties and installation of yellow tie numbers in the center of track every 20 ties. Figure 6 and Figure 7 show these features. For more refined system tuning, footage was marked every 100 feet on the webbing of both the inside and outside rail within the Calibration and Development Zones. Figure 8 shows these markings.

Figure 6. Outside Tie Marking

Figure 7. Yellow Tie Marking

Figure 8. Footage Marking

2.3 Phase III – UCSD Testing Support

The final task was to provide UCSD with engineering support during rail flaw detection system testing on the recharacterized RDTF. In preparation for the tests, TTCI completed the revised datasets and discussed any discrepancies with Volpe before UCSD's system analysis.

3. Conclusion

TTCI recharacterized the Rail Defect Test Facility (RDTF) to improve its accuracy and reliability of results while performing tests on it. The tasks completed include the following:

- Recharacterizing known defects within the RDTF and laydown yard
- Installing rail defects representative of revenue service
- Standardizing rail flaw datasets
- Improving wayside track marking
- Supporting UCSD's testing of rail flaw detection systems

The outcome of this project provides an improved RDTF to support the testing of rail flaw detection system evaluation.

Recommendations for continuous improvement on the RDTF include the installation of ALD markers to more accurately measure linear distances of welds, joint bars, and rail defects, and reduce potential cumulative errors in a measuring system.

4. References

1. American Railway Engineering and Maintenance-of-Way Association. (2012). *Manual for Railway Engineering* (Vol. 1). Lanham, MD: American Railway Engineering and Maintenance-of-Way Association.

Abbreviations and Acronyms

AREMA	American Railway Engineering and Maintenance-of-Way Association
ALD	Automatic Location Determination
CAD	Computer-Aided Design
EFBW	Electric Flash Butt Weld
FRA	Federal Railroad Administration
GPS	Global Positioning System
Volpe	John A. Volpe National Transportation Systems Center
NDT	Nondestructive Testing
RDTF	Rail Defect Test Facility
TIP	Test Implementation Plan
TTC	Transportation Technology Center (the site)
TTCI	Transportation Technology Center, Inc. (the company)
UCSD	University of California at San Diego