Final Report
Blind Area Study
Large Mining Equipment

Blind area diagrams for selected mining vehicles

Contract 200-2005-M-12695

John Steele, PhD, PE
1473 S. Eudora St.
Denver, Colorado 80222-3527
T: 303-300-3573
E: SteeleWorks@mac.com

July 22, 2006

Table of Contents

INTRODUCTION **1**

MOTIVATION 1

BLIND AREA MEASURES 1

MINING EQUIPMENT DESCRIPTION **1**

COMMENTS **2**

MACHINE DESCRIPTIONS, PHOTOS, AND BLIND AREA DIAGRAMS **3**

DOZERS 3

Ground Level Diagram *3*

1.5 Meter Level Diagram *4*

HAUL TRUCKS 5

Ground Level Diagram *5*

1.5 Meter Level Diagram *6*

MOTOR GRADER 7

Ground Level Diagram *7*

1.5 Meter Level Diagram *8*

SHOVEL 9

Ground Level Diagram *9*

1.5 Meter Level Diagram *10*

WHEELED LOADER 11

Ground Level Diagram *11*

1.5 Meter Level Diagram *12*

APPENDICES **13**

MEASUREMENT PROCESS 13

BLIND AREA DATA COLLECTION PROCEDURE 14

DATA FILE DESCRIPTION 16

REFERENCES **17**

Introduction

Motivation

Identifying the areas around large mining equipment in which workers, vehicles and other objects cannot be seen is important. By documenting these areas and communicating the results to operators who run the equipment, the risk of accidents can be more adequately appreciated. Also, mine supervision staff can possibly develop better strategies for dealing with these blind areas once they know their extent.

While the main goal of this project has been to provide NIOSH with the information requested, in the form and style stipulated, a secondary objective was to provide data collection and data conversion methods that could be implemented by NIOSH personnel in future blind area mapping activities, using readily available computer applications (i.e., MS Excel). By in large, this secondary goal was achieved, although the requirement that the bind area plotted should be filled (which was accomplished in Excel) lead to a need to generate positional information on one-degree increments. In retrospect, it would make more sense to plot the diagrams unfilled in Excel and then use another application like Photoshop, Freehand, or OmniGraffle to add the fill to these areas. While this approach has not been tested here, it is the expectation of the author that that approach would be more efficient.

Blind Area Measures

The intent of these measures is to document the area around the operator for which s/he cannot see obstacles (objects). The plots that have been generated are presented for two different elevations: ground level and 1.5 meter above the ground. The choice of the ground level is self-evident, we want to document the area at ground level that cannot be seen. The 1.5-meter elevation represents the elevation at the top of the head for a 5% female (essentially the shortest human expected in the work area. Thus the 1.5-meter plot shows that area where a shorter human would not be observed.

The measurement process follows closely, but not exactly the process described in ISO 5006, *Earth-moving machinery – Operator's field of view* [ISO 5006]. The process uses the SIP (seat index point) [ISO 5353] as the origin from which the lights are positioned, i.e., 660 mm above and 20 mm in front of the SIP. Specifically, the lighting system that is described in the standard was adapted to make the measurement process much more responsive by making the lighting system passive, i.e., no rotation of the lights is required at any point in the measurement process. This was done by expanding the light source from a line to cylinder, with a diameter of 70 mm, in such a manner as to integrate the effects of light rotation (about the origin) without requiring the lamps to move. This greatly increased the efficiency of the measurement process. A full description of the measurement process in provided in Appendix A, and a step-by-step description of how to acquire the data using a Pentax Total Station is provided in Appendix B. Appendix C provides a description of the data format contained in the machine workbooks.

Mining Equipment Description

As stipulated in the RFP (see section Mining Equipment Selection), mining equipment of specific classes (capacities) were to be measured within the categories of dozers, haul trucks, motor graders, shovels and

wheeled loaders. The following five machines were selected and approved for measurement:

- **Cat D11 Dozer [DZ]**
- **EX5400 Euclid Haul Truck [HT]**
- **Cat 16G Motor Grader [MG]**
- **EX5500 Hitachi Shovel [SH]**
- **Cat 992 Wheeled Loader [WL**]

Through the generosity of two Colorado mines (Trapper Mine, Craig, Colorado, and Cripple Creek and Victor Mine, Cripple Creek, Colorado) access to these machines was granted. Measurements were made as equipment became available during the spring of 2006.

Comments

Through the process of refinement, an efficient procedure for measuring large mining equipment blind areas has been developed. A quick review of the plots provided from this work shows that these machines block a considerable amount of the operator's view, even with the aid of mirrors. The process of generating the plots was much more challenging and cumbersome than anticipated, and the general level of support polar plots across a variety of applications is much less than was expected. While the plotting of the blind area at ground level and 1.5 meter provide reasonable boundaries for identifying the blind "volume", a 3-D representation (perhaps with animation) would certainly aid in visualizing the effects of blocking of the operator's view.

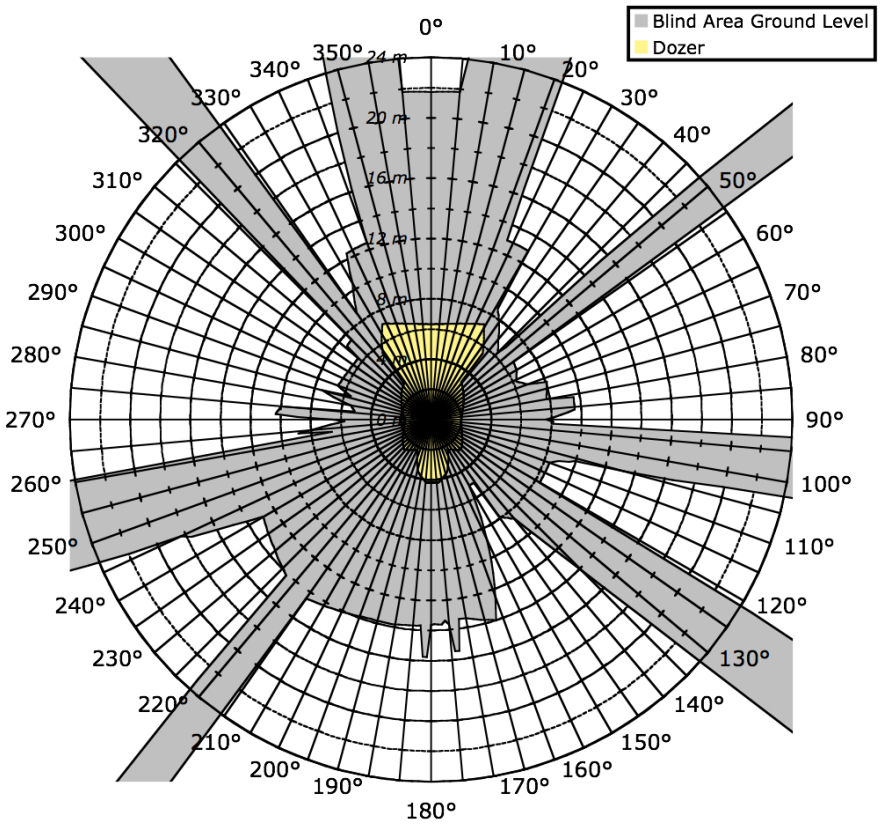
Machine Descriptions, Photos, and Blind Area Diagrams

Dozers

Ground Level Diagram

Dozer (Manuf. & Model)	Cat D11R
GVM	113,000 kg
Machine Dimensions	12 m long, 3 m wide, 2 m tall
Operator Enclosure	Closed ROPS (Roll-Over Protective Structure)
Attachments	Single-shank ripper
Other Information	Blade capacity 43.6 m^3 , 7 mph max, drawbar force 350,000 lbf
Measurement Technique	Physical

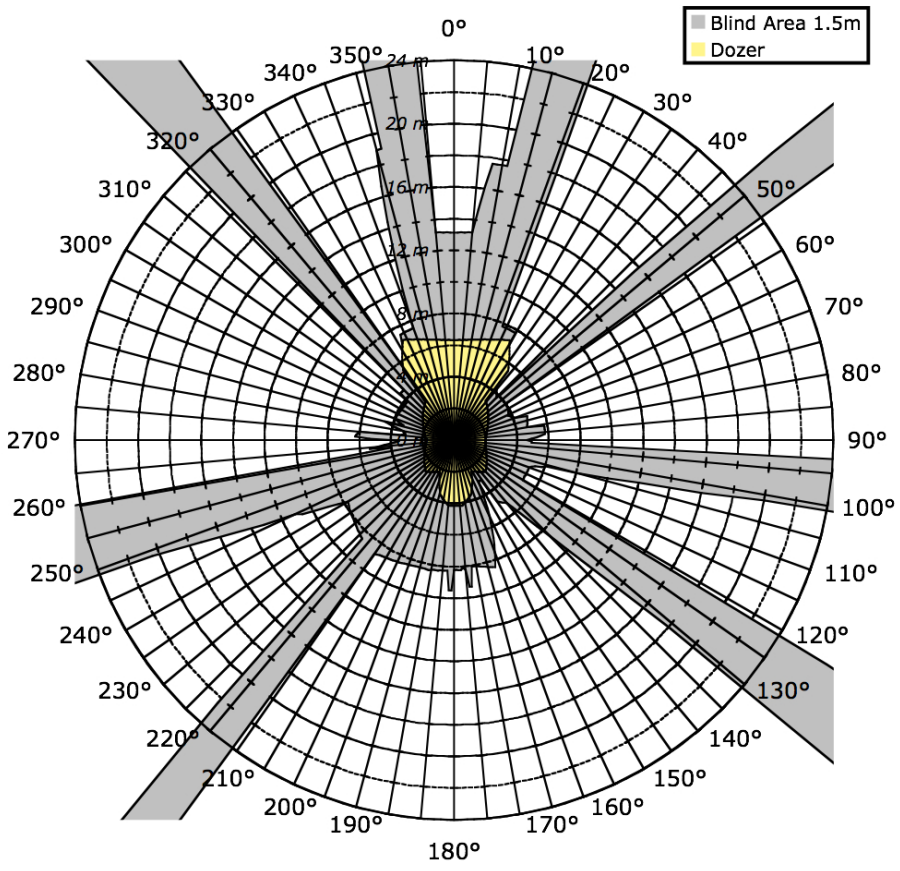
Blind Area Diagram - Dozer
Ground Plane



1.5 Meter Level Diagram

Dozer (Manuf. & Model)	Cat D11R
GVM	113,000 kg
Machine Dimensions	12 m long, 3 m wide, 2 m tall
Operator Enclosure	Closed ROPS (Roll-Over Protective Structure)
Attachments	Single-shank ripper
Other Information	Blade capacity 43.6 m^3 , 7 mph max, drawbar force 350,000 lbf
Measurement Technique	Physical

Blind Area Diagram - Dozer
1.5 meter plane

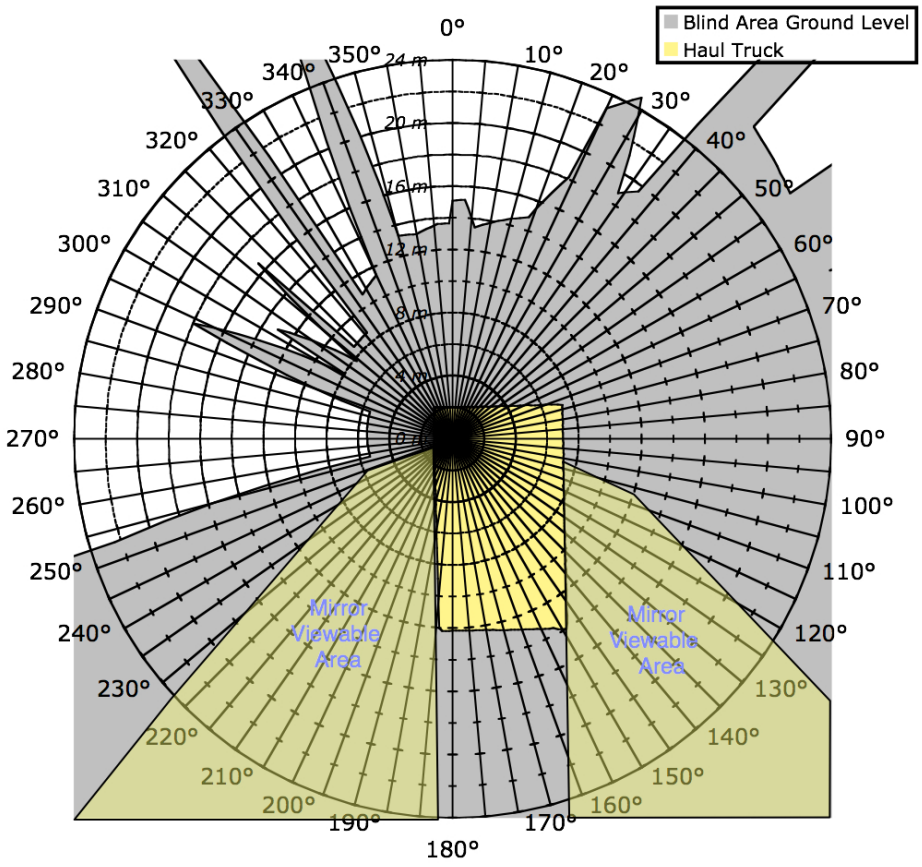


Haul Trucks

Ground Level Diagram

Haul Truck (Manuf & Model)	Euclid EH4500
GVM	435,456 Kg
Machine Dimensions	14.1 m long 8.15 m wide 7.04 m tall
Operator Enclosure	Closed ROPS
Attachments	None
Other Information	255.5 metric ton (281.6 ton) capacity, 2013 kW (2700 hp)
Measurement Technique	Physical

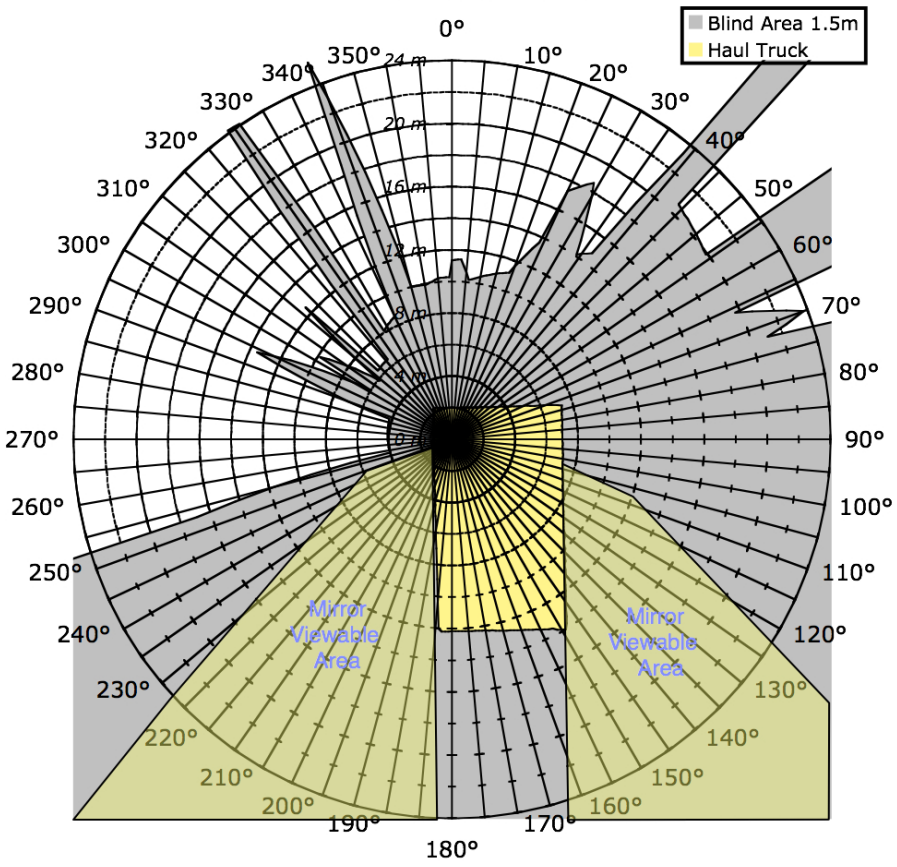
Blind Area Diagram - Haul Truck
Ground Plane



1.5 Meter Level Diagram

Haul Truck (Manuf. & Model)	Euclid EH4500
GVM	435,456 Kg
Machine Dimensions	14.1 m long 8.15 m wide 7.04 m tall
Operator Enclosure	Closed ROPS
Attachments	None
Other Information	255.5 metric ton (281.6 ton) capacity, 2013 kW (2700 hp)
Measurement Technique	Physical

Blind Area Diagram - Haul Truck
1.5 Meter Plane

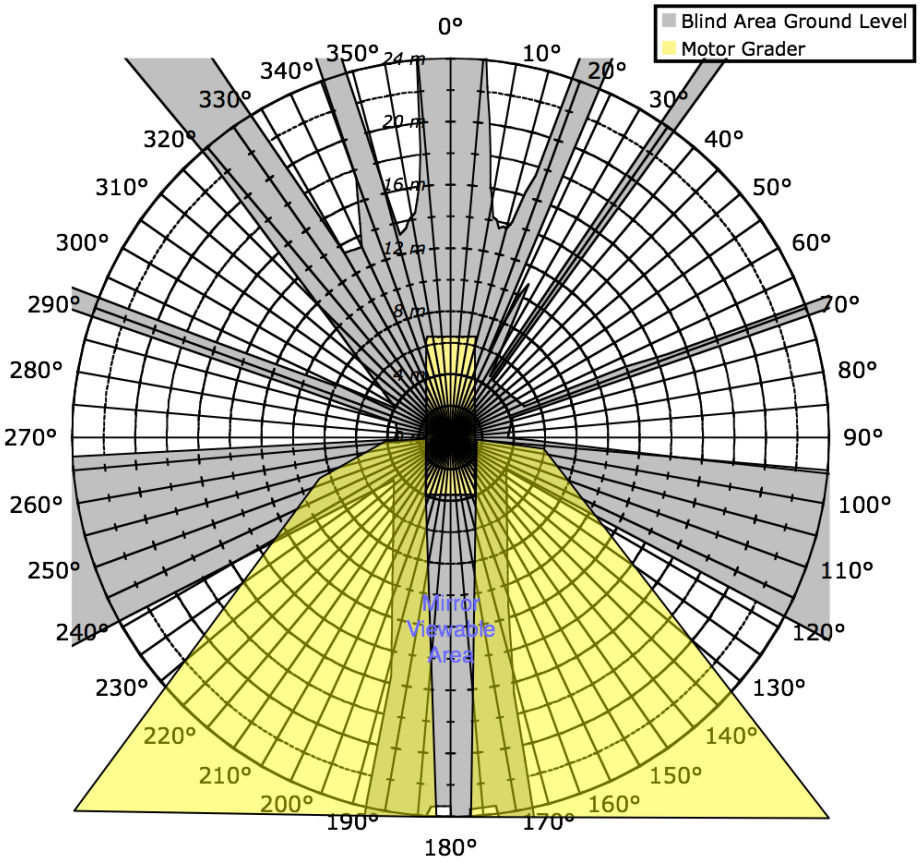


Motor Grader

Ground Level Diagram

Grader (Manuf. & Model)	Cat 16G Motor Grader
GVM	24,800 kg
Machine Dimensions	11.623 m long 3.077 m wide 3.749m tall
Operator Enclosure	Closed ROPS
Attachments	Rear mounted drag blade
Other Information	240 kW (300hp)
Measurement Technique	Physical

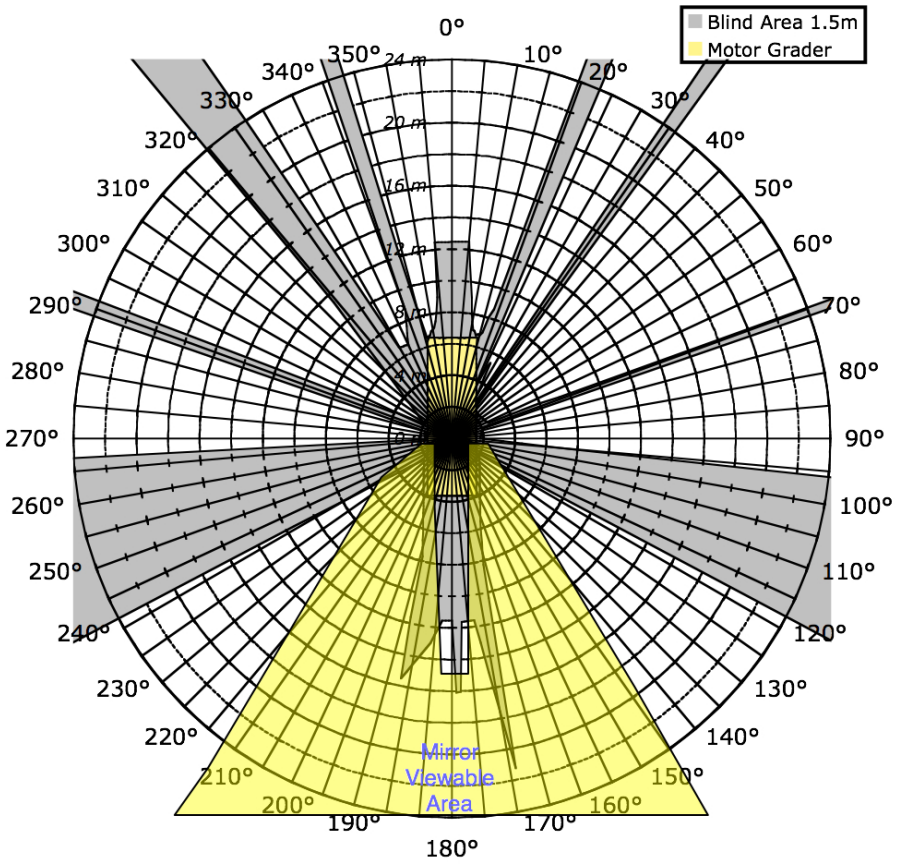
Blind Area Diagram - Motor Grader
Ground Plane



1.5 Meter Level Diagram

Grader (Manuf. & Model)	Cat 16G Motor Grader
GVM	24,800 kg
Machine Dimensions	11.623 m long 3.077 m wide 3.749m tall
Operator Enclosure	Closed ROPS
Attachments	Rear mounted drag blade
Other Information	240 kW (300hp)
Measurement Technique	Physical

Blind Area Diagram - Motor Grader
1.5 meter plane

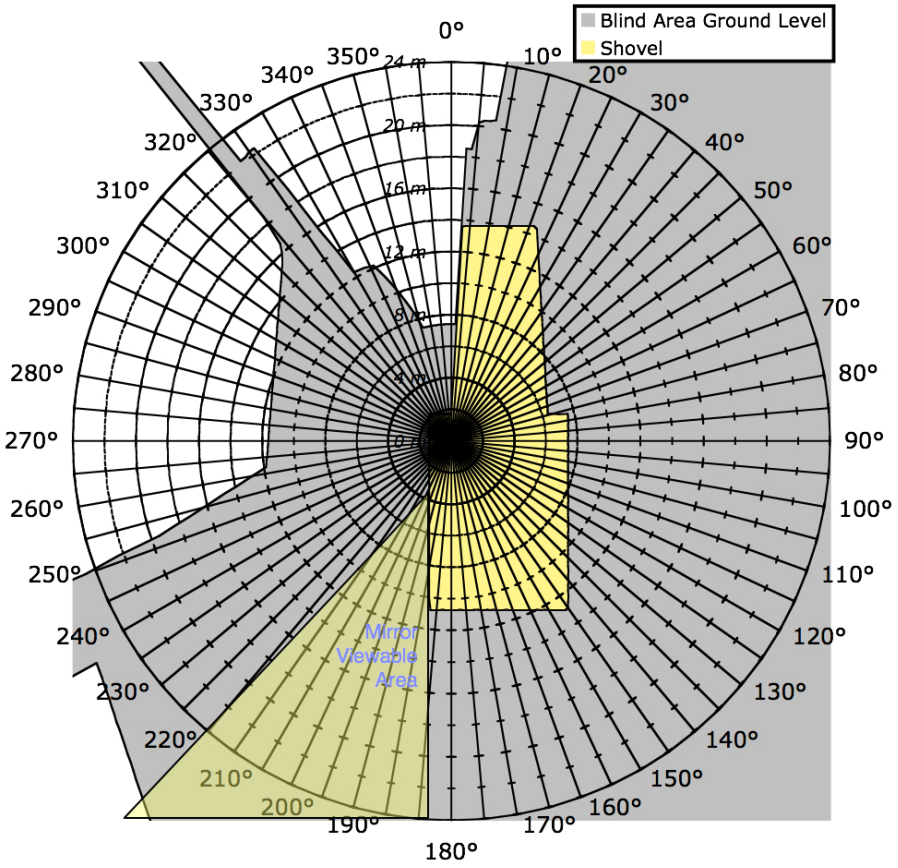


Shovel

Ground Level Diagram

Shovel (Manuf. & Model)	Hitachi EX5500
GVM	518000 kg
Machine Dimensions	23.1 m long 9.850 m wide 8.50 m tall (shovel at full ground level reach) 17.55 x 9.85 x 8.5 (minimum crowding distance)
Operator Enclosure	Closed ROPS
Attachments	none
Other Information	30.6 m^3 (40 yd) bucket 2014 kW (2700 hp)
Measurement Technique	Physical

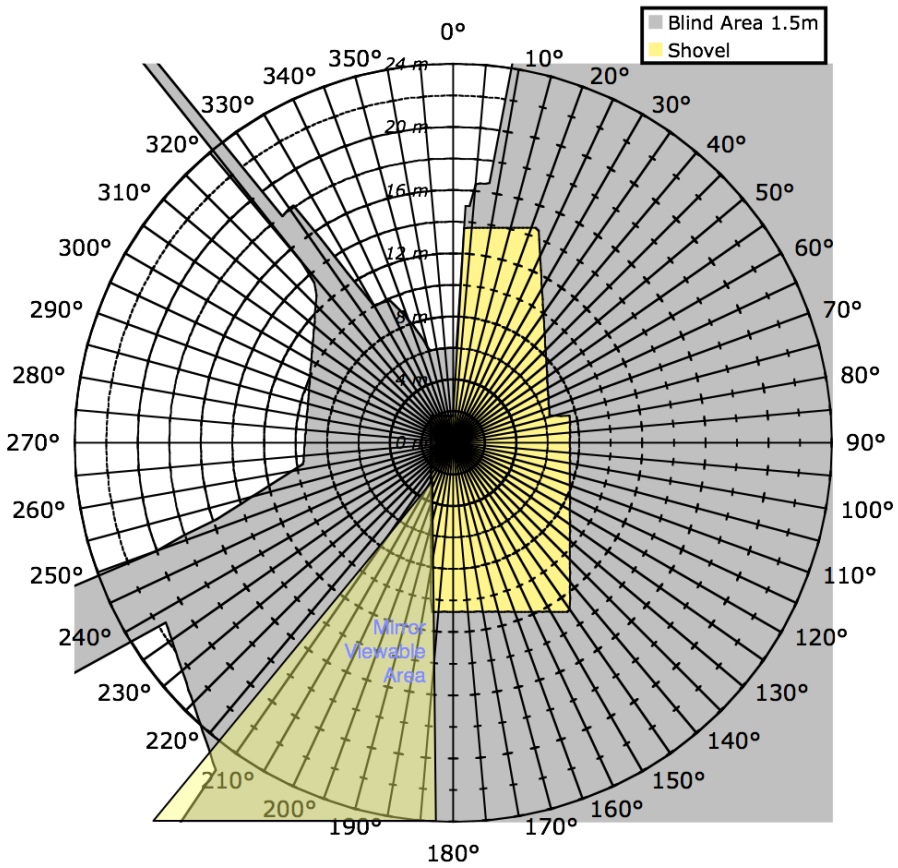
Blind Area Diagram - Shovel
Ground Plane



1.5 Meter Level Diagram

Shovel (Manuf. & Model)	Hitachi EX5500
GVM	518000 kg
Machine Dimensions	23.1 m long 9.850 m wide 8.50 m tall (shovel at full ground level reach) 17.55 x 9.85 x 8.5 (minimum crowding distance)
Operator Enclosure	Closed ROPS
Attachments	none
Other Information	30.6 m^3 (40 yd) bucket 2014 kW (2700 hp)
Measurement Technique	Physical

Blind Area Diagram - Shovel
1.5 Meter Plane

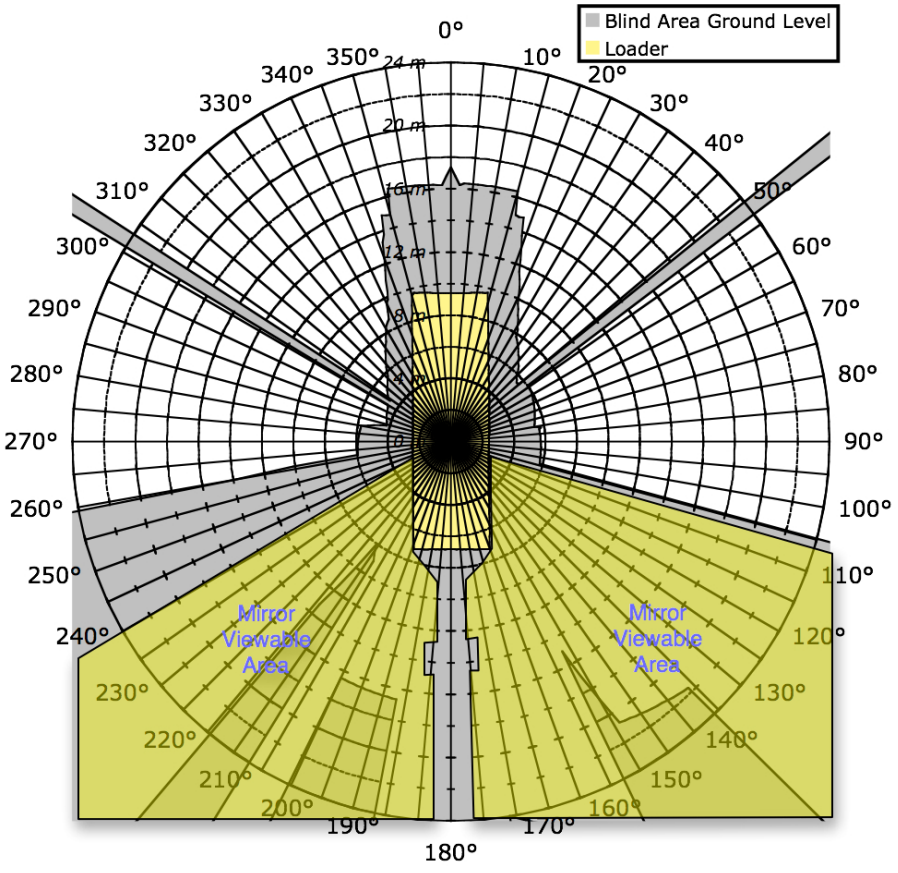


Wheeled Loader

Ground Level Diagram

Loader (Manuf. & Model)	Cat 992G Wheeled Loader
GVM	100,227 kg
Machine Dimensions	16.226 m long 4.84 m wide 5.59 m tall
Operator Enclosure	Closed ROPS
Attachments	None
Other Information	11.5 cu. M bucket
Measurement Technique	Physical

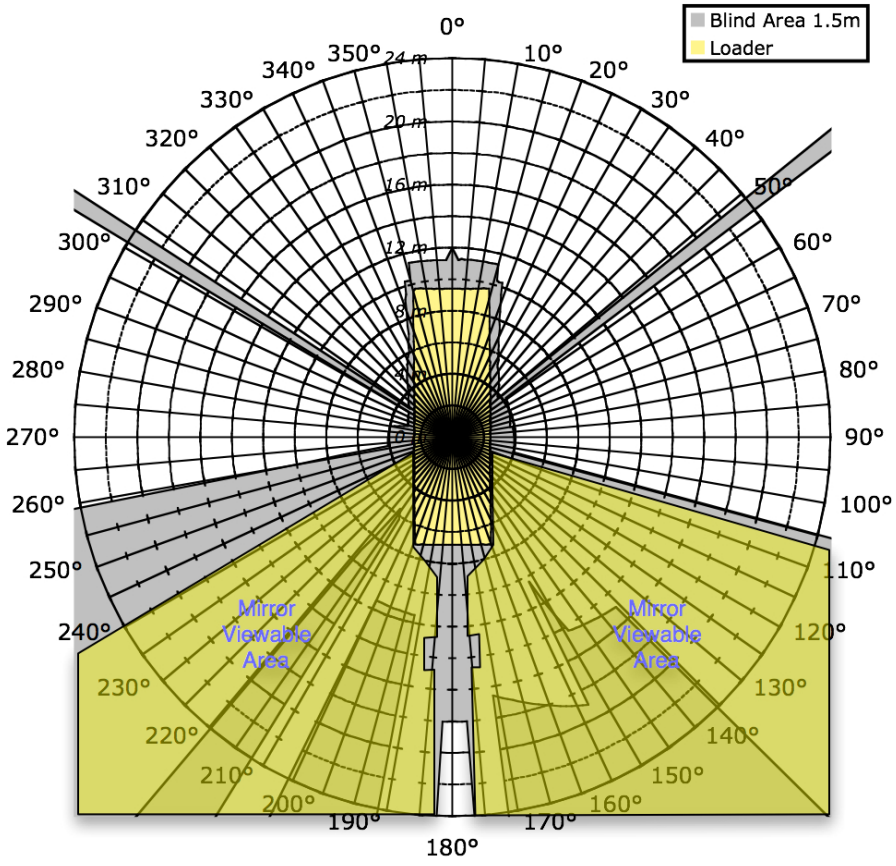
Blind Area Diagram - Wheeled Loader
Ground Plane



1.5 Meter Level Diagram

Loader (Manuf. & Model)	Cat 992G Wheeled Loader
GVM	100,227 kg
Machine Dimensions	16.226 m long 4.84 m wide 5.59 m tall
Operator Enclosure	Closed ROPS
Attachments	None
Other Information	11.5 cu. M bucket
Measurement Technique	Physical

Blind Area Diagram - Wheeled Loader
1.5 Meter Plane



Appendices

Measurement process

The process of acquiring the blind area data went through an evolutionary process. The original plan was to use a camera tethered to a balloon to take photos of the light cast by lamps mounted at the operator's head location. While this had the appeal of being quick to setup and capture, it turned out that finding a camera with the resolution and light sensitivity needed to capture the data was not within the scope of the project, i.e., such cameras are quite expensive. In addition, the issue of how to provide absolute reference markings (i.e., coordinates) for such a lighting system was never fully resolved (an attempt to use light ribbons showed incremental distance but the absolute measure of location was never tested). Thus an alternative method was needed. The first machine measured was the D11 dozer provided by the Trapper Mine, and a protocol based upon previous work done by Todd Ruff [2002] was used. A center point was located and radial lines were staked at 10-degree increments, using a surveying instrument (Total Station), to provide reference for the blind area boundaries. Surveyor's paint was used to mark the boundaries and then these boundaries were surveyed using a Pentax Total Station.

Prior to collecting data for the other machines, it was determined that the Total Station had a feature called coordinate surveying which provides for the conversion of the measured points into (x,y) coordinates, relative to a defined base location. These recorded points could then be uploaded to a computer via a serial connection. This made the process of conversion easier since the points to be analyzed and plotted were already in Cartesian form; they still had to be transformed to locate the origin at the operator's head location and the angular alignment had to be adjusted to coincide with the pointing direction of the machine. This technique was used on the second round of data collection, which took place at the Cripple Creek and Victor Gold Mine. The technique worked well. An additional refinement was added when, because of the need to dispatch the wheeled loader to another task, before all the measurements had been completed the vehicle was moved before the blind area boundaries had been surveyed. This turned out to be a benefit since with the vehicle gone, all the boundary marks could be surveyed from a single location, thus making the process of collecting and integrating the data easier. This approach was used for the last data collection, which involved the motor grader, and proved to be the most efficient method. Because the boundaries are marked on the ground using surveyors (bio-degradable) paint, the various vertices of the boundaries are marked and measured at their location. Thus the resolution is set by the observation and marking capability of the person doing the study. In addition, the process was found to be relative quick once the process was executed a few times – while the Total Station was set up, the lights were installed in the operator's cab at the position stipulated by ISO 5006. Once the lights were installed the process of observing and marking the boundaries at an elevation of 1.5 meters was executed (this is most easily done if a person with eye level at 1.5 meter elevation is used). Once the boundaries are marked, then a second color of paint is used to mark the mirror viewable areas. Once these two sets of boundaries are marked, the machine is moved and the boundaries are surveyed using the Total Station and a retro-reflective prism. Subsequently the data are uploaded to a computer for processing and plotting.

The processing involves transforming the collected data to an "operator centric" coordinate frame. A decision was made to use a readily available application to do the plotting, i.e., MS Excel. Because of the

requirements of Excel specific to plotting filled areas in polar plots, data at one-degree increments were required. This meant that the recorded vertices and their corresponding polar coordinates had to be expanded to identify the location of the boundary for each degree (i.e., 0 to 360). This turned out to be a challenge and algorithms were developed to do the conversion. In Cartesian space, the algorithm fits lines between the vertices recorded, then polar rays, generated at one-degree increments, are intersected with these lines and the radial distance, from the origin, is computed. These polar pairs are stored and then transferred to the Excel spreadsheet for plotting. Macros were written to automate the process of plotting both to improve the efficiency and to help standardize the output. Finally, again because of limitations of Excel polar plots, the mirror viewable areas are added via another graphics program (Omnigraffle), since only regions with origins at the plot's origin (zero) can be plotted in Excel polar (called radar plots) plots.

Blind Area Data Collection Procedure

The following is an outline of the steps needed to survey the results of a blind area study of a piece of equipment. The first part of the outline will go over the basic procedure once arriving on-site, and the second part will enumerate the specific steps for setting up the total station and getting it configured for the coordinate survey.

Arriving on site

1. On arrival at the site, do a walk-around of the site and the vehicle, noting any dangerous or inaccessible areas that could affect instrument placement. Determine by visual inspection whether the site is level enough and large enough to lay out all the sight lines needed. Sight lines will vary widely by the type and size of equipment.
2. After determining that the site and placement of the vehicle are suitable, determine the surveying approach. A complete survey will require 1 - 3 instrument set-ups, and minimizing the number of set-ups will save time. The key factor in determining the approach is whether the vehicle can be moved after sight lines are laid out, and whether moving the vehicle may obliterate markings on the ground. If the vehicle can be moved and won't obliterate markings, then the sight lines can be laid out, the vehicle moved, and the entire site surveyed from a single station point. If the vehicle can't be moved, then 2 - 3 stations will be needed.
3. Once the surveying approach is determined, station set-up points will need to be determined, with the following constraints.
    a. The station point(s) must be able to see all points of interest. Of these, the most important point of interest is the **operator position**. The next most important points of interest are **landmark points** on the vehicle (tires, corners, blade or scraper) that will be used to establish the orientation and position of the vehicle.
    b. If the vehicle can be moved, then one station point can be used. Provided station placement will not hinder moving the vehicle, station points near the center axis of the vehicle, either front or back, will make keeping track of points easier and allow an ongoing logic check of coordinates.
    c. If the vehicle can't be moved, then two or three station points will be needed. Because of the risk of missing points, three stations are probably better, and two station points should only be used if the area of interest is severely limited, or constrained.
    d. If two station points are used, they must be chosen so that they can see each other, all areas of interest, and at least one can see the operator position. One of the station points will also serve as the origin for the coordinate system, and should, if possible, be chosen so as to provide an easy logic check
    e. If three station points are to be used, then one central point should be used as the origin for the coordinate system, and the other two station points should be established on opposite sides of the vehicle where they are visible from the origin. At least one of the

points should be able to see the operator position, and all points of interest should be visible from at least one of the two secondary points.

4. After the station points are chosen, they should be marked with a stake or a nail, preferably with some kind of highly visible ribbon tied around it so that it can be easily retrieved. An additional point should be marked as the **azimuth reference point** for orienting the coordinate system for the survey. To aid in a logic check of the coordinates as they are being surveyed, the azimuth reference point should be placed beyond the origin station point establishing a line between it and the origin station point that is approximately parallel to the center line of the vehicle.
5. Once all points are chosen and marked, and the sight lines established by visible inspection, the coordinate survey can be completed. To save time, the instrument can be set-up, and the operator position and additional station points can be surveyed while the sightlines are being marked.

Instrument set-up

Instrument set-ups come in two varieties. The first instrument set-up establishes the origin and orientation of the coordinate system. Other instrument set-ups are done on points with coordinates established from the first instrument set-up and are used to survey points in the sight lines for the vehicle that aren't visible from other station points. The procedure for setting up the instrument and surveying from the origin point will be outlined first, and that for secondary points second.

Instrument set-up (origin point)

1. Change "mode" to B by pushing the "Mode" softkey (F5).
2. Choose "S. Func." (F1), then use the arrow keys to choose option 2 "Coordinates" and hit the Enter key. Select "Job Name" and hit Enter. Now use arrow keys and alpha-numeric pad to enter the job name. When finished, hit Enter.
3. "Station # list" will come up. The first point # defaults to 0000. Hit Enter. Now the "Station Coord. Input" screen will appear. If the coordinates shown are 0,0, and this is to your liking, hit Enter.
4. "Backsight Selection" will be next. Choose "Azimuth Input" and hit Enter. Sight on the backsight, then go to page 2/2 (F5) and set Horiz. Angle to 0 by pressing "0 set" twice in quick succession (F3). This will "orient" your total station. Now, go back to page 1/2 (F5).
5. Push "measure" (F1). WRITE DOWN THIS INFORMATION! You should record the pt. # with N, E, and elevation. "Store" (F2) after data is recorded. Display will clear and be ready for the next observation.
6. If the origin point will be the only instrument set-up needed, sight the operator position and have a helper hold the prism at the position, and push measure.
    a. If the prism can be measured, then the instrument will output its position. Push store and then move on to measure and store the points establishing the position and orientation of the vehicle.
    b. If the prism can't be measured, then another station point will need to be established that can see into the cab through an open window or door. Establish that point, measure it from the origin, store the point in the instrument, and WRITE DOWN THE COORDINATES AND POINT NUMBER.
    c. After the operator position point and the points establishing the location and orientation of the vehicle have been measured and stored, and the sight lines marked on the ground with surveyor's paint, the vehicle can be moved out of the way.
    d. Once the vehicle has been moved, the surveying of the sight lines can be done. A helper with the Jacob staff will move to each point defining the sight lines. The instrument operator will sight on the prism, push "measure", and if a valid measurement is made, push "store". If the measurement takes an unusually long time, or the high pitched measuring tone is intermittent, then the "measure" button can be pressed again to take a second measurement before pressing "store". NOTE: It is a good idea to divide the points being measured into logical groups and start and end each grouping with an obvious secondary point (origin point, left front tire, etc.) to help delineate the groupings.
7. If additional instrument set-ups besides the origin point will be needed, then the operator position will need to be sighted and measured as in step #6 above, unless one of the additional points was

chosen specifically to sight the operator position. Then, the points for the additional set-ups should be surveyed to establish their position within the established coordinate system. WRITE DOWN THE COORDINATES AND POINT NUMBERS FOR THIS POINTS. After the additional set-up points are surveyed, any other points that it makes sense to survey from the origin should be surveyed.

Instrument Set-up (auxiliary points)

These instructions assume that the point over which you are setting up the instrument has been measured from the origin point and stored in the instrument.

1. Change "mode" to B by pushing the "Mode" softkey (F5).
2. Choose "S. Func." (F1), then use the arrow keys to choose option 2 "Coordinates" and hit the Enter key. Select the job name you entered previously from the list (you may need to scroll to find the name you entered) and hit Enter.
3. "Station # list" will come up. Select the point number you are occupying from the list (you may need to scroll to find it). Hit Enter.
4. The station coordinates will be displayed. Confirm the values given with the coordinates that you wrote down for the point when measured from the origin point. Hit Enter.
5. "Backsight Selection" will come up. Choose "Coordinates Input" and hit Enter. Select the point number (if backsighting to the origin, it should be 0000) from the list and hit Enter. The point coordinates will be displayed. Confirm the values given with the coordinates that you wrote down for the point when measured from the origin point. Hit Enter.
6. Aim at the backsight point. Press Enter. This will orient the coordinate system relative to the point you are occupying.
7. Survey the points for the sightlines of the vehicle. A helper with the Jacob staff will move to each point defining the sight lines. The instrument operator will sight on the prism, push "measure", and if a valid measurement is made, push "store". If the measurement takes an unusually long time, or the high pitched measuring tone is intermittent, then the "measure" button can be pressed again to take a second measurement before pressing "store". NOTE: It is a good idea to divide the points being measured into logical groups and start and end each grouping with an obvious secondary point (origin point, left front tire, etc.) to help delineate the groupings.

Data File Description

This section describes the various worksheets that are part of each machine's data set.

The three-dimensional coordinate data that were collected for each of the machines using the Total Station were uploaded to a comma-separated file (.csv). These lists of data are included in each machine's workbook, typically as machine.csv, where machine should be replaced with the particular equipment, e.g., grader.csv.

In the .csv file, the raw data is listed in columns B through D. Since these data are relative to the Total Station, the data are transformed to an "operator-centric" coordinate system. This is done by translating and rotating (if necessary) original data so that the origin is at the operator's location. These data are all in units of feet. At this point they are converted to polar coordinates and units of degrees and meters.

Additional information about the machine, specifically it's outline coordinates were also added, and all the data is converted into polar coordinates.

Each workbook has the following worksheets

- Machine.csv (or equivalent)
- BA_Data

In addition, each workbook will contain two plots.

- Ground Level Plot
- 1p5 meter Level Plot

As mentioned, the .csv worksheet has the raw data collected.

The BA_Data worksheet is the “workhorse” of the workbook. It contains the coordinate data (r, theta) for the blind area at 1.5-meter elevation, the machine footprint, and blind area at ground level. It also has the reference data for the coordinate axes that were used to generate the plots. Since all plots are polar and the maximum distance (radius) is 24 meters, a special set of coordinates is set up so that each plot is the same. Both the “r” and “theta” values are presented. The angular values are shuffled to every other row so that only the values at 10-degree increments will be printed, but the axes will be drawn at 5-degree increments. In addition, a quantity called the distance ratio, which is the ratio between the radial distance of a blind area edge at 1.5-meter elevation and that same distance at the ground plane, is given on the BA_Data sheet. This quantity is computed from similar triangles based on the operator’s position and elevation and the position and elevation of the prism for the 1.5-meter measurement. The distance ratio is then defined as (b/a) as shown in the figure [1] below. This is used to compute the ground level blind area.

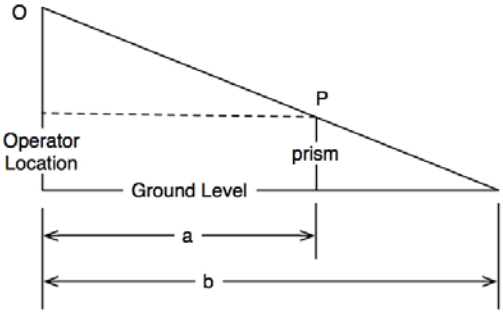


Figure 1: Distance ratio geometry

If there were any special notes about the data or reference information about the locations of specific points, there may be a separate worksheet with “notes” in the title. Finally, every workbook will have the two plots, 1.5-meter level plot and ground level plot that show the blind areas at those levels.

As mentioned in the introduction to this report, the use of filled radar plots as implemented by Excel put special constraints on these plots. Specifically, data for both the blind area and the machine outline had to be generated at one-degree increments in order for Excel to plot with a fill. This meant that between know vertices of the data, one-degree data had to be generated. This was accomplished as follows. Two vertices were selected and the polar coordinates were converted into Cartesian space. Note in every case, these two vertices would span some angular arc in the polar plane. A straight line was fit to these two points. Then starting with the smaller angle vertex plus one degree, a ray was cast from the origin toward the line. The intersection of this ray with the line was solved using simultaneous equations and the (x,y) value of this point was recorded. A list of all of the intermediate intersections was computed and once the list was complete, i.e., we had arrived and the other end of the line, all these vertices were converted into polar coordinates. By this method all the segments of the lines in the polar plot were filled in at one-degree increments so that the Filled Plot could be constructed. This process was carried out in another application, Mathematica, and the code is not included in this report. If interested, please contact the author.

Because the filled plots require all plots to emanate from the origin, the mirror areas cannot be plotted in Excel. Therefore, once the blind areas and the vehicle outline have been generated, the plots are copied into another application (OmniGraffle) to apply the mirror areas. The data for these areas comes from the original total station data.

References

ISO 5006 “Earth-moving machinery --- Operator’s field of view – Part 1: Test Method”, 1991, First edition 1991-11-01, ISO Reference number ISO 5006:1995(E).

ISO 5353 “Earth-moving machinery, and tractors and machinery for agriculture and forestry --- Seat index point”, 1995, Second edition 1995-12-01, ISO Reference number ISO 5006-1:1991(E).

Ruff, T., Procedure for Recording Blind Areas Around Heavy Equipment, 2002, NIOSH/CDC, Feb. 14, 2002.