SPRING/SUMMER 2018

MICHIGAN SURVEYOR

MICHIGAN SOCIETY OF PROFESSIONAL SURVEYORS

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SIMPLE PHOTOGRAMMETRY: Where was that railroad? —

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Simple Photogrammetry:

Where was that railroad? — Part 1

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Figure 1. 1979 photo of Quincy Smelting Works, Hancock, MI by NPS photographer Jet Lowe.

The Mineral Range RR is southerly, the Copper Range RR northerly. A side track runs between the MRRR and the Briquetting building into the railroad warehouse, which no longer exists, at left. The slag trestle at right runs from the Cupola Building to the slag pile, from atop which this photo was taken, nearly 30 feet above the railroads.

Photogrammetry has been employed in a surveying sense since the late 19th century. In 1893, Dr. Albrecht Meydenbauer coined the term and created the Royal Prussian Photogrammetric Institute. His application involved using photographs to make architectural surveys.

Prior to the development of photography, the technique of perspective drawing was invented in the 15th century, one of the early pioneers being Leonardo da Vinci.

The photogrammetric applications of today are much aided by digital technology. Using a computerized camera, the sensor of which is made up of pixels commonly between 4 and 10 microns in size, we can now make very accurate 3-D measurements between discrete points on an object without actually making contact with it. We can generate 3-D point clouds similar to those which can be acquired by terrestrial laser scanners. These applications of photography have been made possible by, among many other things, the development of digital imagery, camera self-calibration, Scale Invariant Feature Transform (SIFT), key point matching, bundle adjustment, linear algebra, and a myriad of commercial and open-source software used to perform the intensive computations and to manipulate and visualize the results.

I **WON'T** be talking about these things in this article. Rather, we will reach back to those 15th century principles of perspective and use them to help in the retracement of the location of an abandoned railroad. "Simple Photogrammetry" is borrowed from the title of a practical manual published in 1969 by J.C.C. Williams describing the use of perspective in map making (references below). The techniques used here are described in that publication.

In Part 1 of this article a digital scan of a 1979 photograph (Figure 1) will be our evidence, and perspective our tool for making basic measurements between a slag trestle and two railroads. The trestle appears in the 1979 image and still exists today. The railroads are gone. Despite its variable scale and perspective view, we can use the image to find out where the railroads were with respect to the trestle. The photo was taken by National Park Service Photographer Jet Lowe and is part of the Library of Congress' Historic American Engineering Record (Library of Congress Prints and Photographs Division, Historic American Engineering Record, Reproduction number "HAER MICH,31-HANC,1--180").

Over 2600 miles of former railroad grades have been converted to recreational trail use in Michigan. The Michigan Dept. of Natural Resources manages about 1200 miles of these trails. The grades often need a little attention to clear up encroachments, and/or define their limits for trail management.

The Michigan Dept. of Natural Resources U.P. Land Survey Unit, in cooperation with MDOT surveyor Brandon Juntunen PS, is retracing two grades over a distance of 3.8 miles: the former Copper Range (CRRR) and Mineral Range Railroads (MRRR). Both of these railroad companies provided transportation services to the mining and logging industries and hauled passengers throughout Michigan's Copper County. The CRRR operated from 1903 to 1972 and the MRRR from 1873 to 1978, when its new operator, The Soo Line, abandoned it.

The grades to be surveyed run between the Portage Lake Lift Bridge connecting Houghton and Hancock on the west, and Dollar Bay on the east, in Houghton County. These two grades wind side-by-side sandwiched in the narrow strip of land between State Highway M-26 on the north and the shore of Portage Lake on the south. They both pass through what was formerly the Quincy Smelting Works, where the Quincy Mining Company refined their copper ore until the copper industry shut down completely in 1967. The CRRR is now managed by the Michigan D.N.R., the MRRR by the Michigan D.O.T. They serve as public snowmobile trails in the winter.

The CRRR rails were removed around 1973 and the MRRR rails in 1979. Since that time, in the more developed areas, the grades have been physically altered by much local use, resulting in the original location of the roads becoming very unclear. In some areas, the CRRR grade is completely obliterated. The rails are long gone and only a couple ties have been found.

Fortunately, the MRRR monumented their alignment with 1" diameter steel pins. These pins were typically placed at the PC, PI, and PT of each curve and occasionally along curve tangent extensions or other locations. We found many of these monuments on the easterly ½ of the 3.8-mile-long corridor. They fit the RR track map's curve and tangent data very well. Developing a very reasonable location for the MRRR along the easterly ½ was easy. But very little physical evidence was found along the westerly ½, including the area photographed.

The root retracement problem here, without overburdening this article with detail, is that the MRRR was constructed off-center within its R/W. The MRRR and CRRR rights-of-way are parallel and adjoining. One of these two railroads will end up being the basis for the reestablishment of both rights-of-way. For various reasons that I won't go into, we may not be able to trust that the MRRR track will be a good basis. We need to know the physical location of the MRRR in order to evaluate it for that purpose.

The nearest evidence in which we can have confidence, relative to the photographed area:

1. a MRRR tie found 1600' east around the bend of a curve;
2. a survey tie to the MRRR C/L made by MDOT in 1979, about 800' west, also around a curve;
3. a RR tie on the CRRR found at the trestle.

In Part 1 of this article we will focus on the trestle crossing, using the 1979 photo and "simple photogrammetry" to obtain the horizontal distance from the trestle legs to the centers of the two railroads. We will assume that the lens distortion of Mr. Lowe's 4"x5" tripod-mounted view camera is negligible. This seems a safe assumption as there is no evidence of radial distortion, no "barrel" or "pincushion" effect. Straight lines appear to be perfectly straight right out to the edges of the photo.

In a perspective projection, all lines that are parallel to each other in the 3-D world converge to the same point at infinity, the vanishing point. If two sets of parallel lines are orthogonal and lie in a plane in the 3-D world, they define a trapezoid in the projection. Using the trapezoid together with the vanishing points, a grid of proportionally similar trapezoids can be created.

In this case, immediately adjacent to the two railroads, we have a perspective view of the rectangular shape formed by the inclined supporting "legs" the trestle. The trestle is straight, level, and regular. We will use the legs of the trestle to define the trapezoid. Then we will extend that trapezoid out over the railroad and, by proportional division, subdivide it to locate the railroad track centerlines at the SW corner and the NE corners of the center section of the trestle. As we extend and subdivide, we will create a grid of similar trapezoids. Having accurately measured the base of our initial trapezoid in the field, we can calculate the distance from the corner of the trapezoid (the edge of the leg) to the centers of the railroads by proportion.

As a means of checking our work, we will be able to compare our calculation at the NE corner of the trestle with the location of the center of the RR tie that was recovered there. The tie plate impressions on that tie were clear and a PK nail placed by

MDOT was found midway between the impressions – as close an estimate as we can get to midway between the gauge points.

We'll look first at the SW trestle corner and the legs on the west side (Figure 2). The vertical vanishing point is at the convergence of the edges of the legs. It is vertically below the photo. The horizontal vanishing lines are perpendicular to the legs. How to get those? Simply count up the same number of little angle braces along each of the legs, draw connecting lines between them, and extend them to their intersection at the vanishing point. Lines emitting from the two vanishing points are parallel in the real world. We will use them to construct the perspective grid. Unlike in the "old days" of drafting, where the process was truly mechanical, we do not have to worry about our vanishing points falling off of the edge of the drafting table. All of this is done in CAD, giving us an unlimited space to work within.

For this method to produce an accurate result, it is important that we make a very good estimation of the height of the RR rails (of the MRRR) and the RR ties (of the CRRR). The line along which we measure the distance to the rails must "rest" directly on top of the rails. The acute angle at which we are viewing the railroad can magnify any error in that estimate. Graphically, the vanishing line coincident with the base of the trapezoid forms an angle of about 20° with the rails. Potential error in the calculated distance from the corner of the leg to the rails is a function of the cosecant of this angle. A one-unit error in the judgement of the location of the height of the rails results in a 3-unit error in the calculated distance from the corner of the leg! So, we must choose the ground level with care! Fortunately, the ground is quite even and level here.

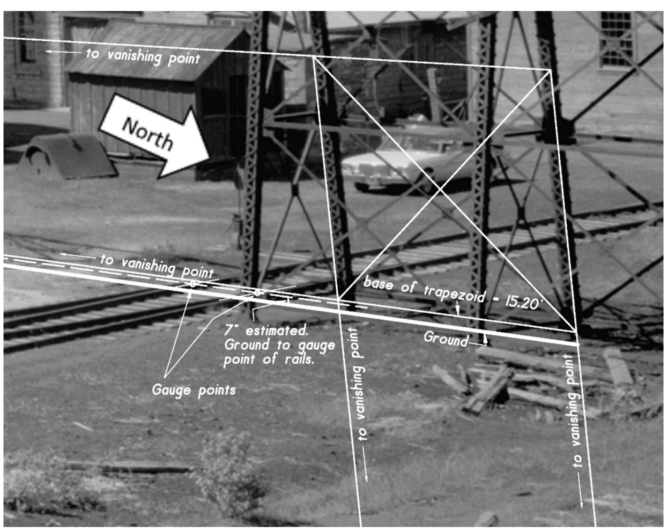

Figure 2. Creating a rectangle in perspective (a trapezoid) using extension of lines to their vanishing points. The horizontal vanishing point to the left was created by extending lines through homologous points on the legs, identified by counting along the angled braces. The vertical vanishing point is the intersection of the edges of the inclined legs. The intersection of diagonals is the center of the rectangle. These lines all fall in the plane of the inside (east) face of the westerly set of legs. Don't get confused by looking at the easterly set of legs.

Helpfully, both railroads are very close to the trestle. At the SW trestle corner in Figure 2, we will presume that the ground at the rails is the same elevation as at the base of the concrete pier supporting the leg. The ground level is very distinct on the photo. Using field measurements made on the trestle, we temporarily resize the photo so that we can be close to true scale at that point, we measure vertically up 7 inches from the ground point to the level of the rails (1.5" estimated from ground to the top of the RR ties + 5.5" from the tie to the gauge point of the rail), and strike a line from that point to the horizontal vanishing point off to the left. This line is our best-guess height of the rails and is the line along which we will make our proportionate measurements. The measuring line, shown as a dashed line in the figures, lies slightly below the base of the trapezoid.

Next, we find the center of our trapezoid by intersecting its diagonals, as shown in Figure 2. Moving to Figure 3, we draw a line from the center to the horizontal vanishing point to obtain the midpoint of the left side of the trapezoid. Striking a line through this point and the lower right corner of the trapezoid and extending it to its intersection with the vanishing line of the top of the trapezoid, gives us the upper left corner of a second trapezoid, identical in dimensions to the first.

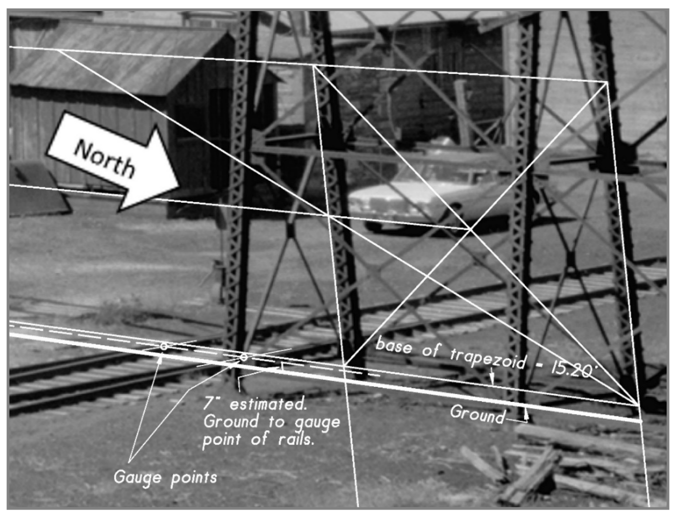

Figure 3. Extending a ½ diagonal to obtain the upper left corner of adjacent trapezoid.

Extending a line from the vertical vanishing point through the new upper left corner gives us a perspective view of a completely identical second trapezoid which we can now begin to subdivide by means of further diagonals and vanishing lines. It is this second trapezoid which we are interested in as that is the one positioned directly over the rails.
See figure 4.

We continue to subdivide the left trapezoid by the same process until the vertical vanishing lines intersect the two gauge points at our measuring line. Here, we happen to intersect the gauge points by subdividing down to the 1/16th level (Figure

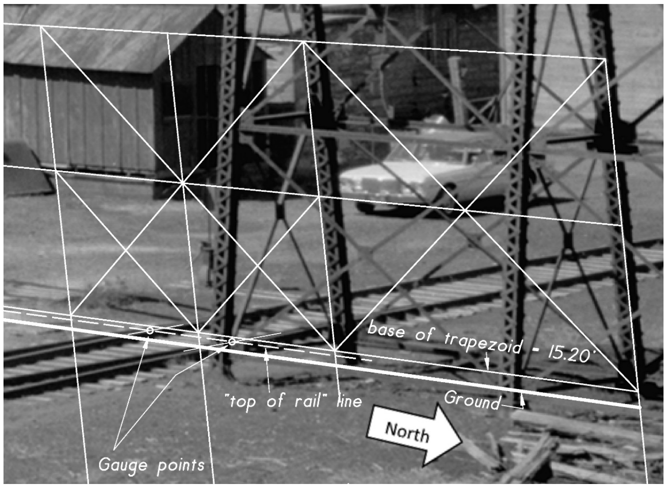

Figure 4. Beginning to subdivide the trapezoid adjacent to the rails.

5). That was good luck. Subdividing these down to the 1/64th or 1/128th level can get confusing and one will need to color code the lines or develop some other means of keeping track of what lines represent what level of subdivision. With a trapezoid base of 15.20', the gauge point on the southerly rail falls (1/2 + 1/8 + 1/16) = 11/16 (68.75%) of that distance, or 10.45' from the SE corner of the SW leg.

The northerly gauge point falls (1/4 + 1/8) = 3/8 (37.5%), or 5.70' from the corner.

The difference between the two is 4.75' and the centerline, midway between gauge points, is 8.08' from the corner of the leg (5.70' + (4.75'/2)=8.08').

The railroad is not square to the trestle but forms an angle with it of about 79 ¾ degrees. Therefore, we should expect to see the standard gauge distance of 4 ft. 8-1/2 inches (4.71') increased to: 4.71 / sin(79.75) = 4.79'. We have come pretty close, our graphical solution being only 0.04' short.

It so happens that by running in the track map's curve and tangent data between the aforementioned control 1600' east and 800' west, the calculated centerline of the MRRR falls 12.7' south of the same leg of the trestle, 4.62' further from the leg than what we calculate graphically. This difference is much greater than what we would expect, having experienced the close agreement between the record data and the MRRR monumentation on the easterly ½ of the project. Thus we suspect that at this place the curve and tangent data on the track maps do not represent the location of the railroad as it existed in 1979. We will need to figure out what is going on here before deciding what evidence to rely upon for the relocation of the centerline of the MRRR Right-of-Way.

The same routine was run at the SE corner of the trestle, but as the process is identical, nothing new can be said and we'll just give the final result: The centerline of the MRRR is 6.24' south of the SE corner of the SE leg.

We'll turn to the Copper Range railroad now, on the north end of the trestle, and see how the result of employing this same technique compares to the location of the RR tie that was recovered there. Again, since the technique used to achieve it

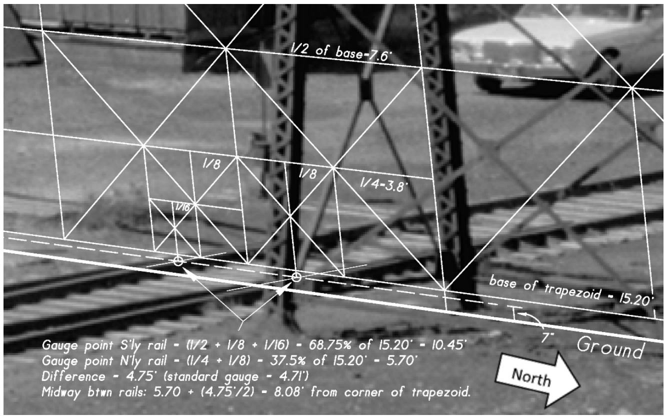

Figure 5. Completion of the subdivision and derivation of the distance of 8.08 feet from the SE corner of the back leg to the center of the railroad in 1979.

is exactly the same as that detailed above let's just skip ahead to the final result. The only difference to note here is that our measuring line will be at the ground, since the ties appear to be flush. Also, since we are using the easterly supporting legs to develop the vertical vanishing point, the vanishing point will be located above, not below, the photo.

As can be seen in Figure 6, with a trapezoid base of 14.53', the inside (closest to the RR C/L) of the northerly tie plate impression falls at (3/4 + 1/32 + 1/64 + 1/128) of that distance, or 11.69' from the NE corner of the NE leg.

The inside of the southerly tie plate impression is at exactly ½, 7.27' to the nearest 0.01'.

The difference between the two is 4.42' and the centerline defined by those impressions is 9.48' from the corner of the trestle leg. The PK nail in the existing RR tie was found 9.24' from the corner of the leg, a difference of only 0.24' from this calculation. This is a very close agreement given the flat angle of the photograph and the difficulty of determining the exact location of the edges of the tie plates at this point on the photo.

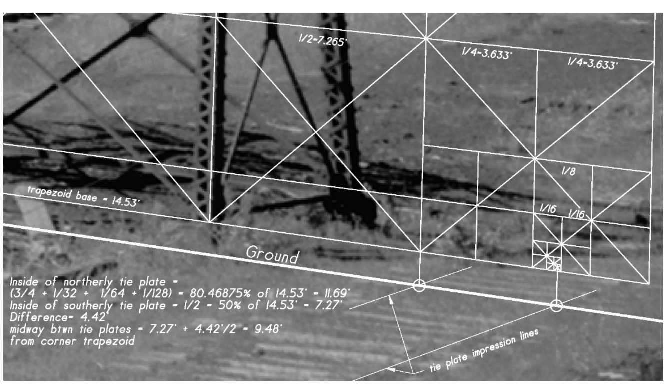

Figure 6. The same technique applied to the Copper Range Railroad at the NE corner of the trestle. The lines representing the tie plate impressions have been extended from the lower left, at which point they are more easily identifiable. These lines all fall in the plane of the easterly face of the easterly legs.

To conclude, with care and attention to detail this technique can be used in favorable circumstances to extract dimensions from photographs. In this case sheer blind luck played a major role by providing not only a quality photograph, but a rectangular structure that happened to be immediately adjacent to the objects of interest.

In Part 2 of this article, we will examine another graphical technique which will reveal whether the rail lines were, in fact, parallel at the time this photo was taken; compute the 3-D location of the camera that recorded the photograph; project the perspective view of the photo onto a horizontal plane allowing creation of a true scale planimetric view of the railroads, the side track, and their relationship to the trestle and the buildings in the background.

References and further reading

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www.close-range.com/reference.html for various papers on the topics mentioned in this article.

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