Simple Photogrammetry: Where was that railroad? Part 2

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In Part 1 of this article, we examined an historic photograph of two railroads and, using the photograph's perspective geometry, extracted a couple of planimetric measurements that helped determine the location of the railroads prior to the removal of the rails. We described how the perspective view of the legs of an iron slag trestle could be used to establish a perspective view of an inclined grid. The grid, when projected over the image of the railroad rails, allowed the calculation of the proportional distances between the trestle legs and the railroads. Since the trestle is still in place, it was a simple matter to measure the distance between the legs and apply the proportion to yield the true distance between the legs and the railroads.

The photo used in this calculation was taken in 1979 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"). The Quincy Smelter site depicted here is now part of the Keweenaw National Historic Park. The same photograph will be the subject of this article.

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 2-story Briquetting building (center) and disappears 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.

Here in Part 2, we'll proceed through the steps that will take us from the perspective projection of this photograph to an orthographic planimetric map of part of the scene. The method to be used will be a more complex application of perspective geometry than that described in Part 1. The planimetric map will describe the true location of the railroads with respect to the trestle and the buildings in the background. The orthogonality necessary to produce a true-scale planimetric map will be derived from the perspective view of the orthogonal Briquetting building, the 2-storied light colored building in the center of the photograph. The techniques used here are described in the texts *Dimensional Analysis Through Perspective: A Reference Manual* by James R. Williamson and Michael H. Brill"[2], and *Simple Photogrammetry* by J.C.C.Williams[3]. So that this article should not consume an overly large amount of this issue of *Michigan Surveyor*, it will attempt to highlight the steps involved in the practical solution to the measurement problem, rather than discuss the detail of the theory. The reader is encouraged to refer to the two texts mentioned for a full discussion of the methods applied here.

First, an inventory of what we know about this scene, and what's been measured:

1) The trestle, Briquetting building, and other buildings to the west are substantially unchanged since the photo was taken in 1979;
2) Both railroads are gone with the exception of one RR tie on the CRRR at the trestle;
3) A small portion of the side track that falls within the warehouse still exists (the warehouse is gone);
4) The camera station is on the top of the slag pile and its position was determined in the field to an accuracy of a few feet by comparing the alignments of the objects in the photo. See Figure 2 for the view today;
5) HABS/HAER photographers used an approach to photography similar to surveyors—their setups are levelled using vials on the camera and tripod[1]. The Z vanishing point of this photo – the intersection of the vertical lines (building edges and any other lines presumed to be plumb) – is very far below the photo, around 90 times the height of the photo. While it will ultimately be possible to calculate the zenith angle of the camera (something we won't be doing here), suffice it to say that the axis of the camera is less than 1° from the horizontal. Therefore, the geometry of this photo is for all practical purposes one of 2-point perspective. The solution will proceed on this basis;
6) A 1902 blueprint shows the CRRR and MRRR centerlines separated by 47.7 feet. Presumably, the railroads are parallel but this is not known for sure. The legal descriptions indicate that the Rights-of-Way are parallel but there is good evidence that the rails of the MRRR were relocated in front of the smelter complex. The 1902 dimension may no longer be reliable and the tracks no longer parallel. In addition, the RR plans show the MRRR entering a curve immediately east of the trestle, while the CRRR continues on a tangent.
7) The elevations of the RR ties are unknown except for the single tie on the CRRR and the portion of the side track previously mentioned;
8) The building corners of the face of the briquetting building, the trestle structure, the single CRRR tie, and the side track were coordinated in MCS83 (Michigan Coordinate System of 1983);
9) The elevation differences between the briquetting building, the existing RR ties, and the current graveled surfaces approximating the original RR grades were measured.

Figure 2.
2018 photo taken from approximately the 1979 photo station. The railroads are obliterated and the grades are now serving as snowmobile/ATV trails. The RR engine was removed for restoration and display elsewhere shortly after this photo was taken.

To create our planimetric map, we will complete the following steps[2], focusing first on the CRRR:

1) Establish a horizontal plane perpendicular to the face of the briquetting building at the height of CRRR;
2) Create two line features along the CRRR tie plate impressions, one on each side of the centerline;

3) Create a perspective view of a rectangle on the horizontal plane established in Step 1), the width of the briquetting building;
4) Extend the rectangle into a grid of similar rectangles so that the entire area of interest falls within the grid;
5) Establish the principle line (**PL**) of the photograph at a right angle to the XY Horizon Line (**HLXY**) and passing through the center of the photograph (this is an approximate determination, but it's position will be close enough, given other error sources, as will be seen);
6) Plot the camera station on the photo using the **PL**, the **HLXY**, and the X and Y vanishing points;
7) Project the grid, using the **HLXY** and the camera station to create an orthographic view of the grid from above;
8) Project (as in step 7) the intersections of the tie plate impression lines with the grid lines to the orthogonal view of the grid. This yields a planimetric not-to-scale map of the grid, the CRRR, and the face of the Briquetting building;
9) Repeat the procedure for the MRRR and the railroad siding. Add the now-missing warehouse;
10) Translate, scale, and rotate the model to MCS83;
11) Add the features tied by conventional methods – the trestle, the fence (on 2018 photo), other buildings;
12) Compare the results to known values.

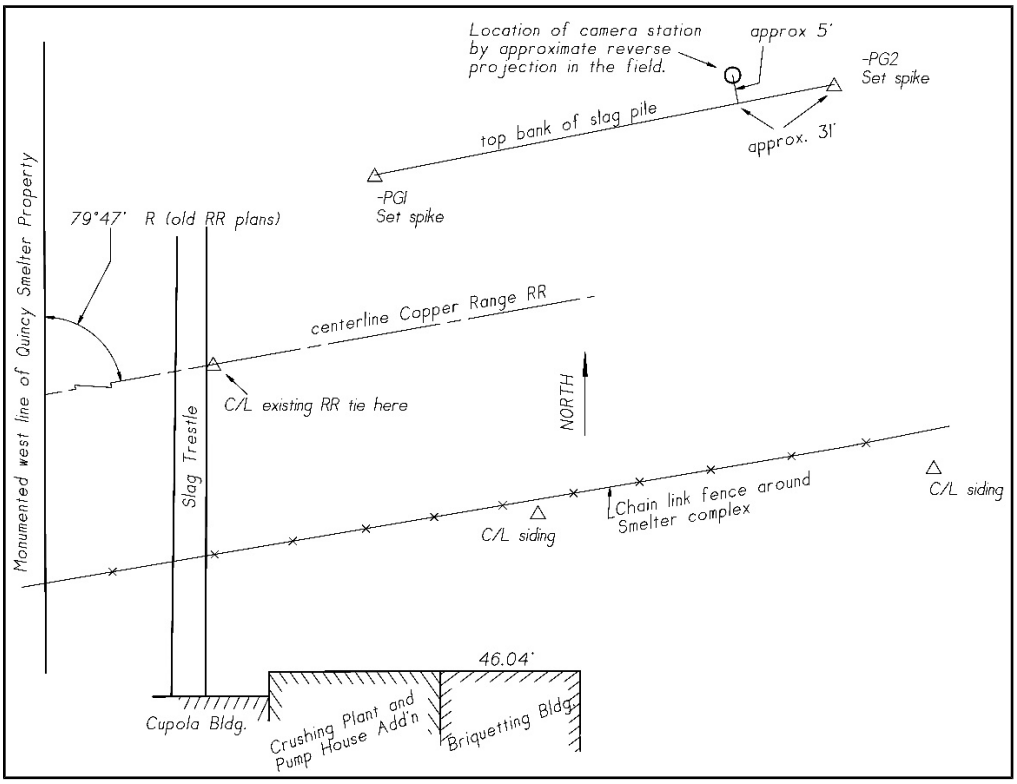

Figure 3. Showing the known location of existing features (the CRRR is the record position). Two GPS traverse points, "**-PG1**" and "**-PG2**" were established on the slag pile from which ties were made to the features shown.

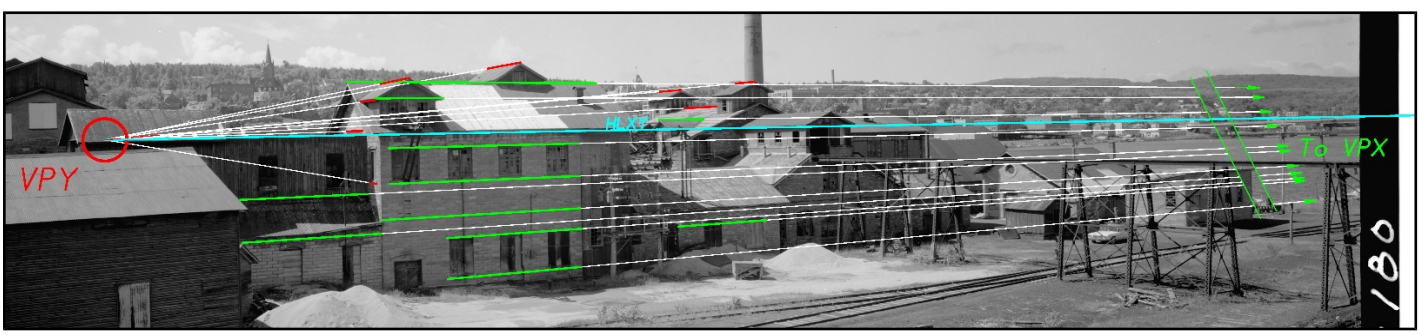

Figure 4. Establish the X and Y vanishing points (**VPX** and **VPY**) using the orthogonal lines given by the Briquetting building (and adjacent parallel building). The red segments are extended to intersect at **VPY**, and the green to **VPX**. Draw the X-Y horizon line (**HLXY**) as a straight line between **VPX** and **VPY**. Note the relatively short lengths of the lines from which **VPY** is determined. This is a source of error and consequently we can say that the perspective of this photo is weak.

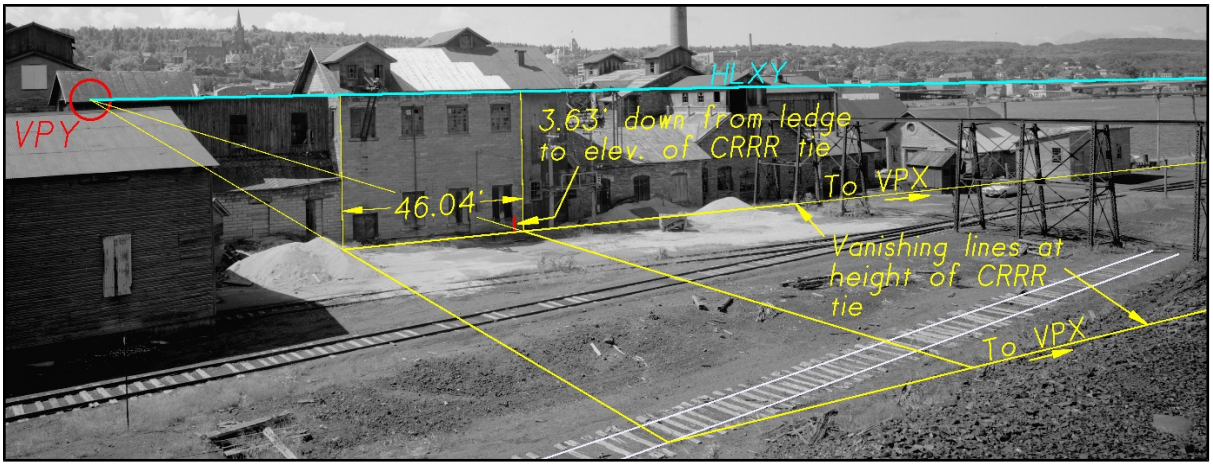

Figure 5. The aforementioned CRRR tie elevation is 3.63' lower than the window ledge at the lower right corner of the Briquetting building. We establish a rectangle in perspective of width 46.04' (the width of the building) and a length so as the lower left corner of the rectangle intersects the outside tie plate impression line of the CRRR.

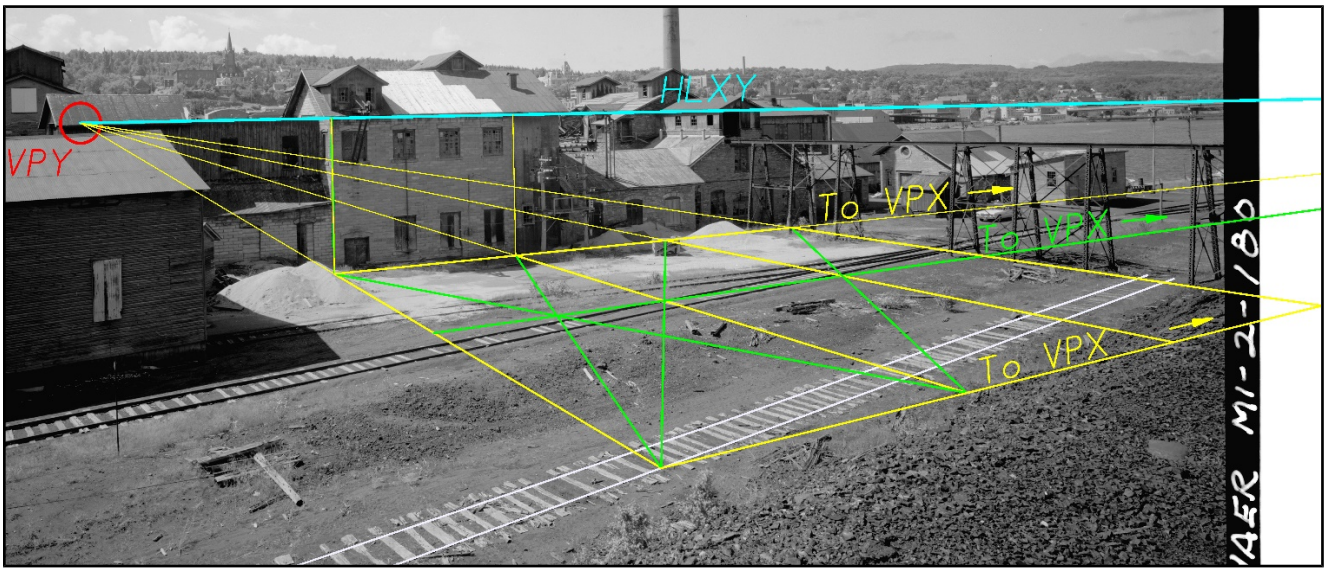

Figure 6. In a manner described in Part 1 of this article, we extend the rectangle to create two identical and adjacent copies which form a grid of 3 identically-dimensioned units. The green lines are construction lines.

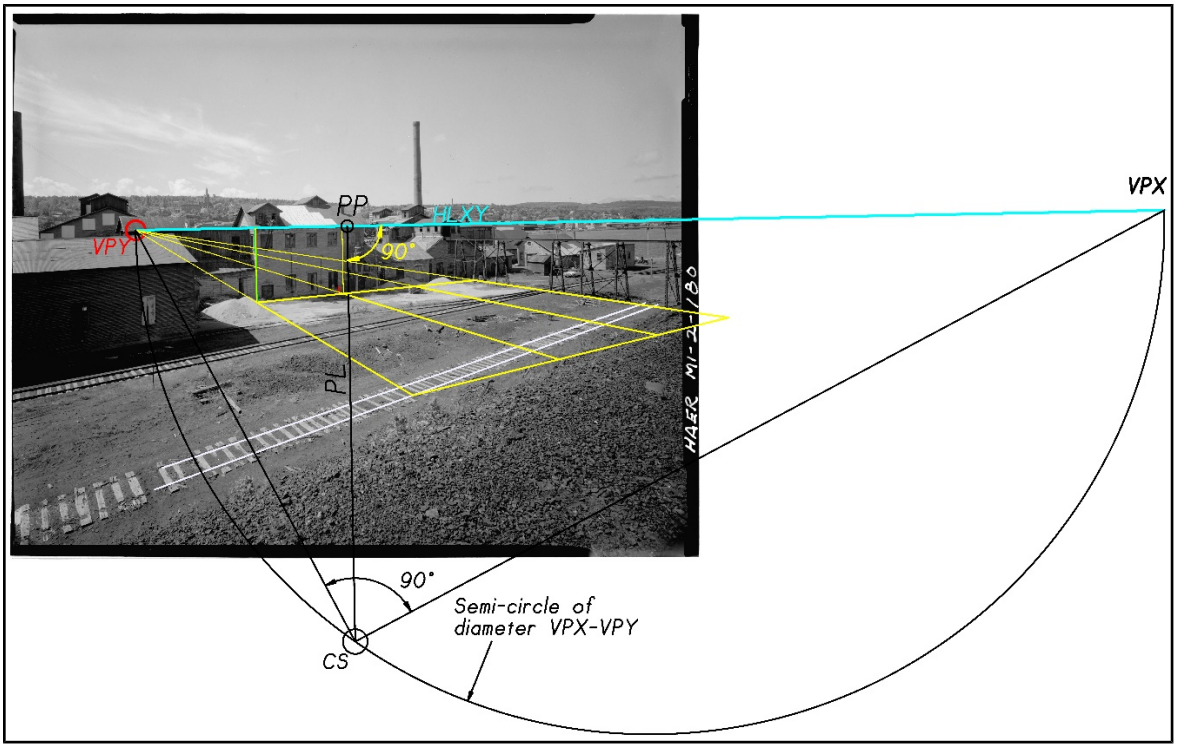

Figure 7. Construct a semicircle with **VPX** and **VPY** as the diameter. Picture the semicircle as a hinged horizontal plane with **HLXY** being the hinge and the plane perpendicular to the page you are reading, but here shown folded down about the hinge and into the plane of the image. Since **VPX** and **VPY** are orthogonal, geometry dictates that the camera station in 2-point perspective must fall on this semicircle. In the absence of knowledge of the true principle point (**PP**), we are creating the principle line (**PL**) perpendicular to **HLXY** and passing through the center of the image. The intersection of **PL** and **HLXY** is the **PP**. Note that **HLXY** is located well above the horizontal centerline of the photo, and the **PP** is therefore not near the center of the photo, as one would normally expect. This is due to the downward offset of the lens of the view camera at the time the photo was taken. HABS/HAER photographers raise or lower the front or rear standard of the camera (maintaining parallelism with the back) to improve the composition of the image[1]. It is not known if the lens was shifted right or left, another possible error source. We are here assuming there was no horizontal shift and that the **PP** still lies near the vertical centerline of the photo. Given the **PL** shown, the camera station in planimetric view is at the intersection of the semicircle with the extension of the **PL**. Williamson[1], details a method by which a known horizontal or vertical angle in the scene can be used to help determine the location of the **PP**. The author applied the published method but did not observe an improvement in the final results in this case.

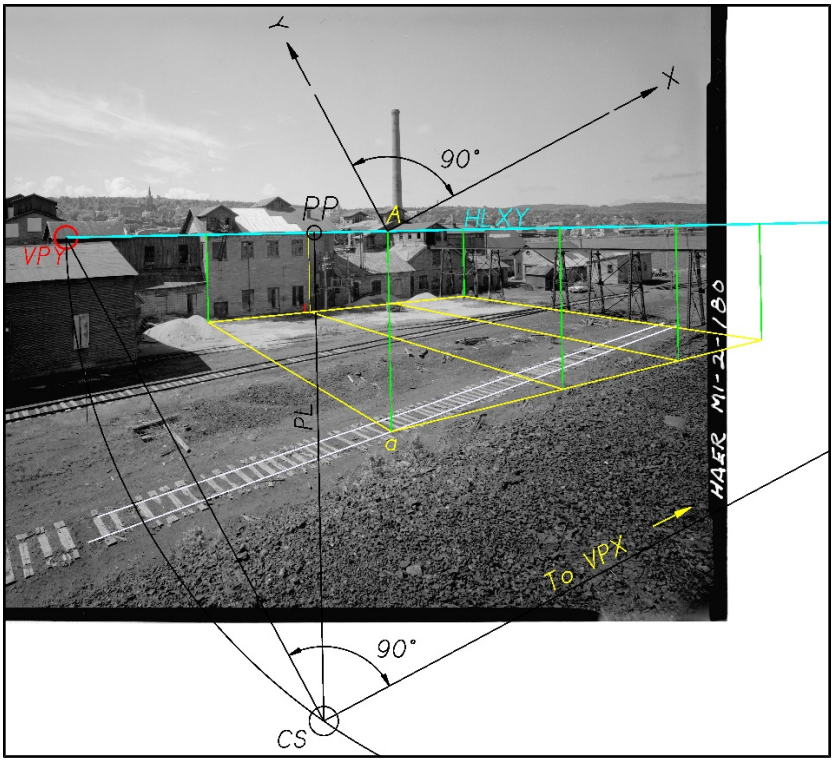

Figure 8. From the corners of the perspective grid, erect lines (green) perpendicular to **HLXY**. Point **A** will be the origin of the XY plan view. The plan coordinate axes are parallel to the corresponding **CS-VPX** and **CS-VPY**.

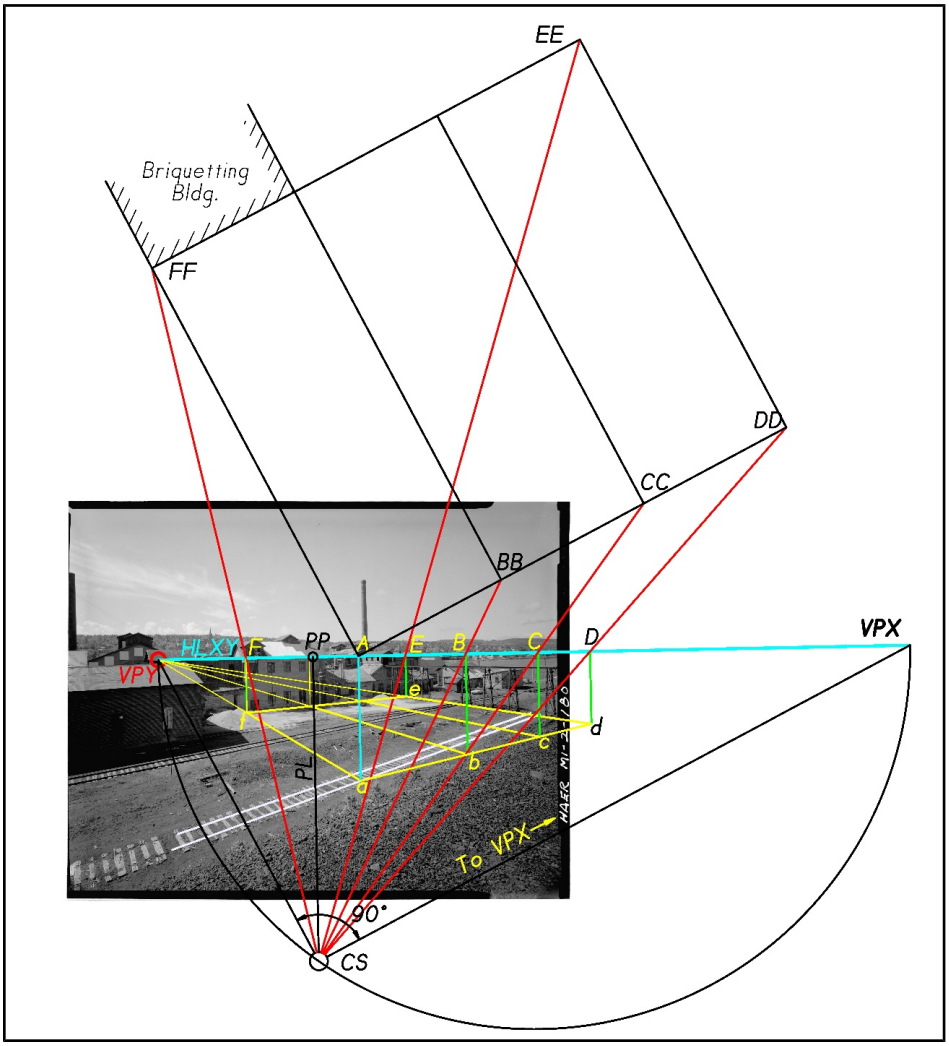

Figure 9. The plan view of the entire grid is created. Extend lines (red) from **CS-B**, **CS-C**, **CS-D**, and **CS-F** to **BB**, **CC**, **DD**, and **FF**, respectively. Square off the grid through **EE** and erect orthogonal lines through **BB** and **CC.**

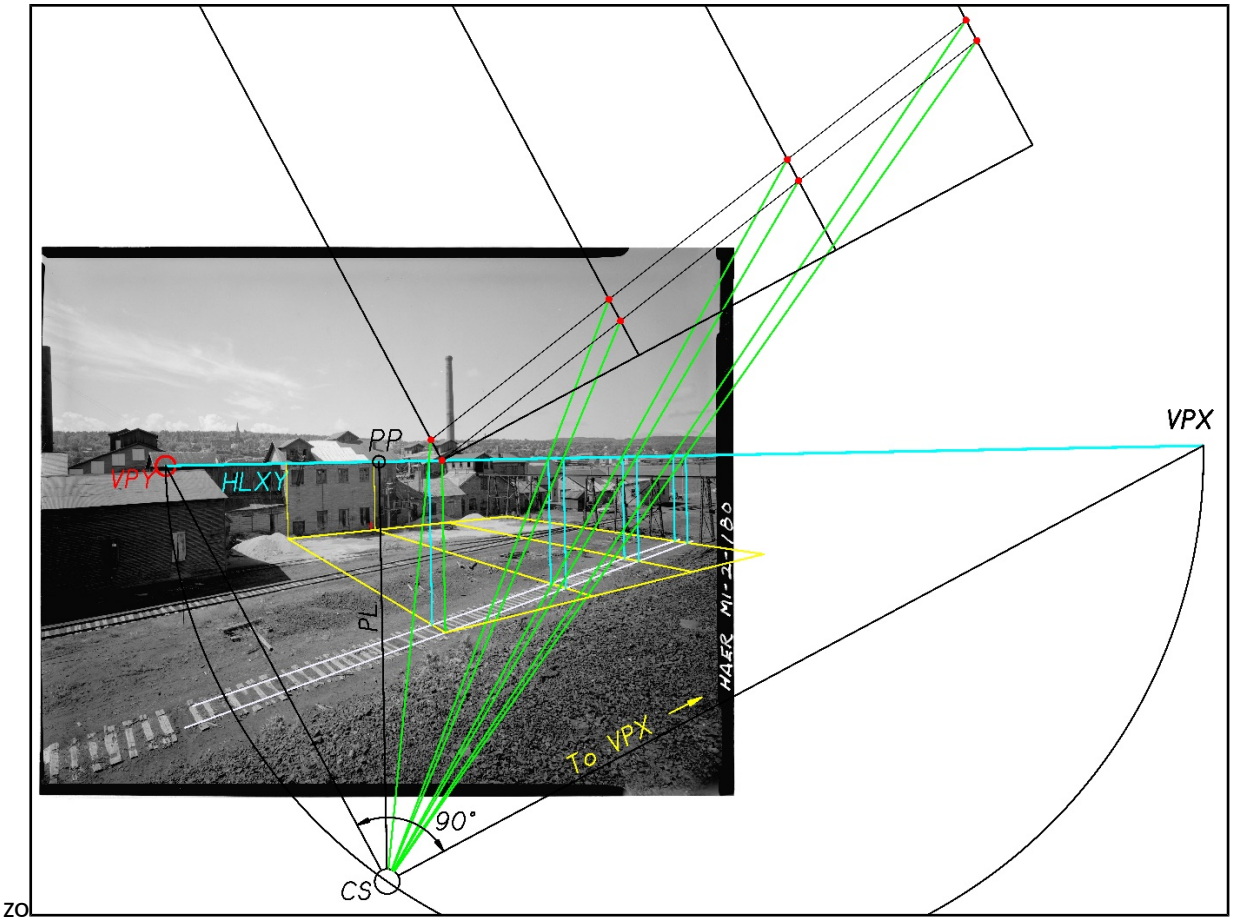

Figure 10. In a similar manner, erect perpendiculars (cyan) to **HLXY** from the intersections of the grid sidelines with the CRRR tie plate impression lines. Construct and extend lines (green) from **CS** through those intersections to the corresponding plan view grid lines. The **CS** and the plan view of the grid are in the same plane and scale. The projected CRRR tie plate impression lines connect the red dots.

At this point, Figure 10,we have a planimetric view of the grid, the CRRR, and the camera station. Each rectangle of the grid is 46.04' wide (the width of the Briquetting building) and the grid lines are parallel with the building lines. As shown in Figure 9, the upper left grid line is coincident with the face of the Briquetting building.

Now we must repeat the entire procedure for the MRRR and the siding. Since the rails show up nicely on the 1979 photo we can trace line features along the tops of the rails. The perspective grid (yellow) must be reestablished at the elevation of the rail tops. We will have to presume that the siding and the MRRR were at the same height and we'll use the measured elevation of the siding RR tie near the center of the photographed area, 607.9', and add to it 6" for a top-of-rail elevation of 608.4'. This is 1.1' higher than that used for the CRRR, and is 2.54' below the window ledge of the Briquetting building. The creation of the plan views of the MRRR and siding proceed through the same steps as above. I'll not be showing the details of those reconstructions here but I've run through the entire method for those two sets of tracks and the final results are shown below.

Once all of the features have been plotted to the plan view the map, including the camera station position, is translated, rotated, and scaled to fit the MCS83 position of the face of the Briquetting building.

The final result is shown in Figure 11. Behind the scenes, I've also extended the grid by one more cell, to include the corner of the RR warehouse building.

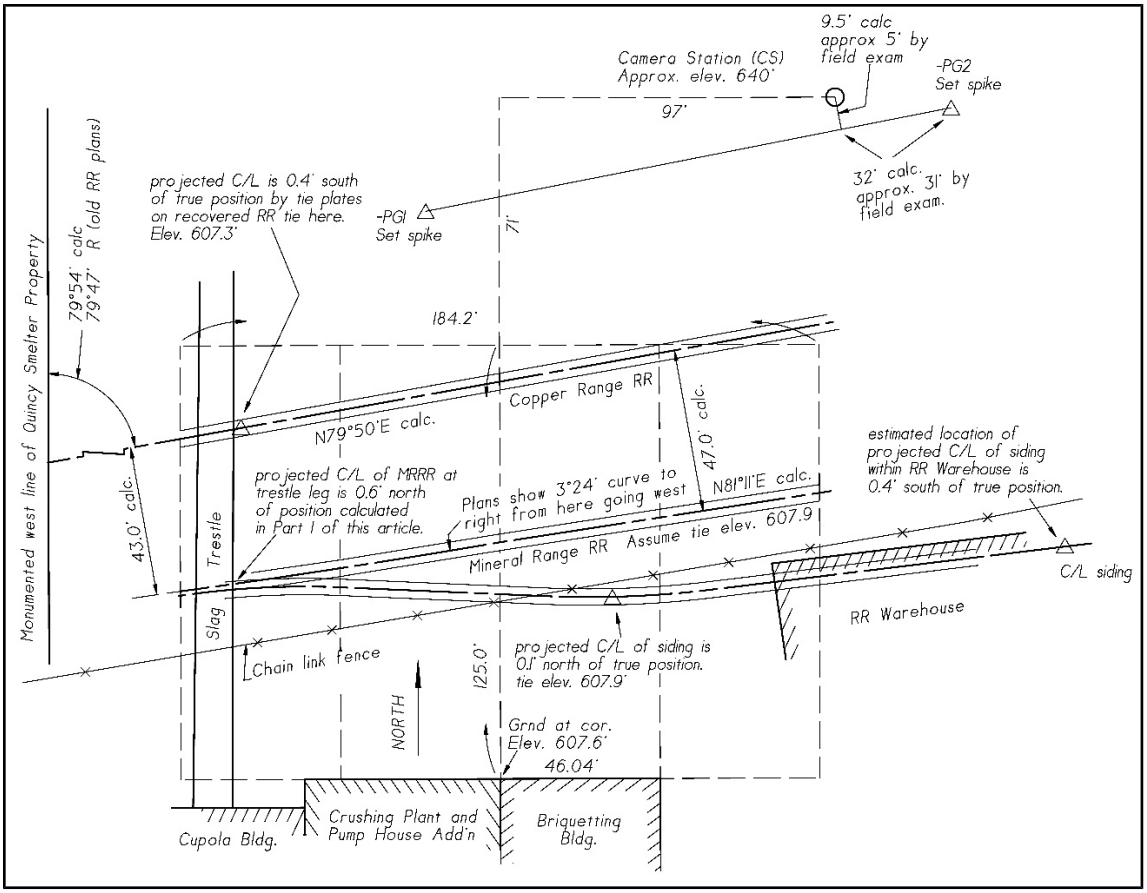

Figure 11. The resulting planimetric map of the area depicted in the 1979 photo

We have five observations against which we can check the accuracy of this model -- the RR tie at the trestle on the CRRR, the calculated centerline of the MRRR at the trestle in Part 1 of this article, the two ties to the existing tracks on the RR side track, and the reverse projection location of the **CS**. Four of these (all but the **CS**) check to better than a foot. The record angle at the west property line also checks well against this solution.

This is a remarkable result considering the vast array of error sources lined up against this project and the close agreement that these check points exhibit might be attributable in some measure to coincidence and/or luck. Since there are many potential sources of error, it would be unwise to make a broad generalization about the overall accuracy based on these few checks. The error sources include: geometrically very poor 2-point perspective making **VPY**, in particular, very difficult to determine accurately; an unknown **PP** of the photograph (due to possible left or right shift of the front standard of the view camera; only a few spot elevations were available, requiring assumptions about the height of the railroads; the whole model was extrapolated from a relatively small section of the entire photograph; the margins of the photo are irregular, making definitive location of the center of the photo impossible; the assumptions regarding the perfect orthogonality of the structures used to develop the grid may not be valid; and unknown stretching or shrinkage of the photo prior to scanning (or introduced by scanning). It is very difficult (for this author, at any rate) to develop an intuitive grasp of how each of the various sources of error, in their own way, influence the final results.

The most questionable position is that of the camera station. After carefully investigating the likely position of the camera in the field, I had come to the conclusion that the **CS** could not have been located more than 5 or 6 feet northerly of the line **-PG1** to **-PG2.** Were the camera more than 5 or 6 feet north, the crest of the slag pile would have obscured certain portions of the trestle legs from view, portions that are visible on the 1979 photo.

According to this solution the tangent portions of the CRRR and MRRR tracks were not parallel by nearly 1.5 degrees; the calculated bearings of each are shown on the sketch. The calculated distance between the railroads (47.0') checks well with the 1902 blueprint 47.7' but since they are not parallel, this is not a valuable check measurement.

To conclude, using an old photograph and the principles of perspective geometry, it **IS** possible to answer the question: *"Where was that railroad?"*.

I hope that these articles have sparked renewed interest in "simple" photogrammetry or has been a refresher for those who have not employed these techniques in a while. To be sure, dimensional analysis through perspective is a fascinating discipline and a tool well suited to anyone who enjoys unique ways of measuring things.

References and further reading

1. Jet Lowe, email to the author, August 2018. http://www.jetlowe.com
2._J.R.Williamson and M.H.Brill, "Dimensional Analysis Through Perspective, A Reference Manual". American Society for Photogrammetry and Remote Sensing, 1990
3. J.C.C. Williams, "Simple Photogrammetry". Academic Press, 1969

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T.O. McCartney, "Precision Perspective Drawing". McGraw-Hill, 1963

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

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