MANITOBA-MINNESOTA TRANSMISSION PROJECT

Socio-Economic Technical Data Reports

2.6 Assessment of Land Usage for Hydro Towers

Project No. 21214
Date: August 4, 2015
Portage La Prairie, MB

Farming Around Hydro Towers

For:
PRA Inc.

Innovative Solutions
for Agriculture and Beyond

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1. Executive Summary

PAMI investigated land use changes associated with transmission lines on agricultural land in Manitoba. A number of scenarios (listed below) were developed for the evaluation that represents structure types and alignments typically used in Manitoba Hydro projects, so that this information can be applied broadly. Two general supporting structures of either H-frame or steel towers were assessed for three different scenarios of transmission lines and easements:

Scenario 1 – Transmission lines installed parallel to the road

- H-frames – centered 3.75 m from field edge, with 23.75 m total easement width
- Steel towers – centered 40 m from field edge, with 80 m total easement width

Scenario 2 – Transmission lines installed perpendicular to the road

- H-frames – centered along edge of quarter section, with 40 m total easement width (i.e. 20 m into each quarter section)
- Steel towers – centered along edge of quarter section, with 80 m total easement width (i.e. 40 m into each quarter section)

Scenario 3 – Transmission lines installed diagonally (45° to road) corner to corner

- H-frames – with 40 m total easement width
- Steel towers – with 80 m total easement width

Changes in land use due to transmission lines create land area that is no longer seeded to crop (unused), may create areas receiving double the crop inputs (fertilizer, herbicide, pesticide) due to overlapping passes (overlap), and in some cases add field area that needs to be traveled twice to move machinery (transport area), all of which negatively impact the producers by either reducing revenue, increasing chemical inputs or adding labour. These areas were determined for grain production, livestock manure injection and potato production which have different production limitations. In the case of grain production, the areas were determined for small implement widths (to represent seeding and fertilizer application) and large implement widths (spraying herbicides or pesticides) and expressed as percentages (% area unused, % area overlap, and % transport area) of the scenario's easement area and could be used as multiplication factors applied to the production cost for a particular field operation for determining additional costs.

Guidelines For Estimating Crop Production Costs 2014 in Western Manitoba obtained from Manitoba Agriculture, Food and Rural Development (MAFRD) was used to estimate production costs broken down into categories for particular field operations and more general costs for a variety of crops. The production cost for a potato producer of 780 acres were also estimated from *Guidelines for estimating irrigated processing potato costs* from MAFRD.

The % area unused, % area overlap, and % transport area for the corresponding width of equipment were used as multiplication factors on production cost categories to find the additional cost due to transmission lines. If a cost category involved both narrow and wide equipment, the multiplication factors were applied in relation to their contribution to the production cost. PAMI provided an example of how the multiplication factors would be used to determine the financial impact of the transmission lines.

PAMI also calculated a theoretical value, known as the percentage of easement unaffected by transmission lines. This theoretical value can be used to compare the different scenarios and shows the percentage of the easement per field that is not affected by the transmission tower footprint, overlapping crop inputs, or additional transport area and can therefore be farmed as usual.

In addition to wide and narrow implement widths, the multiplication factors, % easement area unaffected, and % field area unaffected were determined for equipment 20% larger to assess the effect increased equipment size has on additional costs to producers. In general, a larger width implement caused greater area to be affected as can be seen in **Figure 1-1** for H-frames and **Figure 1-2** for steel towers. For the majority of situations a sizable fraction of the easement area remains unaffected for production to continue as normal. Scenario 2 had the least percentage of easement area affected for H-frame and steel structures, above 95% for the four implement widths. Scenario 2 for H-frames was above 90%, and steel towers above 80%. Scenario 3 was similar to scenario 2 for steel towers while the area unaffected dropped significantly for H-frames at larger implement widths.

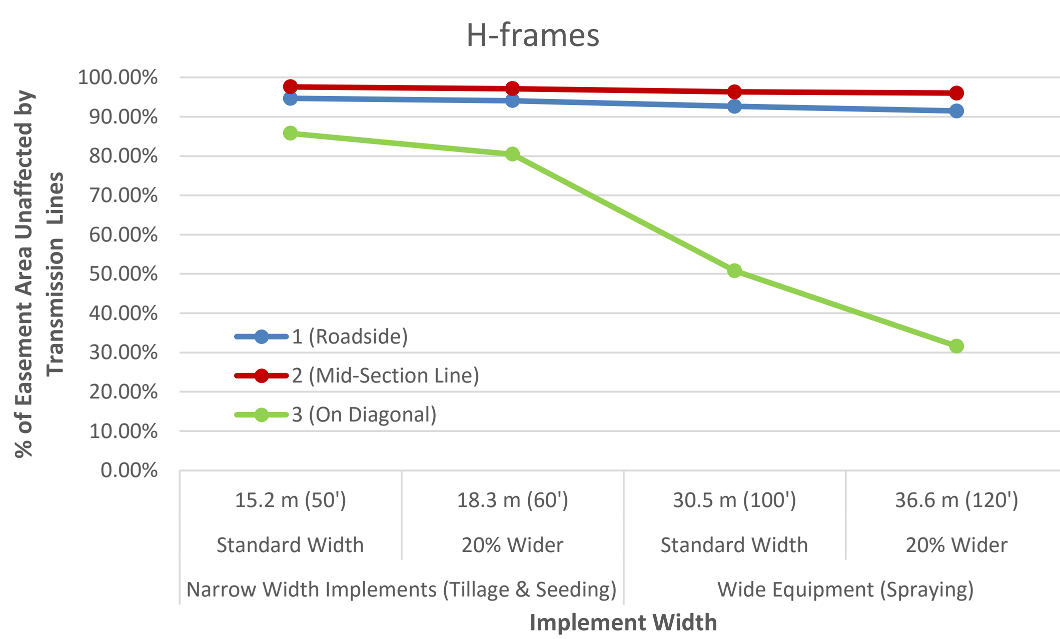

Figure 1-1. % of easement area unaffected by transmission lines across fields in crop production (except potatoes) in the three layout scenarios for H-frames.

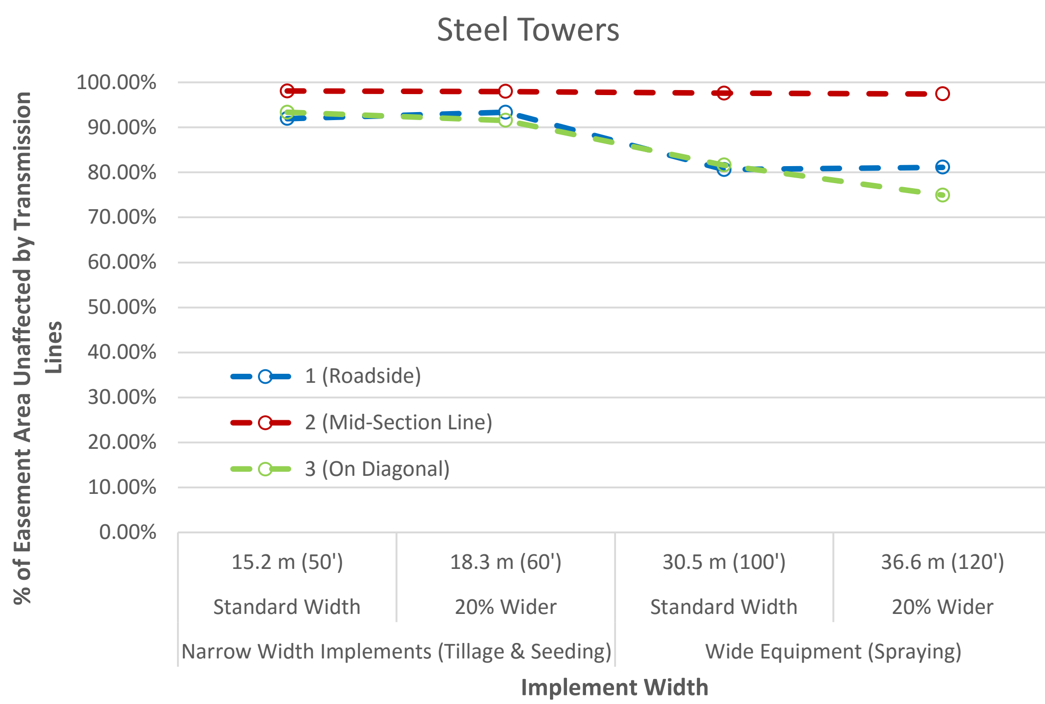

Figure 1-2. % of easement area unaffected by transmission lines across fields in crop production (except potatoes) in the three layout scenarios for steel towers.

An example calculation of the additional costs was done for wheat production. The percent total lost value relative the field easement production costs and the total cost per field growing wheat is shown in **Error! Reference source not found.** for H-frames and **Figure 1-4** for steel towers. Scenario 2 (transmission line on the quarter section line) causes the least loss in value to the producer for both H-frame and steel structures ranging between 1.6 and 2.6% of the easement production cost for wheat translating to $18 to $27 loss of value per field per year growing wheat. Scenario 1 is comparably low for the H-frames. Costs are dramatically more for a diagonal field crossing and H-frame transmission line, rising to 27% of the easement production cost for wheat ($575 per field per year). The higher impact of a diagonal field crossing is due to both the longer length of the route (more towers to a field) and there being a greater area affected around individual structures when they are approached in the field and are circled by machinery (overlap of inputs or added field area to transport equipment is present on all sides of the structure) as opposed to structures being approached at the field edge (where only one side is affected where machinery is driven into the field to avoid the structure).

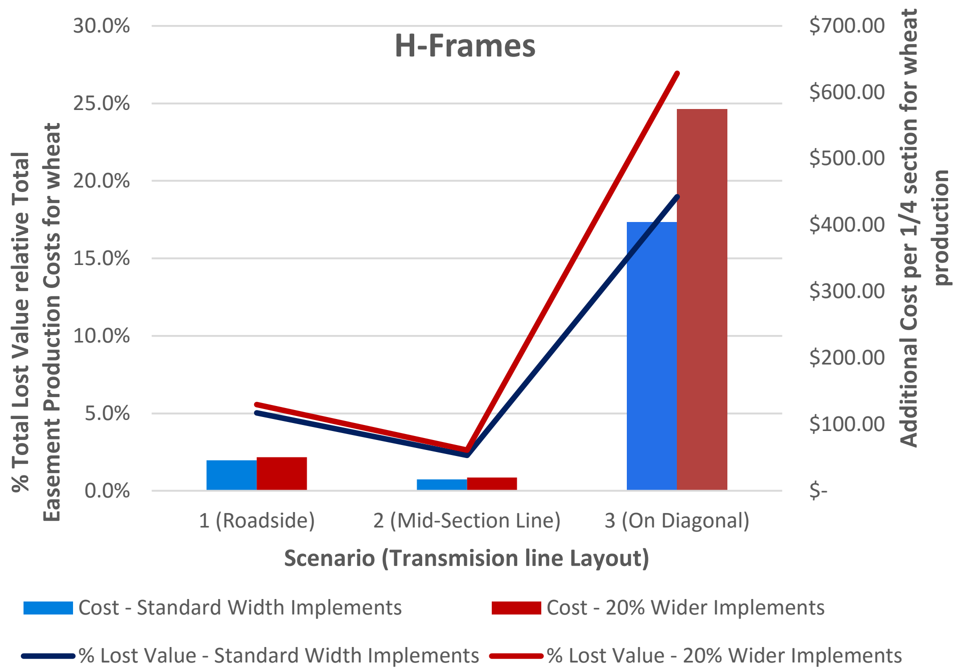

Figure 1-3. % total lost value relative to the total easement production costs growing wheat and associated total additional cost per quarter section for the 3 scenario and H-frames structures.

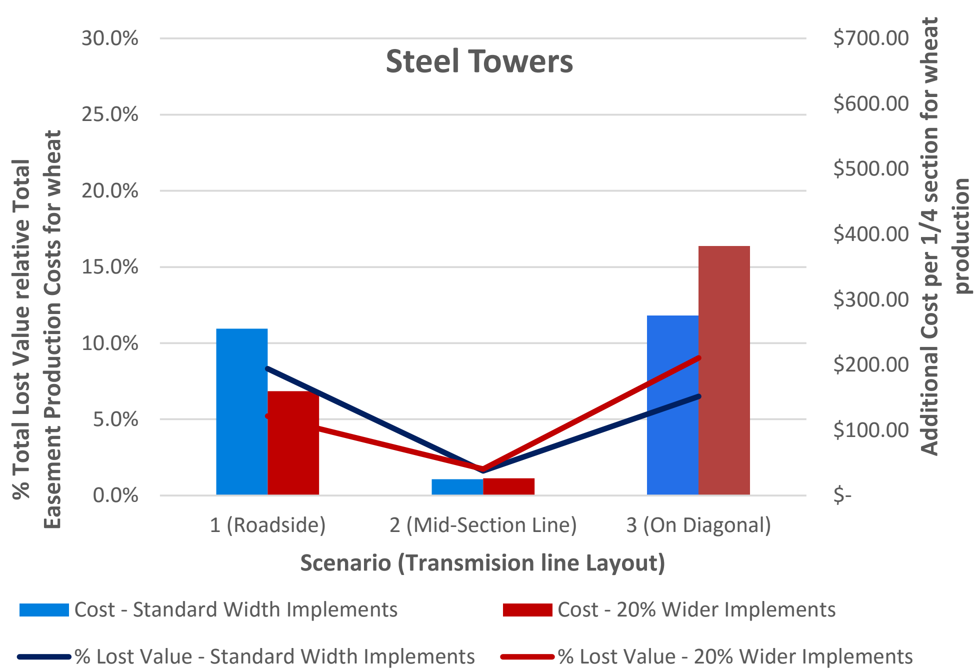

Figure 1-4. % total lost value relative to the total easement production costs growing wheat and associated total additional cost per quarter section for the 3 scenario and steel towers.

While the example is for wheat production, the relative trend between scenarios on the increased production costs for other crops is not expected to be significantly different.

The data suggested that transmission lines running at a right angle to a roadway along the dividing line of a section into quarters, would be optimal for both H-frame and steel towers. This scenario would also be expected to have reduced additional labour requirements for equipment movement in the cases of irrigated potatoes or livestock manure injection by drag hose since the edge of the transmission line could be treated similarly to the edge of a field; however, these are considerations on a case-by-case basis. Such a scenario would involve farm machinery operations similar to the headland of the field without the installation of the towers and would also result in reduced input overlap. Therefore, a scenario where transmission lines follow the quarter section dividing line is optimal for both reducing costs to producers, and facilitating farm machinery operations for grain production.

Additional input, reductions in value, yield, and safety implications of the transmission lines were discussed. Although the multiplication factors can be used for a number of production input and yield situations for a variety of crops, they cannot be used to estimate costs incurred from crop damages due to soil compaction, weed introduction/additional spraying requirements near towers, yield losses due to doubling crop input rates, safety considerations, and some other implications of transmission lines on agricultural land.

It was further determined, that there are a number of other important yield and safety considerations that cannot be accounted for when using multiplication factors to determine the additional costs of working around transmission lines. There may be yield losses associated with soil compaction due to tires or construction, overlapping inputs, or weed introduction. Safety concerns due to the potential for equipment to contact the towers or transmission lines, may also result in additional time and effort for producers who must avoid contacting these structures with their equipment. With increased equipment size and implement widths being an ongoing trend, safety concerns are anticipated to continue as producers adjust to larger equipment and the necessary judgment needed to operate this equipment safely around towers.

Further to this report, Manitoba Hydro has contracted PAMI to engage in additional research to further understand the considerations related to working around transmission lines that are not captured in this report, which includes (and is not limited to):

- fertilizer, herbicide, and insecticide application as well as application method (aerial vs ground)
- construction damages
- crop growth and quality due to soil compaction
- risk of damage to equipment or people
- insurance requirements
- future agricultural technology

The following are high-level conclusions regarding tower-type and and additional cropping costs:

1. Scenario 2 (mid-section line) stands out as being optimal for both tower types
2. Scenario 3 (On diagonal) is the least optimal for both tower types, due to the increased crop inputs and labour requirements associated with negotiating infield obstacles.
3. Steel towers are best for Scenario 3 (On diagonal).
4. Scenario 1 (Roadside) is not much different in terms of additional costs than Scenario 2 (mid-section line) for H-frame transmission towers.
5. Scenario 1 (Roadside) is much different in terms of additional costs than Scenario 2 (mid-section line) for Steel towers.
6. H-Frame transmission towers are best for Scenario 1 (Roadside) and Scenario 2 (mid-section line).

2. Introduction

A land use change estimate, basic cost analysis, and technical summary was completed to assess how the placement of H-frame and steel towers affect agricultural operations. To assess the impact the structures would have on land use for agricultural operations, a number of different scenarios were investigated. The scenarios investigated were based on a variety of ways producers could navigate and farm around the structures using typical farm machinery implement widths and the resulting field footprint of unfarmed area, overlapping crop inputs, and extra area needed to transport equipment. Photos of typical equipment used in grain production, including a combine, high clearance sprayer, heavy harrow, and air drill are shown in **Appendix A**.

3. Land Use Change Results and Implications

When H-frame and steel towers are installed on agricultural land, agricultural production is affected. The extent of this effect was investigated by assessing changes in land use associated with the towers along with resulting costs and implications of the land use changes.

3.1 Land Use Changes

The changes in land use associated with H-frame and steel towers were assessed by taking into account a range of machinery implement widths typical for different agricultural production practices in Manitoba. Computer aided design software (SolidWorks) was used to investigate the footprint area of the towers (including a safety radius) and overlapping areas for crop inputs, which are the two major factors influencing additional costs or lost agricultural value of the land from the installation of the transmission lines. In addition some scenarios made it necessary for equipment to be transported over ground previously covered. The added labour was an additional factor considered.

A base case for the easement area associated with a field size of 160 acres (typical one-quarter section of land) was used to estimate the area occupied by the towers that would no longer be used for agricultural production (footprint). For the footprint, the structural bases of the H-frame and steel towers were considered to be 5.5 m x 1.0 m and 9.0 m x 9.0 m respectively. In addition to the lost production area due to the footprint of the towers, a safety radius of 1 m was also included in the footprint to prevent collisions between farm machinery and the towers. Sketches of the tower base dimensions with safety radius used to assess land use changes are shown in **Appendix B**. To calculate the footprint from the number of towers on a field, a span of 250 m and 400 m between towers were used for the H-frame and steel tower transmission lines respectively. The average number of towers per field where towers either run parallel or cross a roadway at a right angle was determined to be 3.22 towers for the H-frame structures and 2.01 towers for the steel tower self-supporting structures. For the case where H-frame and steel tower transmission lines cross a field at 45 degrees, an average of 4.55 and 2.85 towers per quarter section respectively were determined.

There were three different scenarios investigated for the placement of H-frame and steel towers on the field. These scenarios investigated various ways of maneuvering around towers by farm machinery of various implement widths to determine tower footprint and crop input overlap areas. The three scenarios were:

Scenario 1 – H-frame or steel tower transmission lines installed parallel to the road, along the edge of the field with a 23.75 m or 80 m easement respectively, shown in **Figure 3-1**

Scenario 2 – H-frame or steel tower transmission lines installed perpendicular to the road, along the border of the one-quarter section with a 40 m or 80 m easement respectively (half of easements extending into each of the adjacent quarter sections), shown in **Figure 3-2**

Scenario 3 – H-frame or steel tower transmission lines installed diagonally (45° to road) across the field, with a 40 m or 80 m easement respectively, shown in **Figure 3-3**

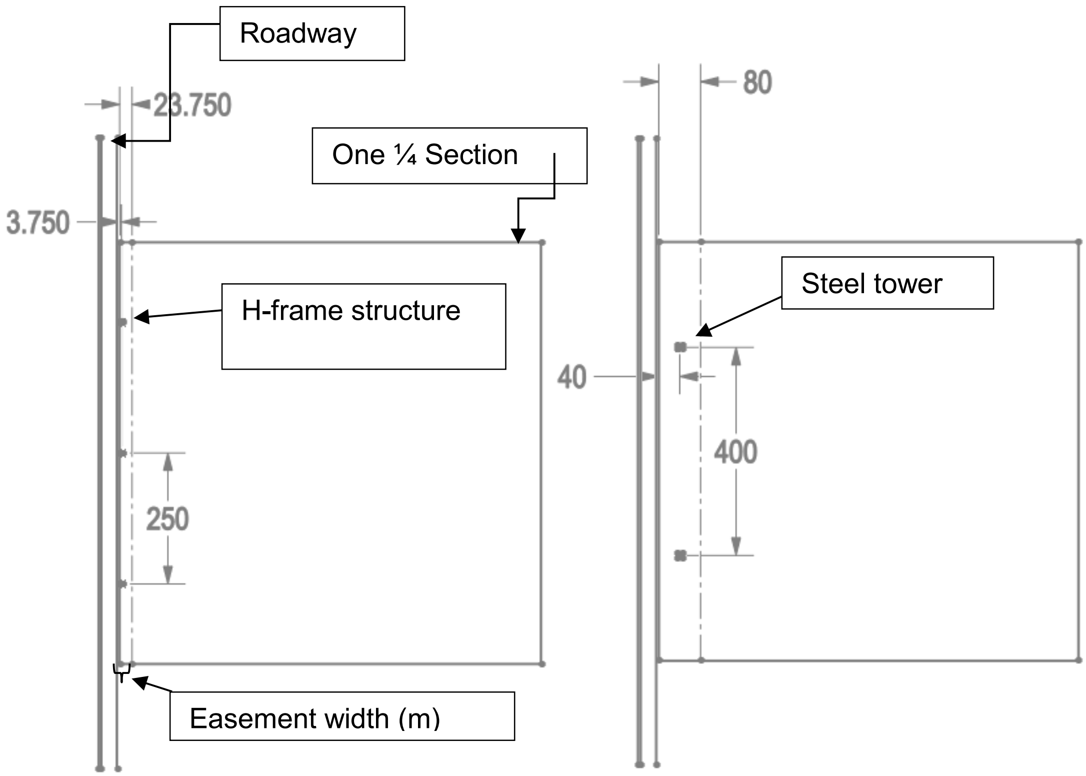

Figure 3-1. Scenario 1 for a ¼ section of land for H-frame transmission lines, with a 23.75 m easement (left) and steel tower transmission lines, with an 80 m easement (right).

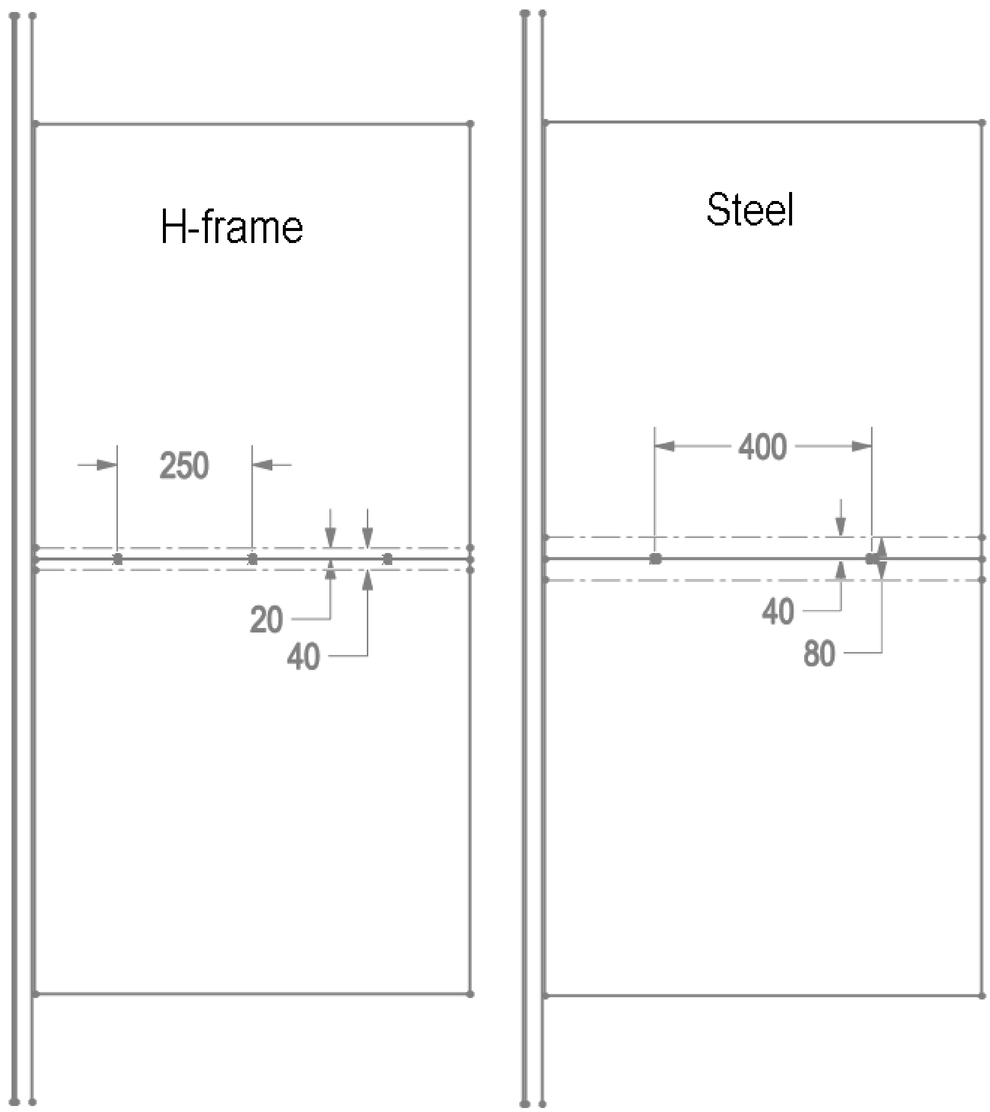

Figure 3-2. Scenario 2 for a ¼ section of land for H-frame transmission lines, with one half of a 40 m easement shown (left) and steel tower transmission lines, with half of an 80.0 m easement shown (right).

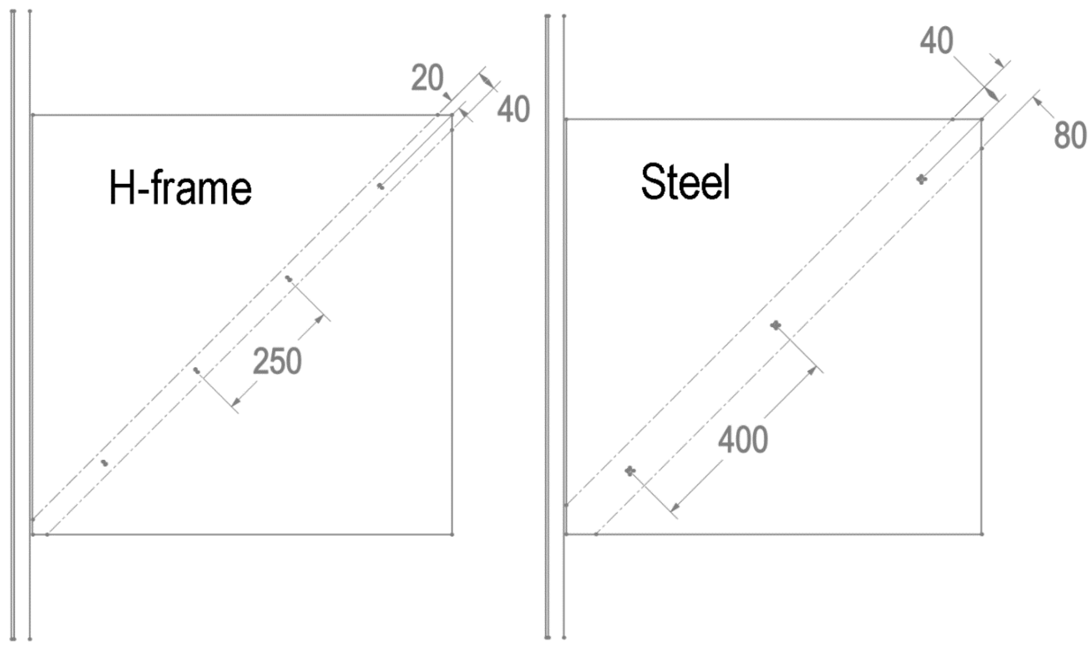

Figure 3-3. Scenario 3 for a ¼ section of land for H-frame transmission lines, with a 40 m easement (left) and steel tower transmission lines, with an 80 m easement (right).

Tower footprints and crop input overlap areas were then investigated for three different agricultural production practices in Manitoba: dry land grain farming, irrigated potato farming, and livestock manure injection, each resulting in different machinery sizes and approaches to farming around the towers.

For each scenario, it was assumed that the towers would be approached by the farm machinery in a way to minimize lost production area. The footprint area for each scenario was calculated by taking the overlap or missed area shape drawn in SolidWorks and measuring the area. To calculate the areas, the different implement widths, tower footprints, safety radii, and machinery tower approaches were drawn up as shown in **Appendix B**. The scenarios drawn up in SolidWorks represent ideal or best-case scenario driving where the driver is very accurate, with minimal overlap and unused footprint. However, since the overlap areas represented optimal driving, the overlap areas were multiplied by 1.5 (150% of best-case), to be representative of average driving in agricultural operations (half way between best- and worse- case scenarios). In addition to unused footprint and overlap areas, some scenarios required the transportation of machinery over land passed over previously. This area does not have an effect on overall inputs but was used to determine the additional labour requirement. From SolidWorks drawings, it was determined that the overlap and footprint areas would be accurate for an average driver to +/- 33%. For the case of scenario 3, it was recognized that the approach of a field implement relative to the tower base would be different depending on where the tower is in the field. In theory the case of the implement end meeting the tower would happen twice as often as when the tower was directly in the middle of the implements path. A general case was selected of an implement approaching the towers center one sixth of the implement width in from one end of the implement as a weighted average of the two cases.

For the dry land grain farming operation, which was assumed to be also representative of peas, corn, and soybeans, implement widths of 50 ft (15.2 m), 60 ft (18.3 m), 100 ft (30.5 m), and 120 ft (36.6 m) were used to calculate the overlap areas for crop inputs, lost production due to the lost tower footprint, and additional area required to transport machinery and equipment. For either H-frame or steel towers, Scenario 2 results in the least impact from a producer's perspective. For machinery operations and tower approaches to H-frame towers, Scenario 1 is very much alike Scenario 2 and both result in similar overlapping of crop inputs and footprint areas, however differ in size of the easements. Scenario 3 is least preferable for both H-frame and steel tower transmission lines due to the amount of overlap and additional area needed to transport machinery caused by circling the towers. **Figure 3-4** is shown as an example of the additional overlap and field area needed to transport machinery caused by circling the tower as compared to **Figure 3-5** of scenario 2 for the same implement width of 50ft (15.2m) where towers are not circled.

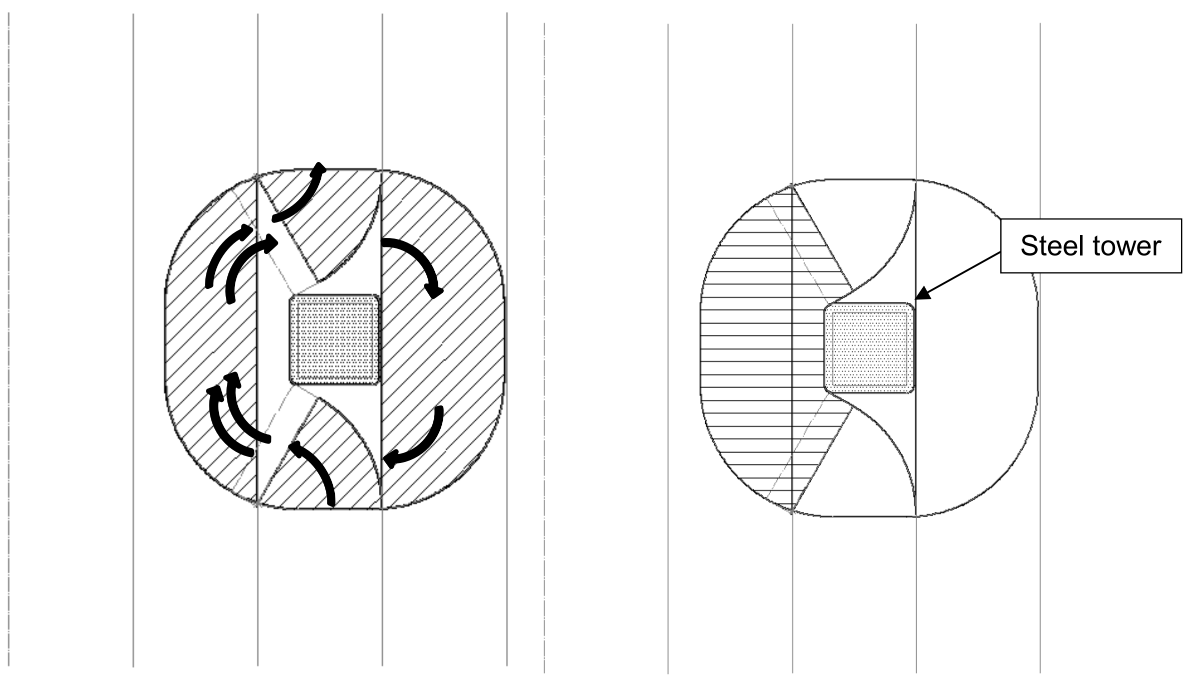

Figure 3-4. Scenario 1, steel tower, 50 ft, with examples of footprint area (dotted) and overlap areas (hashed) on encircling pass, Left, and transport area (horizontal lines) on the Right.

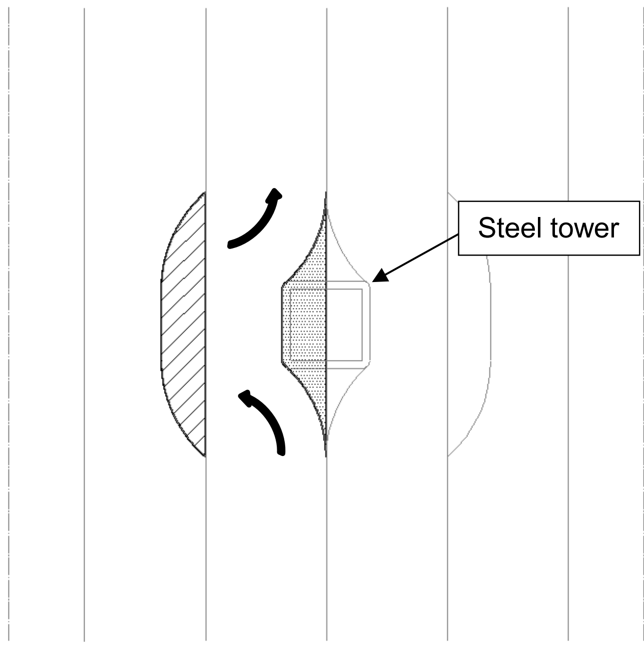

Figure 3-5. Scenario 2, steel tower, 50 ft, with examples of footprint area (dotted) and overlap areas (hashed) on completing field passes.

For the irrigated potatoes, it was determined that the overlap associated with crop inputs would be negligible due to typical potato production practices. For Scenario 1 and Scenario 2, pivot or linear irrigation could take place as usual with the reduced footprint of the towers by the road, which differs depending on the easement. For Scenario 3, however, irrigation would need to be split up into two pivots or linear systems or moved across the field (linear system only), resulting in increased labour requirements or increased capital costs if an additional irrigation system were to be purchased to minimize time and labour requirements. Therefore, Scenario 2 for either towers would likely be the most favored by irrigated potato producers as they would not have to change their irrigation practices or purchase additional equipment.

For the manure injection intensive livestock farming operation, manure injection lines would be typically run on a diagonal across the field. Typically producers would move the drag hose to inject manure for the longest run, and then move over incrementally in a zigzag back and forth over the field. For Scenario 1 and Scenario 2, there would likely be no changes in production practices for manure injection other than the reduced footprint associated with the towers. Scenario 3 would have two different starting points for the manure injection line (**Figure 3-6**) However, due to the fact that producers would still need to maneuver the hose around the towers in Scenario 3, requiring additional time and labour, Scenario 2 would be optimal from a producer's perspective.

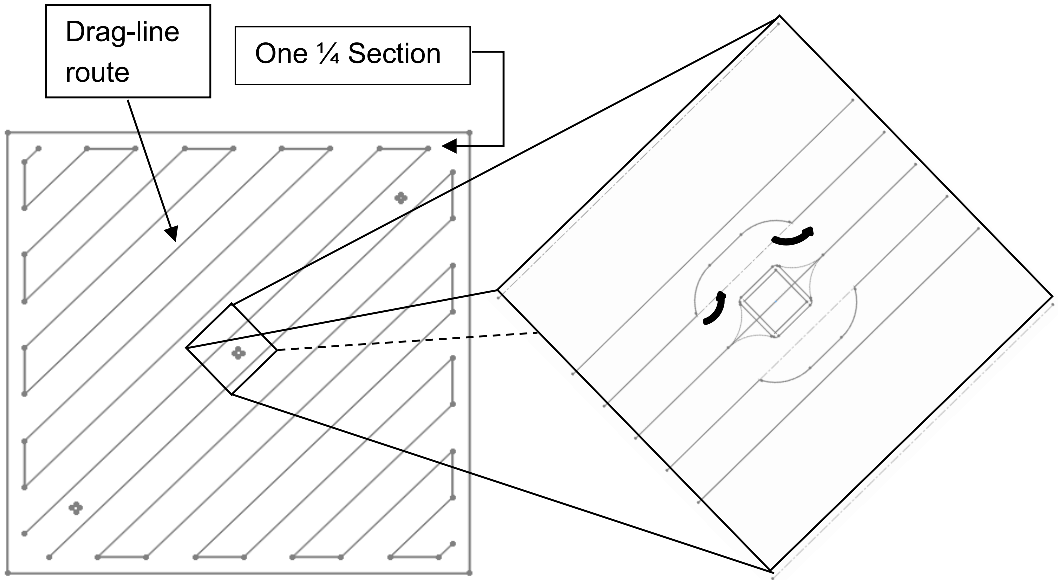

Figure 3-6. Route taken with a dragline manure injector for Scenario 3 (field divided) with close-up of 30ft implement pass of a steel tower.

The easement area is an important quantity as part of producer compensation is based on this amount. Easement area will be used to get a sense of the relative magnitude of land area that may be farmed without significant changes to use. The easement areas are calculated based on the transmission line length per ¼ section and width of easements. Since the H-frame and steel towers have different associated easement widths and scenario three's transmission line, being on the diagonal, is longer than the other two scenarios, the different tower easement widths and scenario combinations result in unique field easement areas per quarter section field and are shown in **Table** 1.

Table 1. Easement Areas for Route Scenario and Structure type Combinations

Easement Areas		
Structure	**Route Scenario**	**Field Easement Area (acres)**
H-frame	Scenario 1 (23.75 m easement)	4.72
	Scenario 2 (40 m easement)	3.98
	Scenario 3 (40 m easement)	11.07
Steel	Scenario 1 (80 m easement)	15.91
	Scenario 2 (80 m easement)	7.96
	Scenario 3 (80 m easement)	21.95

It can be noted that the easement areas of the transmission lines supported by steel towers are approximately two to three times greater than those supported by the H-frame structures due to their greater specified easement widths. In addition, the easement areas associated with scenario 2 (structures on mid-section line) are calculated on a per field basis. For scenario 2, the transmission line, being along the mid-section line, has an easement extending into both adjacent fields. Only one of the field easement areas is counted of the two affected fields (effectively 40 m or half of the 80 m total easement width covering the two fields).

The lost production area of the footprint, additional input area in overlap, and additional area required to transport machinery were compared to the respective easement areas for the different scenarios, and implement widths to come up with multiplication factors for use in additional cost and reduced value calculations. The multiplication factors are based on the percentage of overlapping area (**Equation 1**) for additional crop inputs, the percentage of unused area (**Equation 2**) for lost value due to a decrease in crop production, and the percentage area requiring the transport of equipment without field inputs (**Equation 3**) for determining additional labour requirements.

$$\%\ area\ overlap = \frac{crop\ input\ overlap}{field\ easement\ area} \qquad \textbf{Equation 1}$$

$$\%\ area\ unused = \frac{footprint}{field\ easement\ area} \qquad \textbf{Equation 2}$$

$$\%\ area\ transport = \frac{extra\ travel\ area}{field\ easement\ area} \qquad \textbf{Equation 3}$$

The percentage of the easement area per field theoretically unaffected by transmission lines (**Equation 4**) was also calculated. This theoretical value of % easement unaffected by transmission lines considers the footprint area that is taken away due to transmission line support structures, the land that is affected by additional crop inputs, and the land that needs to be travelled over twice to transport equipment. In similar fashion, the percentage of field area theoretically unaffected by transmission lines (**Equation 5**) is also calculated. The multiplication factors (which are +/- 30%) to use for crop production, livestock manure injection, and irrigated potato farming are shown in
Table 5, Table 6, and **Table 7** respectively in **Appendix C**.

$$\%\ easement\ unaffected = 1 - \frac{footprint + crop\ input\ overlap + transport\ area}{field\ easement\ area} \qquad \textbf{Equation 4}$$

$$\%\ of\ field\ unaffected = 1 - \frac{footprint + crop\ input\ overlap + transport\ area}{160\ acres\ field\ area} \qquad \textbf{Equation 5}$$

The resulting multiplication factors and % areas unaffected are shown graphically in the following **Figure 3-7** through **Figure 3-16**. The Easement area that is overlap (field area that receives double the crop inputs due to overlapping field passes created when navigating around an obstacle with a fixed width implement) for the three scenarios of H-frame transmission lines at several implement widths is shown in **Figure 3-7**. What can be seen immediately is that scenario 3 has much more area in overlap for the greater implement widths. This is due to the infield placement of H-frame structures with a diagonal field crossing allowing towers to be circled to minimize the area of land unused. Overlap is created on three additional sides of the structures and the width of overlap grows with implement size, as compared to the roadside or mid-section line placement where overlap is limited to the one strip of consistent width. The result is that scenarios 1 and 2 show a more linear relationship of overlap to implement width. Scenario 1 and scenario 2 are very similar, differing only by a 3.75 m offset in H-frame placement relative each other. Effectively, field passes must swing 3.75 m further into the field for scenario 1 as compared to scenario 2 creating a 3.75 m wider and slightly longer strip of overlap. The result is that scenario 2 generates the least amount of overlap for a given implement width. It should be noted again that scenario 2, with structures half on one field and half on another, affects two fields but easement area in overlap is the overlap for one field only.

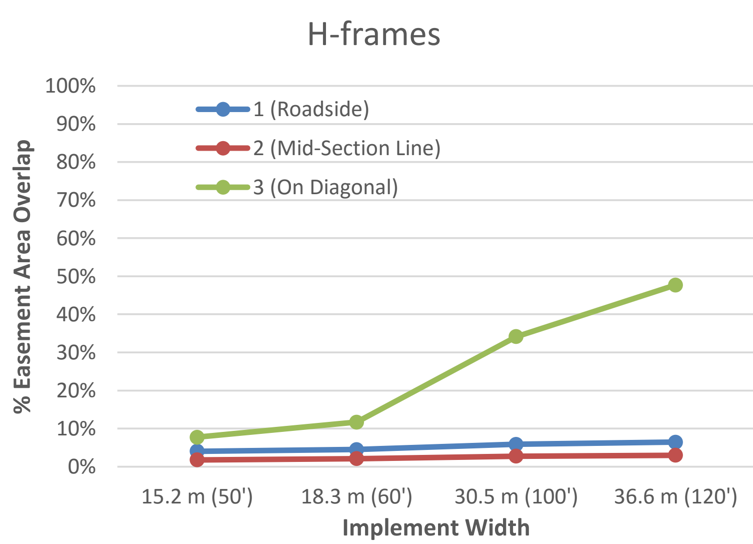

Figure 3-7. % of Easement Area that is Overlap at several implement Widths for the 3 Scenarios and H-frame structures.

Figure 3-8 shows the results for easement area in overlap for steel towers. Here an odd phenomenon is observed for scenario 1 where the larger implement widths of 60 ft (18.3m) and 120 ft (36.3 m) create less overlap than implements of 50 ft (15.2 m) and 100 ft (30.5 m) respectively. The placement of steel towers 40m from the field edge in scenario 1 is partway between the second and third field pass from the field edge for the larger 60 ft (18.3 m) implement. This is similar in a sense to scenario 2 of being on the mid-section line (negating that towers are circled) where the implement needs to turn out a lesser distance to get the tower compared to the situation of towers near the middle of the third pass of a 50 ft wide implement which generates wider strips of overlap. The minimal overlap for a 120 ft (36.6 m) wide implement as compared to the 100 ft (30.5 m) implement is due to a different observation. There is not enough space between the field edge and towers for a 120 ft wide implement to pass. The implement must be turned into the field get around. Towers are not circled and since the tower sits on the border of where two field passes would normally pass if the tower were not there, the overlap generated is of minimal width. Scenario 2 and 3, (towers on the mid-section line and on the diagonal) for the steel towers follow the same trends observed with H-frames as the transmission line placements are the same for the steel towers as they are with the H-frames. One thing to note is that the % of easement area in overlap is less in scenario 2 and 3 for the steel towers than for H-frames. This is largely due to the greater easement areas associated with steel towers and the fact there are fewer towers to a field with the 400 m span of steel towers as compared to 250 m for H-frames.

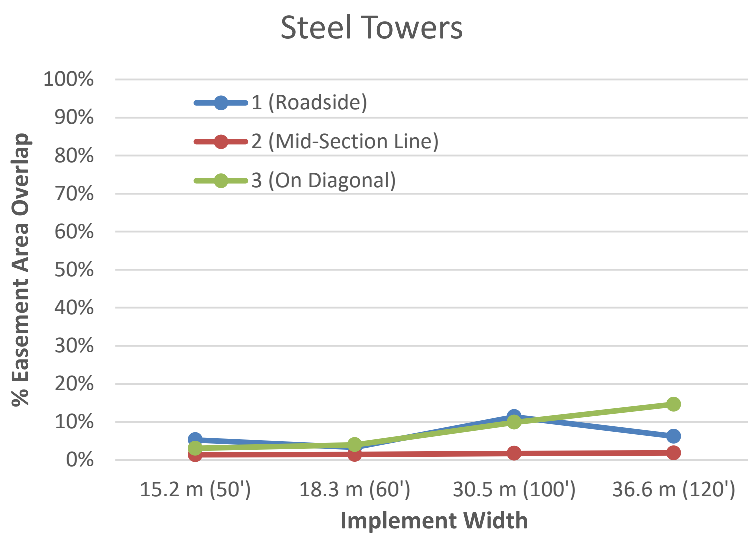

Figure 3-8. % of Easement Area that is Overlap at several implement Widths for the 3 Scenarios and Steel Towers.

Figure 3-9 shows the area of land relative to easement area that is left unused due to the presence of towers for several implement widths and the three scenarios for the H-frame transmission line. Scenario 3 exhibits the least unused area relative to the easement area because the infield placement allows the towers to be circled leaving only the land occupied by the H-frame structures (foot print with safety radius) unused. Scenario 2, with H-frames on the mid-section line has slight more unused area at the field mid-section line due to the limited turning radius of field equipment. Scenario 1 has the H-frames set into the field which increased the amount of unused area as implements must begin turning sooner to make the turn around the structures. The relative area unused to easement area in all cases is fairly insignificant.

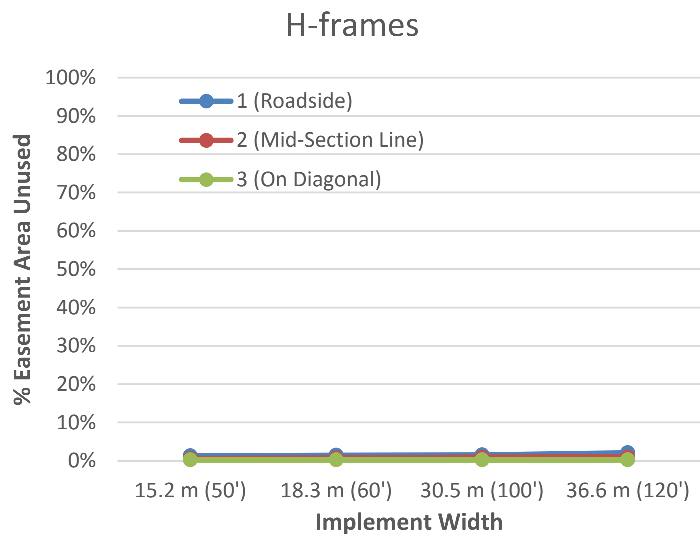

Figure 3-9. % of Easement Area that is Unused at several implement Widths for the 3 Scenarios and H-frame structures.

Figure 3-10 shows the area of land relative to easement area that is left unused due to the presence of towers for several implement widths and the three scenarios for the steel tower transmission line. Notable is the greater unused area for the combination of scenario 1 and largest implement width of 120 ft (36.6 m). In this case, since the towers are set back from the road the implement width is too great to pass the towers along the field edge and field passes must swing into the field, leaving a more significant area of land unused compared to the other scenarios but still a relatively small amount compared to the overall easement size.

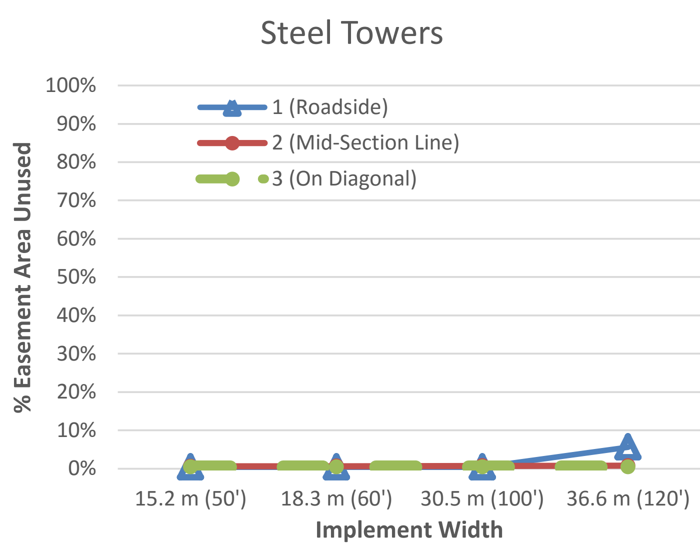

Figure 3-10. % of Easement Area that is Unused at several implement Widths for the 3 Scenarios and Steel Towers.

Figure 3-11 shows the additional field area relative the easement area that is required to transport equipment for H-frame transmission lines. This factor only occurs when structures are circled which is done in scenario 3. The field side placements of H-frame structures for scenarios 1 and 3 do not cause any additional field area needed to transport equipment.

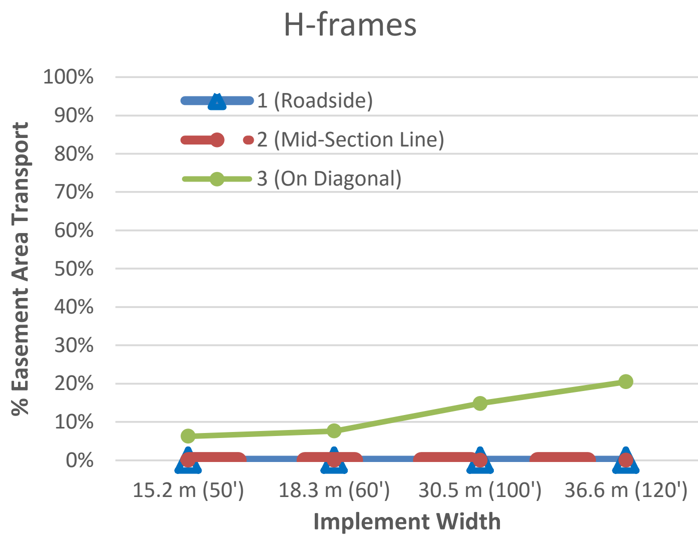

Figure 3-11. % of Easement Area that requires machinery Transport at several implement Widths for the 3 Scenarios and H-frame structures.

Figure 3-12 shows the relative area needed to transport equipment for steel towers and the three scenarios. Scenario 2 does not create a transport area, while scenarios 1 and 3 create transport areas similar to each other which increase with increasing implement widths.

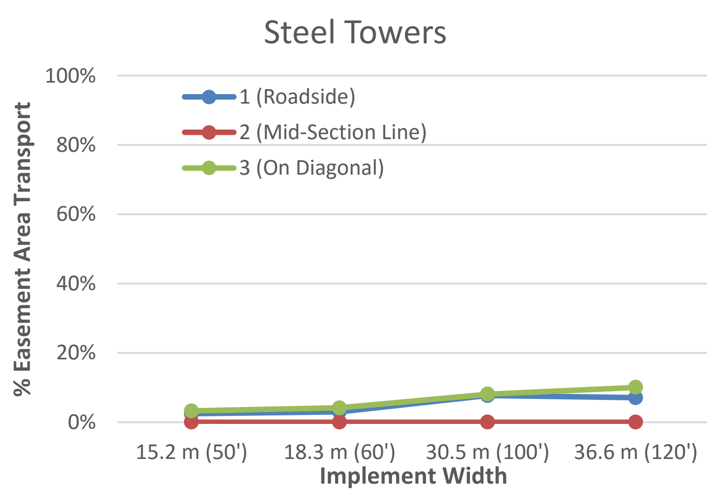

Figure 3-12. % of Easement Area that requires machinery Transport at several implement Widths for the 3 Scenarios and Steel Towers.

Figure 3-13 shows the percentage of easement area that in unaffected for H-frame transmission lines for different scenarios and implement widths. Placing H-frame structures on the mid-section causes the least easement area to be affected (less than 5% across the various implement widths). Placing structures on the field diagonal causes a significant amount of the easement area to be affected for larger implement widths.

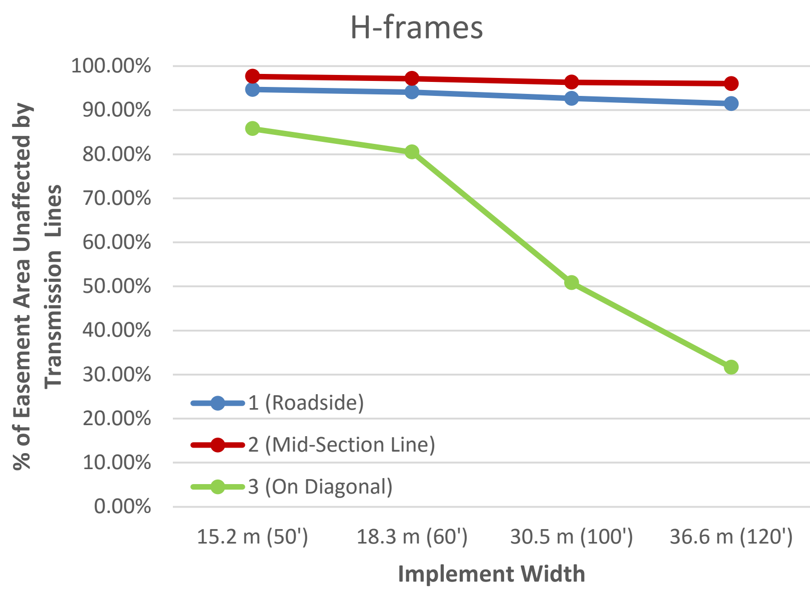

Figure 3-13. % of easement area unaffected by transmission lines in the three layout scenarios for an H-frame transmission line.

Figure 3-14 shows the % easement area unaffected for steel towers. Placing towers on the mid-section line clearly causes the least easement area to be affected. Scenarios 1 and 3 are similar to each other and a significant amount of the easement area remains unaffected by the transmission line and available for production to continue as normal.

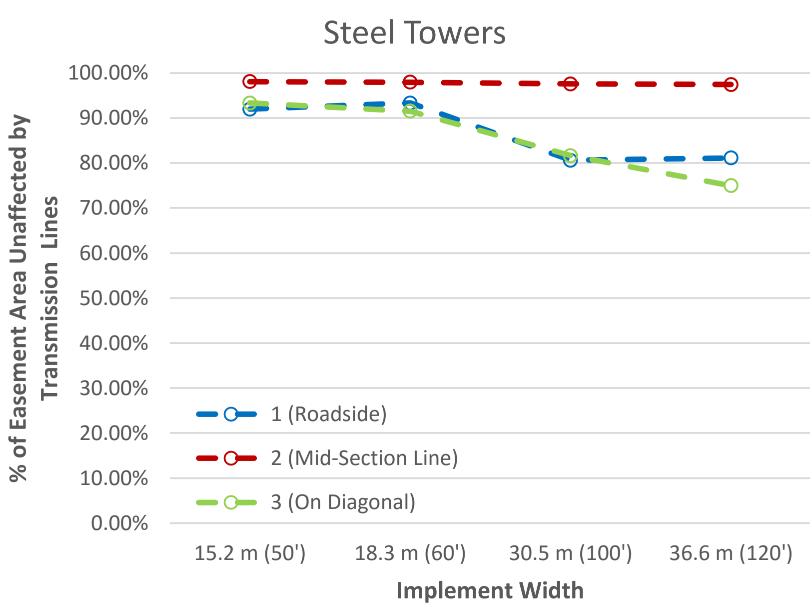

Figure 3-14. % of easement area unaffected by transmission lines in the three layout scenarios for steel towers.

Remember easement areas are different between scenarios. To get a sense of the affected areas of each scenario relative to each other, **Figure 3-15** and **Figure 3-16** shows the area of the quarter section which remains unaffected by the presence of transmission lines for H-frame and steel towers respectively for various implement widths. The mid-section line placment leaves the greatest area unaffected on a per field basis for both H-frames and steel towers.

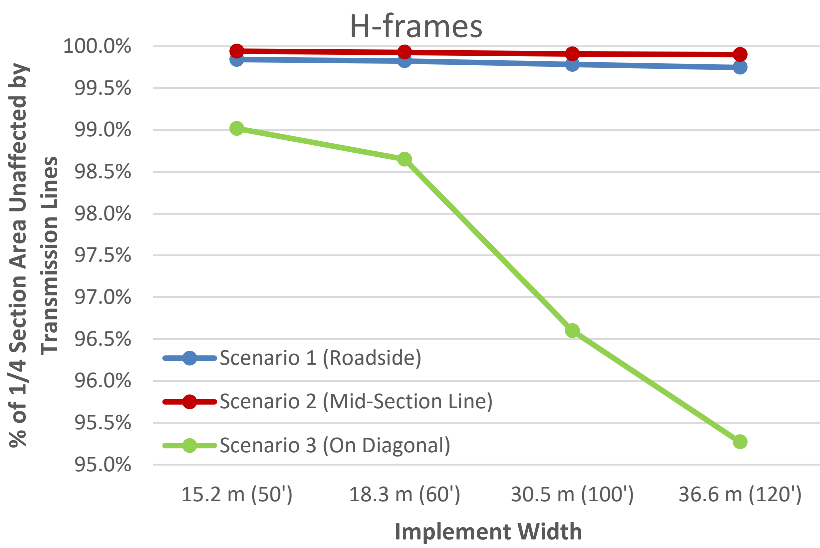

Figure 3-15. % of field area unaffected by transmission lines in the three layout scenarios for an H-frame transmission line.

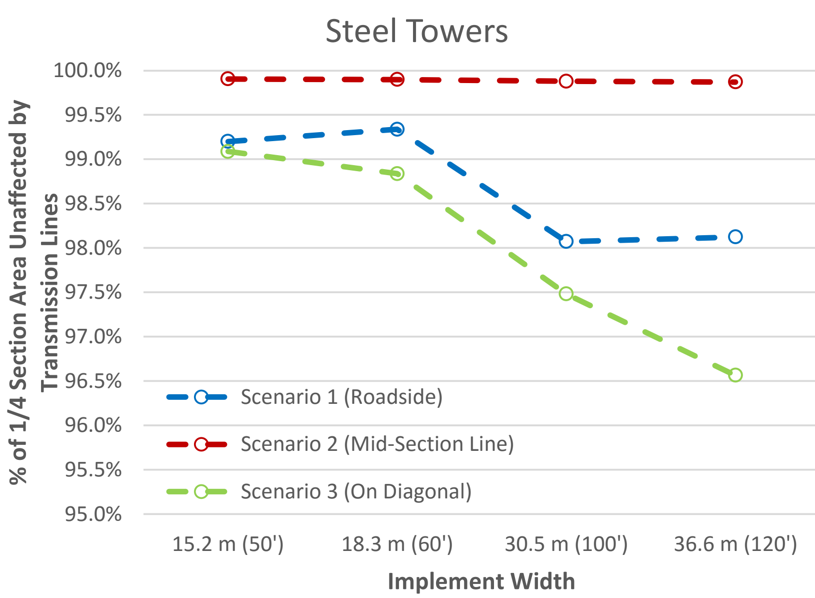

Figure 3-16. % of field area unaffected by transmission lines in the three layout scenarios for steel towers.

3.2 Costs Associated with Land Use Changes

Once the percentage of overlap area, unused area, and transport area are determined for a particular situation, crop production costs, values, and yields can be used to calculate the financial impact of the transmission lines. It should be cautioned that the costs and values used in this section are estimates only based on literature values. It should be noted that there are many other factors that require consideration when evaluating the financial impact of transmission lines; however, these factors require consideration on a case-by-case basis.

The crop production costs were estimated using Manitoba Agriculture, Food and Rural Development's *Guidelines for Estimating Crop Production Costs 2014* for Western Manitoba (MAFRD, 2014b). The guide was used for all crops, with the exception of potatoes, where input costs were estimated using Manitoba Agriculture, Food and Rural Development's *Guidelines for Estimating Irrigated Processing Potato Costs – 2014*, which is based on 780 acres of potato production (MAFRD, 2014a). Data used from these documents are summarized in **Table 2** for costs and represent the cost of production for a field without transmission lines.

It should be cautioned that the following estimates for increased cost to production as a resulting of transmission lines over agricultural land do not take into account additional consequences or activities that would result from transmission lines such as increased input costs for areas sprayers cannot reach (for example - directly under tower for hand spraying), or decreased yields as a result of overlapping inputs, soil compaction, or additional access areas to the towers. Factors that require consideration when evaluating the financial impact of transmission lines; however, these factors require consideration on a case-by-case basis.

Table 2. Baseline costs of crop production inputs and activities that would change as a result of transmission line installation. Costs shown are estimates of costs prior to the installation of hydro towers.

Component	Winter Wheat[2] $/acre	Wheat[2] $/acre	Malt Barley[2] $/acre	Feed Barley[2] $/acre	Oats[2] $/acre	Corn[2] $/acre	Canola Invigor[2] $/acre	Canola Nexera[2] $/acre	Flax[2] $/acre	Soybeans Roundup[2] $/acre	Peas[2] $/acre	Potatoes[1] $/acre
Crop Input Costs												
Seed (includes treatment)	25.50	21.50	15.00	14.5	16.88	78.30	53.44	53.44	21.60	95.81	38.50	385.00
Fertilizer	81.56	70.16	62.99	62.99	59.4	94.40	92.21	92.21	53.26	10.24	12.80	329.83
Herbicides	7.90	23.32	25.50	25.5	7.9	6.63	11.17	11.17	11.95	9.01	16.78	48.00
Fungicide & Insecticide	14.90	14.90	8.90	8.9	8.9	0.00	21.17	26.02	12.02	0.00	15.03	131.50
Other Costs												
Fuel ($1.17/L)	24.42	22.86	26.42	26.42	29.39	29.52	22.85	22.85	19.49	20.80	22.34	75.71
Machinery operating	8.00	10.00	10.00	10.00	10.00	13.00	10.00	10.00	10.00	10.80	10.50	324.78
Labour (own)	30.00	30.00	30.00	30.00	30.00	45.00	30.00	30.00	36.00	30.00	36.00	450.00
Irrigation fuel												57.60

[1] MAFRD, 2014a
[2] MAFRD, 2014b

It should be cautioned that the following estimates for additional cost to production as a resulting of transmission lines over agricultural land do not take into account additional consequences or activities that would result from transmission lines such as increased input costs for areas sprayers cannot reach (for example - directly under tower for hand spraying), or decreased yields as a result of overlapping inputs, soil compaction, or additional access areas to the towers. Factors that require consideration when evaluating the financial impact of transmission lines; however, these factors require consideration on a case-by-case basis.

For informative purposes costs are categorized as costs due to overlap or cost due to unused land occupied by the towers then added for the total lost value to producers. Additional costs due to towers are calculated by multiplying the production cost categories in **Table 2** with a calculated factor considering overlap area, footprint area, and transport area. The production costs are identified alphabetically in capital letters, cost increases in lowercase.

3.2.1 Costs due to overlap

To determine the additional costs associated with added crop inputs, the costs of production for crop inputs (Seed, Fertilizer, Herbicide, Fungicide and Insecticide) as shown in **Table 2** are multiplied by the percentage of area overlap for the size implement used (obtained from
Table 5 of multiplication factors for all crops except irrigated potatoes for which case **Table 7** is used in **Appendix C**).

$a = Additional\ costs\ for\ seed = A \cdot O_S$ **Equation 5**

$b = Additional\ cost\ for\ fertilizer = B \cdot O_S$ **Equation 6**

Where,
A = Seed cost (includes treatment) ($/acre)
B = Fertilizer cost ($/acre)
O_S = % Area Overlap of Small Implement width

$c = Addtional\ herbicide\ cost = C \cdot O_L$ **Equation 7**

$d = Additional\ fungicide\ and\ insceticide\ cost = D \cdot O_L$ **Equation 8**

Where,
C = Herbicides cost ($/acre)
D = Fungicide & Insecticide cost ($/acre)
O_L = % Area Overlap of Large Implement width

To determine additional costs associated with the fuel and machinery categories, it is recognized that about half of field operations for crop production are completed with smaller width equipment such as cultivating, seeding, applying fertilizer and combining, and the other half with larger width equipment such as the application of herbicide, fungicide and insecticide. In addition, these costs are more significant when inputs are being applied (especially in the cases of cultivating and combining). Therefore the cost of production values for fuel and machinery from **Table 2** were multiplied by the average of the two multiplication factors for overlapping inputs from **Table 5** (or **Table 7** for potato production) for the case of large and small size equipment used in determining cost increases to fuel and machinery cost categories.

$$e = Additional\ fuel\ cost = E \cdot (O_S + O_L)/2$$ **Equation 9**

$$f = Additional\ machinery\ operating\ cost = F \cdot (O_S + O_L)/2$$ **Equation 10**

Where,
E = Fuel cost ($1.17/L) ($/acre)
F = Machinery operating cost ($/acre)

The added need to transport equipment without adding inputs adds additional labour requirements to complete field operations. Therefore the additional labour cost of production due to transmission lines is estimated by multiplying the labour cost of production from **Table 2** with the sum of the averages of percent overlap areas and percent transport area from **Table 5** (or **Table 7** for potato production) for the case of small and large implement sizes.

$$g = Additional\ labour\ cost = G \cdot (O_S + O_L + T_S + T_L)/2$$ **Equation 11**

Where,
G = Labour cost (own) ($/acre)
T_S = % Area Transport of Small Implement width
T_L = % Area Transport of Large Implement width

For the case of potato production there is a cost for irrigation. Any additional cost due to tower installations would be calculated by multiplying the irrigation cost with the percent overlap area in **Table 7**.

$$h = Additional\ irrigation\ cost\ = H \cdot O$$ **Equation 12**

Where,
H = Irrigation fuel cost (for potatoes only) ($/acre)
O = % Area Overlap

The total cost due to overlap is the sum of the additional cost seed, fertilizer, herbicides, fungicide, insecticide, fuel, machinery (operating), labour (own), and for the case of potatoes irrigation fuel.

$$i = Overlap\ costs = a + b + c + d + e + f + g + h \qquad \textbf{Equation 13}$$

3.2.2 Costs due to lost land use

For the lost value due to lost production area for grain production, the net value of the crop is multiplied by the percentage of unused area created during the seeding operation, which is represented by implement widths of 50 ft (15.2 m) or 60 ft (18.4 m) obtained from
Table 5, for potato production **Table 7** is used. The rationale is that losses are most significant where crop is not seeded which is done with the smaller width implement and less significant if some spray applications are missed. Simply put, crop is not produced unless it is seeded. Note that the net value of a crop is highly variable and depends on the crop yield, crop value, as well as the operating and fixed costs of the farming operations.

$$j = Lost\ net\ crop\ value\ = J \cdot U_S \qquad \textbf{Equation 14}$$

Where,
J = Net crop value (Value - operating costs - fixed costs) ($/acre)
U_S = % Area Unused of Small Implement width

This is identically equivalent to the lost value due to tower land use.

$$k = Lost\ value\ due\ to\ tower\ land\ use\ = j \qquad \textbf{Equation 15}$$

3.2.3 Total cost

The total lost value per easement acre is then the sum of the overlap costs per easement acre and lost value due to tower land use per easement acre.

$$m = Total\ lost\ value\ (\$/easement\ acre)) = i + k \qquad \textbf{Equation 16}$$

Finally the total lost value per easement acre is then multiplied by the easement area (**Table 1**) to get the total lost value per field quarter section.

$$n = Total\ lost\ value\ \ (\$/field\ easement) = m \cdot field\ easemenent\ acres \qquad \textbf{Equation 17}$$

3.2.4 Additional Cost (%) relative Total Production Costs for Easement or Field Areas

The additional cost due to the presence of a transmission line is also expressed in relative terms as a percentage of the cost of production for the easement area.

$$o = Total\ lost\ value\ (\%\ of\ production\ cost\ for\ easement\ area = m/I \qquad \textbf{Equation 18}$$

Where,
I = production cost ($/acre) prior to tower installation

In addition, the additional cost due to the presence of a transmission line is shown relative to the production costs for a quarter section as a percentage.

$$p = Total\ lost\ value\ (\%)\ relative\ production\ cost\ for\ field\ area,$$
$$p = \frac{m}{I} \cdot (Easement\ Acres)/(160\ Acres\ per\ Quarter\ Section) \qquad \textbf{Equation 19}$$

3.2.5 Example Calculation

An example calculation follows for the following conditions:

- Scenario 1, steel tower transmission line
- Production methods use a 15.2 m (50 ft) seeder and a 30.5 m (100 ft) sprayer
- Crop grown is wheat

First the required information, shown in **Table 3,** needed to perform the estimated cost increases, is gathered from **Table 1**, **Table 2**, and **Table 5**.

Table 3. Information specific to the scenario, transmission line size, and implement widths required for calculating the estimated additional costs due to transmission line installation.

Easement Acres - Scenario 1, steel tower (Table 2)				
15.91 acres				
Multiplication Factors (Table 3)				
Implement Width	**Nominal Size**	**% Area Overlap**	**% Area Unused**	**% Area Transport**
15.2m (50')	**Small**	5.26%	0.37%	2.41%
30.5m (100')	**Large**	11.32%	0.37%	7.70%

Cost of production estimates for wheat (Table 6)	
Component	**Wheat² $/acre**
Crop Input Costs	
(A) Seed (includes treatment)	21.50
(B) Fertilizer	70.16
(C) Herbicides	23.32
(D) Fungicide & Insecticide	14.90

Other Costs	
(E) Fuel ($1.17/L)	22.86
(F) Machinery operating	10.00
(G) Labour (own)	30.00

Table 4 shows on the right hand side the estimated increase in production costs expected to change due to the presence of the transmission line. The production costs are displayed again on the left for convenience. A net value of $50/acre was used, which would be an example of one farmer's profit margin for wheat; however, the profit margin can be anywhere from a negative value to well over $100/acre depending on the year, crop, and land.

Table 4. Additional costs to production due to transmission line for the example conditions: Scenario 1, steel tower transmission line, 50 ft and 100 ft implement widths.

	Component	Wheat[2]	Additional Costs due to Transmission Line	
		$/acre	Formula	$/easement acre
	Crop Input Costs			
(A)	Seed (includes treatment)	21.50	$a = A \cdot O_S$	1.130
(B)	Fertilizer	70.16	$b = B \cdot O_S$	3.689
(C)	Herbicides	23.32	$c = C \cdot O_L$	2.639
(D)	Fungicide & Insecticide	14.90	$d = D \cdot O_L$	1.686
	Other Costs			
(E)	Fuel ($1.17/L)	22.86	$e = E \cdot (O_S + O_L)/2$	1.894
(F)	Machinery operating	10.00	$f = F \cdot (O_S + O_L)/2$	0.829
(G)	Labour (own)	30.00	$g = G \cdot (O_S + O_L + T_S + T_L)/2$	4.002
(H)	Irrigation fuel		for Potatoes only $h = H \cdot O$	
(i)	Total overlap costs	192.74	$i = a + b + c + d + e + f + g + h$	**15.87**
	Net crop value			
(J)	Value – operating costs – fixed costs	50.00	$j = J \cdot U_S$	0.19
(k)	**Lost value due to tower land use**		$k = j$	**0.19**
(m)	**Total Lost Value ($/easement acre)**		$m = i + j$	**16.06**
(n)	**Total Lost Value ($/field easement)**		$n = m \cdot Easement\ acres$	**255.52**
(o)	**Total Lost Value relative Total Easement Production Costs**		$o = m/I$	**8.3%**
(p)	**Total Lost Value relative Total Field Production Costs**		$p = \frac{m}{I} \cdot (Easement\ acres)/160$	**0.83%**

The same calculations are performed for a case where the field equipment used on the farm are 20% wider (i.e. a 18.3 m (60 ft) seeder used with a 36.6 m (120 ft) sprayer). In this case the multiplication factors for a 18.3 m (60 ft) implement are used where calculations refer to a "small implement" (S subscript) and the multiplications factors for a 36.6 m (120 ft) implement used when a “large implement” is referenced (L subscript) in the tabulated formulas. For the other two scenarios of transmission line layouts, the same procedure is followed and formulas used but multiplication factors for the particular scenario are selected and used in the calculations.

The following **Figure 3-17** through **Figure 3-22** display the results of the same calculations performed for wheat for scenario 1, scenario 2, and scenario 3 tower layouts for both H-frame and steel tower transmission lines and two cases each where operations use either a 15.2 m (50 ft) seeder used with a 30.5 m (100 ft) sprayer or a 18.3 m (60 ft) seeder used with a 36.6 m (120 ft) sprayer.

Note: η is the abbreviation for the % of easement area that is unaffected by transmission lines

Scenario 1 – Transmission lines parallel to road along field edge
H-frame tower

Implement Width	% Area Overlap	% Area Unused	% Area Transport	η
15.2m (50')	4.07%	1.26%	0.00%	94.67%
18.3m (60')	4.50%	1.41%	0.00%	94.09%
30.5m (100')	5.86%	1.50%	0.00%	92.64%
36.6m (120')	6.44%	2.09%	0.00%	91.47%

Easement Area = 4.72 Acres

Component	Wheat²	Tower Installation (by implement width)	
		30.5 m (100' sprayer)	36.6 m (120' sprayer)
	$/acre	$/easement acre	$/easement acre
Crop Input Costs			
(A) Seed (includes treatment)	21.50	0.874	0.967
(B) Fertilizer	70.16	2.854	3.155
(C) Herbicides	23.32	1.367	1.502
(D) Fungicide & Insecticide	14.90	0.873	0.960
Other Costs			
(E) Fuel ($1.17/L)	22.86	1.135	1.250
(F) Machinery operating	10.00	0.496	0.547
(G) Labour (own)	30.00	1.489	1.641
(H) Irrigation fuel	0.00		
(i) Overlap costs	**192.74**	**9.09**	**10.02**
Net crop value			
(J) Value - operating costs - fixed costs	50.00	0.63	0.71
(k) Lost value due to tower land use		**0.63**	**0.71**
(m) Total Lost Value ($/easement acre)		**9.72**	**10.73**
(n) Total Lost Value ($/field easement)		**45.92**	**50.69**
(o) Total Lost Value (%) relative Total Easement Production Costs		**5.0%**	**5.6%**
(p) Total Lost Value (%) relative Total Field Production Costs		**0.15%**	**0.16%**

Figure 3-17. Additional costs for wheat with H-frame towers on land placed parallel to the road along the field edge.

The H-frame transmission line installed parallel to the roadway does not add a lot of additional costs in the above examples. An estimated $45.92 per quarter section for an operation using a 15.2 m (50 ft) seeder and 30.5 m (100 ft) sprayer and marginally more ($50.69 per quarter section) when using an 18.3 m (60 ft) seeder with a 36.6 m (120 ft) sprayer due to the slightly greater overlapping and unused areas with using the larger equipment. The % of easement area unaffected by the transmission line is quite high, ranging from 91% to 95% between the four implement widths. The lost value due to tower land use is quite low compared to the overlap costs.

Steel tower

Implement Width	% Area Overlap	% Area Unused	% Area Transport	η
15.2m (50')	5.26%	0.37%	2.41%	91.96%
18.3m (60')	3.29%	0.37%	3.01%	93.33%
30.5m (100')	11.32%	0.37%	7.70%	80.61%
36.6m (120')	6.18%	5.62%	7.06%	81.14%

Easement Area = 15.91 Acres

Component	Wheat²	Additional Costs Associated with Tower Installation (by implement width)	
		30.5 m (100' sprayer)	36.6 m (120' sprayer)
	$/acre	$/easement acre	$/easement acre
Crop Input Costs			
(A) Seed (includes treatment)	21.50	1.130	0.707
(B) Fertilizer	70.16	3.689	2.306
(C) Herbicides	23.32	2.639	1.441
(D) Fungicide & Insecticide	14.90	1.686	0.921
Other Costs			
(E) Fuel ($1.17/L)	22.86	1.894	1.082
(F) Machinery operating	10.00	0.829	0.473
(G) Labour (own)	30.00	4.002	2.930
(H) Irrigation fuel	0.00		
(i) Overlap costs	**192.74**	**15.87**	**9.86**
Net crop value			
(J) Value - operating costs - fixed costs	50.00	0.19	0.19
(k) Lost value due to tower land use		**0.19**	**0.19**
(m) Total Lost Value ($/easement acre)		**16.06**	**10.05**
(n) Total Lost Value ($/field easement)		**255.52**	**159.89**
(o) Total Lost Value (%) relative Total Easement Production Costs		**8.3%**	**5.2%**
(p) Total Lost Value (%) relative Total Field Production Costs		**0.83%**	**0.52%**

Figure 3-18. Additional costs for wheat with steel towers on land placed parallel to the road along the field edge.

The steel tower transmission line installed parallel to the roadway adds relatively more cost in the above example than an H-frame. Costs are greater because the towers are located 40 m into the field from the edge, as opposed to at the edge. In-field placement directs implement passes to circle the towers which creates overlap on three additional sides of the tower and the need to re-travel ground covered circling the tower, increasing input costs and labour. It is interesting to note that costs are slightly less with the larger 18.3 m (60 ft) seeder and 36.6 m (120 ft) sprayer equipment ($159.89 as opposed to $255.52 per quarter section). This is due to a combination of factors; the field passes line up in such a way to reduce the overlap area for the 18.3 m (60 ft) implement over the 15.2 m (50 ft) one. In addition the 36.6 m (120 ft) wide implement is too wide to pass between the tower and the field edge and has to swing into the field to pass the tower. This reduces overlap and transport areas. The % of easement area unaffected by the transmission line is still quite high, ranging from 81% to 93% between the four implement widths. The lost area due to tower land use is minimal compared with the overlap costs.

Scenario 2 – Transmission lines perpendicular to road along quarter section line. Note that the total lost value calculated is for one quarter section only. Scenario 2 is unique in that the easement covers two fields.
H-frame tower

Implement Width	% Area Overlap	% Area Unused	% Area Transport	η
15.2m (50')	1.77%	0.60%	0.00%	97.63%
18.3m (60')	2.13%	0.72%	0.00%	97.15%
30.5m (100')	2.76%	0.92%	0.00%	96.32%
36.6m (120')	3.00%	1.00%	0.00%	96.00%

Easement Area = 3.98 Acres

Component	Wheat²	Additional Costs Associated with Tower Installation (by implement width)	
		30.5 m (100' sprayer)	36.6 m (120' sprayer)
	$/acre	$/easement acre	$/easement acre
Crop Input Costs			
(A) Seed (includes treatment)	21.50	0.381	0.458
(B) Fertilizer	70.16	1.242	1.494
(C) Herbicides	23.32	0.644	0.700
(D) Fungicide & Insecticide	14.90	0.411	0.447
Other Costs			
(E) Fuel ($1.17/L)	22.86	0.518	0.586
(F) Machinery operating	10.00	0.227	0.257
(G) Labour (own)	30.00	0.680	0.770
(H) Irrigation fuel	0.00		
(i) Overlap costs	**192.74**	**4.10**	**4.71**
Net crop value			
(J) Value - operating costs - fixed costs	50.00	0.30	0.36
(k) Lost value due to tower land use		**0.30**	**0.36**
(m) Total Lost Value ($/easement acre)		**4.40**	**5.07**
(n) Total Lost Value ($/field easement)		**17.51**	**20.18**
(o) Total Lost Value (%) relative Total Easement Production Costs		**2.3%**	**2.6%**
(p) Total Lost Value (%) relative Total Field Production Costs		**0.06%**	**0.07%**

Figure 3-19. Additional costs for wheat with H-frame towers on land placed perpendicular to the road along the ¼ section line.

The H-frame transmission line located on the border between quarter sections adds even less additional costs in the above examples than when aligned parallel to and adjacent to a roadway. An estimated $17.51 per quarter section for an operation using a 15.2 m (50 ft) seeder and 30.5 m (100 ft) sprayer and marginally more ($20.18 per quarter section) when using an 18.3 m (60 ft) seeder with a 36.6 m (120 ft) sprayer due to the slightly greater overlapping and unused areas with using the larger equipment. The % of easement area unaffected by the transmission line is quite high, ranging from 96% to 98% between the four implement widths. The lost value due to tower land use is quite low compared to the overlap costs. The lost value due to tower land use is the lowest of the three scenarios.

Steel tower

Implement Width	% Area Overlap	% Area Unused	% Area Transport	η
15.2m (50')	1.33%	0.59%	0.00%	98.08%
18.3m (60')	1.42%	0.62%	0.00%	97.96%
30.5m (100')	1.70%	0.71%	0.00%	97.58%
36.6m (120')	1.83%	0.76%	0.00%	97.42%

Easement Area = 7.96 Acres

Component	Wheat²	Additional Costs Associated with Tower Installation (by implement width)	
		30.5 m (100' sprayer)	36.6 m (120' sprayer)
	$/acre	$/easement acre	$/easement acre
Crop Input Costs			
(A) Seed (includes treatment)	21.50	0.286	0.306
(B) Fertilizer	70.16	0.933	0.999
(C) Herbicides	23.32	0.397	0.426
(D) Fungicide & Insecticide	14.90	0.254	0.272
Other Costs			
(E) Fuel ($1.17/L)	22.86	0.347	0.371
(F) Machinery operating	10.00	0.152	0.162
(G) Labour (own)	30.00	0.455	0.487
(H) Irrigation fuel	0.00		
(i) Overlap costs	**192.74**	**2.82**	**3.02**
Net crop value			
(J) Value - operating costs - fixed costs	50.00	0.29	0.31
(k) Lost value due to tower land use		**0.29**	**0.31**
(m) Total Lost Value ($/easement acre)		**3.12**	**3.33**
(n) Total Lost Value ($/field easement)		**24.80**	**26.52**
(o) Total Lost Value (%) relative Total Easement Production Costs		**1.6%**	**1.7%**
(p) Total Lost Value (%) relative Total Field Production Costs		**0.08%**	**0.09%**

Figure 3-20. Additional costs for wheat with steel towers on land placed perpendicular to the road along the quarter section line.

The steel tower transmission line located on the border between quarter sections adds significantly lower additional costs in the above examples than when aligned parallel to and adjacent to a roadway. An estimated $24.80 per quarter section for an operation using a 15.2 m (50 ft) seeder and 30.5 m (100 ft) sprayer and marginally more ($26.52 per quarter section) when using an 18.3 m (60 ft) seeder with a 36.6 m (120 ft) sprayer due to the slightly greater overlapping and unused areas with using the larger equipment. The % of easement area unaffected by the transmission line is quite high, ranging from 97% to 98% between the four implement widths. The lost value due to tower land use is higher than in scenario 1 but still quite low overall.

Scenario 3 – Transmission line diagonal across quarter section of land
H-frame tower

Implement Width	% Area Overlap	% Area Unused	% Area Transport	η
15.2m (50')	7.73%	0.24%	6.25%	85.78%
18.3m (60')	11.69%	0.24%	7.61%	80.46%
30.5m (100')	34.14%	0.24%	14.80%	50.82%
36.6m (120')	47.69%	0.24%	20.47%	31.60%

Easement Area = 11.07 Acres

Component	Wheat[2]	Additional Costs Associated with Tower Installation (by implement width)	
		30.5 m (100' sprayer)	36.6 m (120' sprayer)
	$/acre	$/easement acre	$/easement acre
Crop Input Costs			
(A) Seed (includes treatment)	21.50	1.661	2.513
(B) Fertilizer	70.16	5.421	8.201
(C) Herbicides	23.32	7.961	11.121
(D) Fungicide & Insecticide	14.90	5.087	7.105
Other Costs			
(E) Fuel ($1.17/L)	22.86	4.785	6.787
(F) Machinery operating	10.00	2.093	2.969
(G) Labour (own)	30.00	9.438	13.119
(H) Irrigation fuel	0.00		
(i) Overlap costs	**192.74**	**36.45**	**51.82**
Net crop value			
(J) Value - operating costs - fixed costs	50.00	0.12	0.12
(k) Lost value due to tower land use		**0.12**	**0.12**
(m) Total Lost Value ($/easement acre)		**36.57**	**51.94**
(n) Total Lost Value ($/field easement)		**404.65**	**574.72**
(o) Total Lost Value (%) relative Total Easement Production Costs		**19.0%**	**26.9%**
(p) Total Lost Value (%) relative Total Field Production Costs		**1.31%**	**1.86%**

Figure 3-21. Additional costs for wheat with H-frame towers on land placed diagonal to the road.

The H-frame transmission line located on the diagonal across a quarter section adds significantly more cost in the above examples than when aligned on the border between quarter sections or when parallel and adjacent to a roadway. An estimated $404.65 per quarter section for an operation using a 15.2 m (50 ft) seeder and 30.5 m (100 ft) sprayer and $574.72 per quarter section when using an 18.3 m (60 ft) seeder with a 36.6 m (120 ft) sprayer due to the slightly greater overlap and transport areas with using the larger equipment. It is interesting to note the additional costs for the larger sized implements exceeds the breakeven point for the easement area at a net crop value of $50 per acre. While the assumption was made that farmers would try to minimize lost acres, savings could be made by reducing spraying or fertilizer inputs where the majority of the implement width is crossing previously covered ground. The % of easement area unaffected by the transmission line is higher for the smaller implements, ranging from 80% to 86% between the four implement widths but lower for the wider implements (32% to 51%). The lost value due to tower land use is the highest of the three scenarios.

Steel tower

Implement Width	% Area Overlap	% Area Unused	% Area Transport	η
15.2m (50')	3.06%	0.39%	3.22%	93.34%
18.3m (60')	3.98%	0.39%	4.11%	91.52%
30.5m (100')	9.90%	0.39%	8.09%	81.63%
36.6m (120')	14.62%	0.39%	10.04%	74.95%

Easement Area = 21.95 Acres

Component	Wheat² $/acre	Additional Costs Associated with Tower Installation (by implement width) 30.5 m (100' sprayer) $/easement acre	36.6 m (120' sprayer) $/easement acre
Crop Input Costs			
(A) Seed (includes treatment)	21.50	0.657	0.855
(B) Fertilizer	70.16	2.145	2.790
(C) Herbicides	23.32	2.308	3.410
(D) Fungicide & Insecticide	14.90	1.475	2.179
Other Costs			
(E) Fuel ($1.17/L)	22.86	1.481	2.126
(F) Machinery operating	10.00	0.648	0.930
(G) Labour (own)	30.00	3.639	4.913
(H) Irrigation fuel	0.00		
(i) Overlap costs	**192.74**	**12.35**	**17.20**
Net crop value			
(J) Value - operating costs - fixed costs	50.00	0.19	0.19
(k) Lost value due to tower land use		**0.19**	**0.19**
(m) Total Lost Value ($/easement acre)		**12.54**	**17.40**
(n) Total Lost Value ($/field easement)		**275.29**	**381.76**
(o) Total Lost Value (%) relative Total Easement Production Costs		**6.5%**	**9.0%**
(p) Total Lost Value (%) relative Total Field Production Costs		**0.89%**	**1.24%**

Figure 3-22. Additional costs for wheat with steel towers on land placed diagonal to the road.

The steel tower transmission line located on the diagonal across a quarter section adds significantly more cost in the above examples than when aligned on the border between quarter sections. The cost is comparable to when the transmission line is parallel and adjacent to a roadway. The cost is estimated at $275.29 per quarter section for an operation using a 15.2 m (50 ft) seeder and 30.5 m (100 ft) sprayer and $381.76 per quarter section when using an 18.3 m (60 ft) seeder with a 36.6 m (120 ft) sprayer due to the slightly greater overlap and transport areas from using the larger equipment. It is interesting to note that the additional costs for the steel tower transmission line are lower than those of the H-frame in the same scenario. This is due to a geometrical effect where the effective width of the tower obstructing a field pass increases for the steel towers square base when placed at a 45 degree angle to a favorable ratio increasing transport area but reducing overlap where the majority of costs are incurred. In the case of the H-frame structures, the effective width of the more linear footprint become shorter when approached at a 45 degree angle and a greater portion of the affected area becomes overlap. These observations would be different if a different lateral approach distance was chosen relative the tower, however, the overall difference is not expected to be extreme. The other consideration is that H-frame structures are spaced closer together and so there are more to a field. The % of easement area unaffected by the transmission lines is modest, in the range of 75% to 93% between the four implement widths and the lost value due to tower land use is low.

3.2.6 Conclusions

Figure 3-19 summarizes the results of the additional cost associated with transmission lines crossing agricultural land in wheat production. Looking at the percentage of easement unaffected by transmission lines and the example calculations, Scenario 2 stands out as being optimal for both transmission lines and the two different production cases (using a 15.2 m (50 ft) seeder and 30.5 m (100 ft) sprayer or an 18.3 m (60 ft) seeder and 36.6 m (120 ft) sprayer. Placing transmission line support structures on the mid-section line incurs the least additional costs to the producer. In general, Scenario 3 is the least optimal due to the increased crop inputs and labour requirements associated with negotiating infield obstacles. Scenario 1 is not much different in terms of additional costs than Scenario 2 for H-frame transmission lines. For steel tower transmission lines the associated additional costs are less preferable (similar to the Scenario 3) than Scenario 1. The production of other crops would likely show similar trends; however, numbers will vary based on production costs, crop values, and potential yields and would require calculation as previously explained.

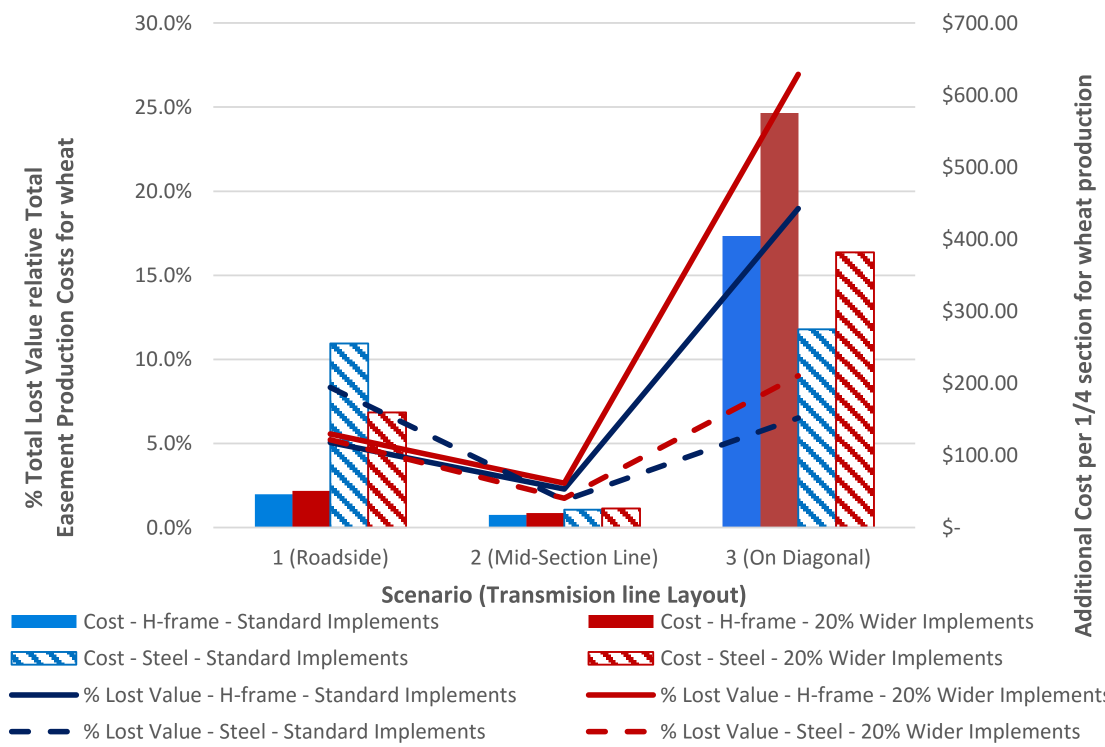

Figure 3-23. % total lost value relative total easement production costs growing wheat and yearly cost for the three scenarios and H-frame and steel structures.

3.3 Limitations and Future Work

Further to this report, Manitoba Hydro has contracted PAMI to engage in additional research to further understand the considerations related to working around transmission lines that are not captured in this report, which includes (and is not limited to):

- Fertilizer, herbicide, and insecticide application as well as application method (aerial vs ground)
- Construction damages
- Crop growth and quality due to soil compaction
- Risk of damage to equipment or people
- insurance requirements
- Future agricultural technology

4. References

Manitoba Agriculture, Food and Rural Development (MAFRD). (2014a). Guidelines for estimating irrigated processing potato costs – 2014 based on 780 acres production. Retrieved from http://www.gov.mb.ca/agriculture/business-and-economics/financial-management/pubs/cop_crop_irrigatedpotato.pdf

Manitoba Agriculture, Food and Rural Development (MAFRD). (2014b). Guidelines for estimating crop production costs 2014 in western Manitoba. Retrieved from http://www.gov.mb.ca/agriculture/business-and-economics/financial-management/pubs/cop_crop_productionwesternmb.pdf

Appendix A

Typical Grain Farming Equipment

Figure A-1. Present-day combines.

Figure A-4-1. A present day high clearance spreader.


Photo credit: http://www.brandt.ca/Divisions/AgriculturalProducts/Products/Pages/Product.aspx?cat=Products&pid=HeavyHarrow_001(Brandt)&vid=7000_001(Brandt)

Figure A-3. A present day heavy harrow.


Photo credit: http://www.agannex.com/images/machinery-manager/Air%20Seeders%20and%20drills/Feb_2014/SeedMaster_drill_V2.jpg

Figure A-4. A present day air drill.

Appendix B

Diagrams of Land Use Changes

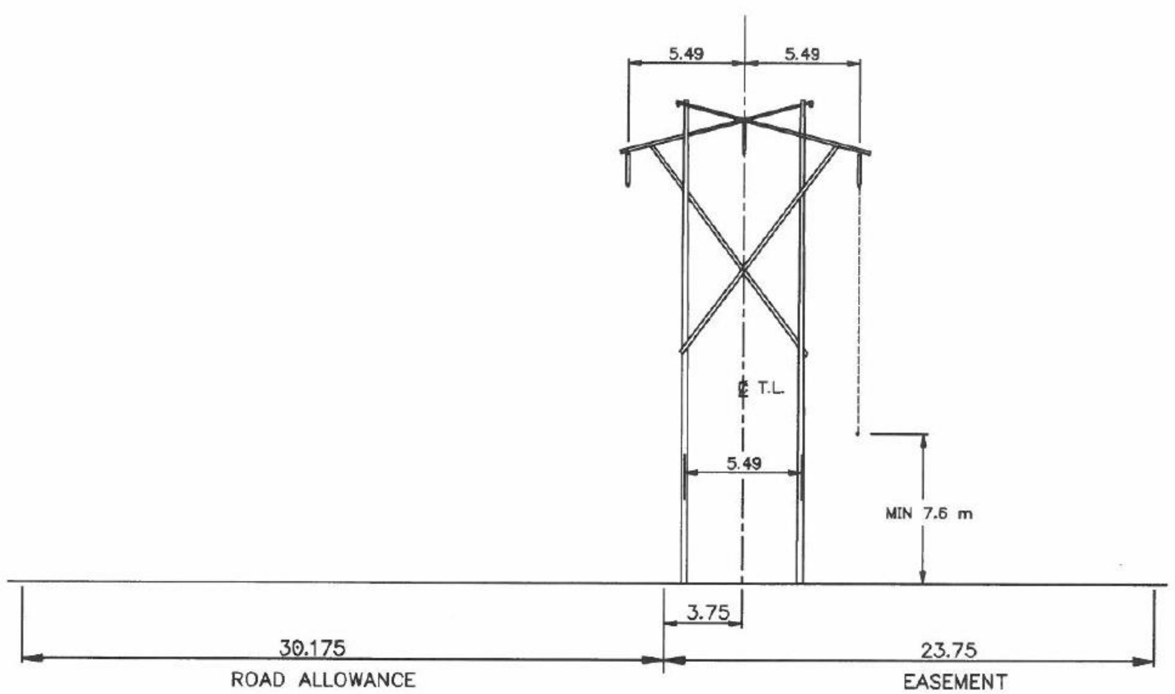

Figure A-1. Typical H-frame transmission line cross-section adjacent to a road allowance (scenario 1)

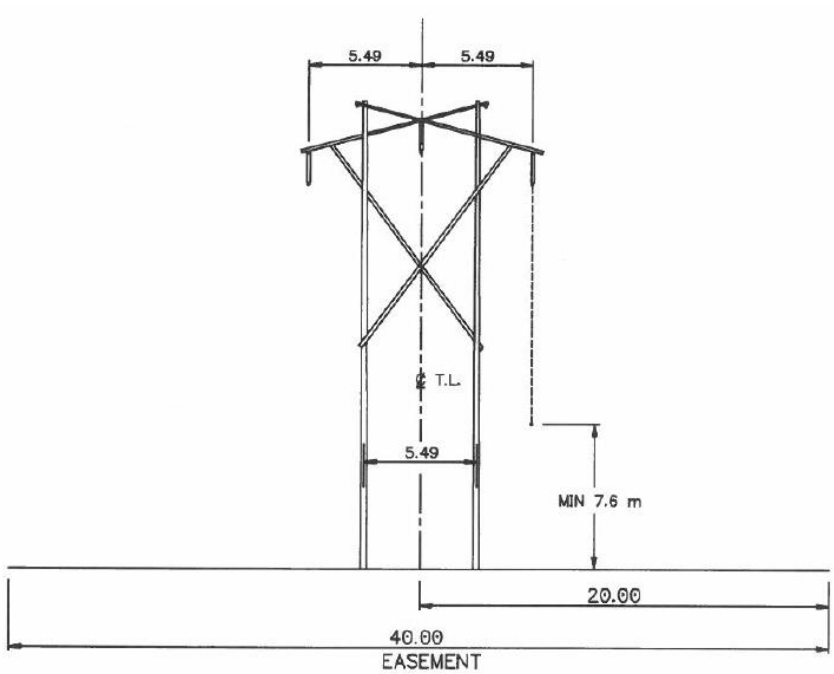

Figure A-2. Typical H-frame transmission line cross-section located on ¼ section line (scenario 2) or diagonally across a field (scenario 3).

Figure A-3. Tower base dimensions (m) with 1 m safety buffers for H-frame tower.

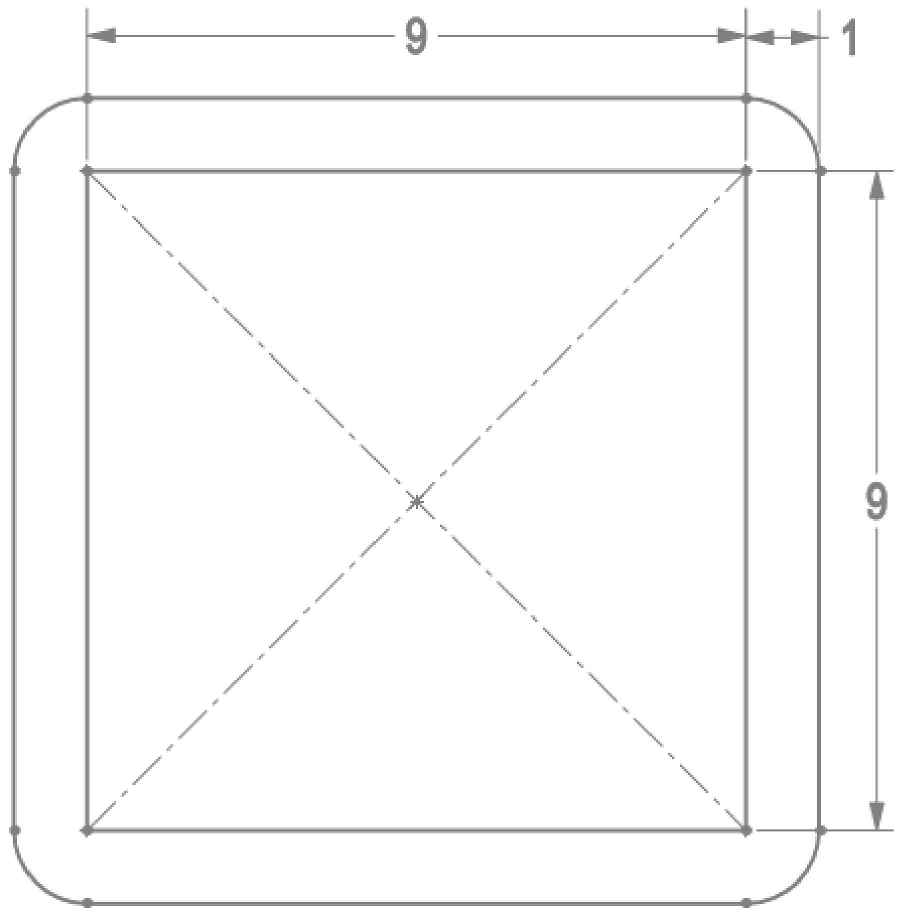

Figure A-4. Tower base dimensions (m) with 1 m safety buffers for steel tower.

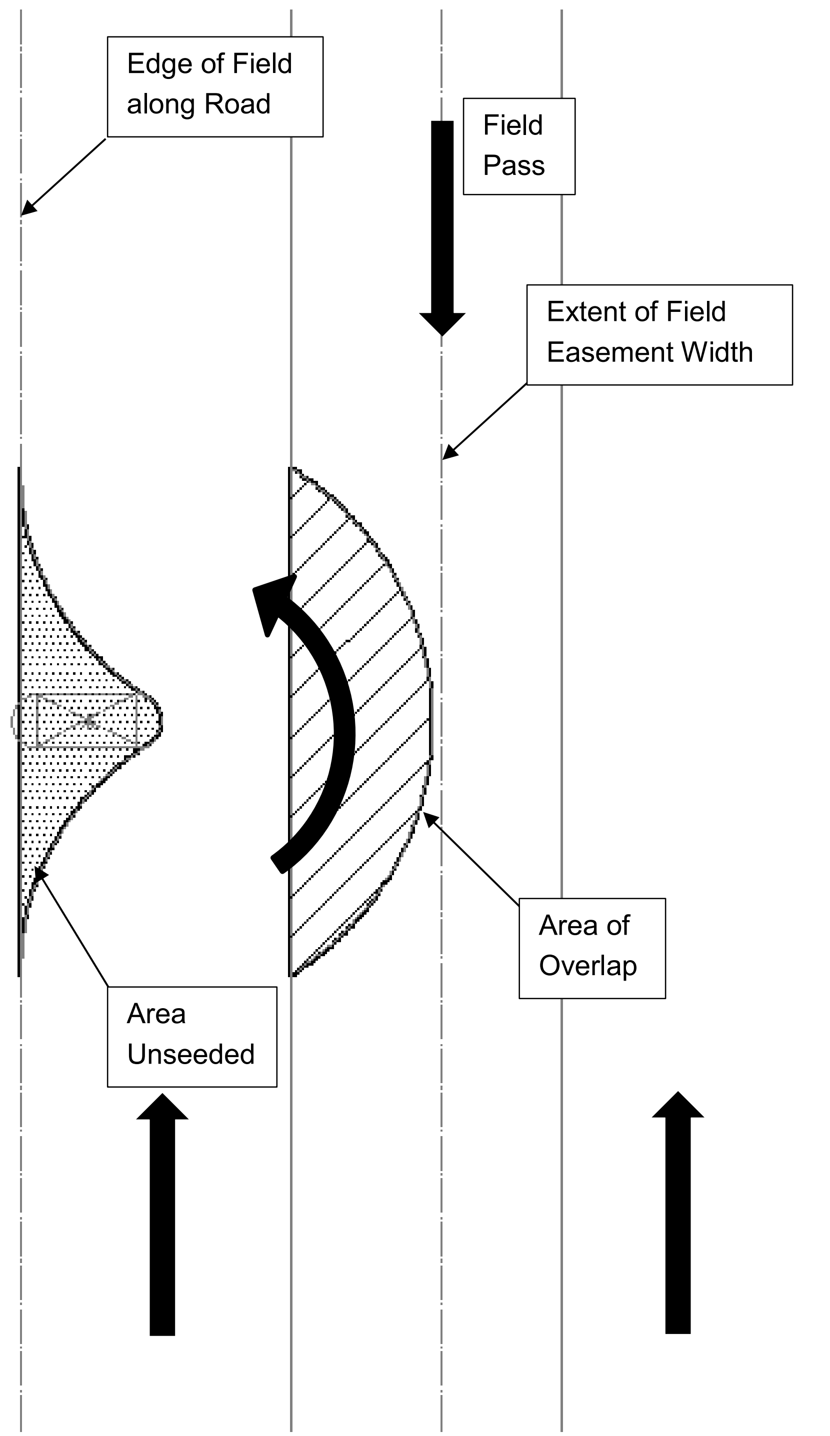

Figure A-5. Scenario 1, H-frame, 50 ft, with examples of footprint area (doted) and overlap areas (hashed) on completing field passes.

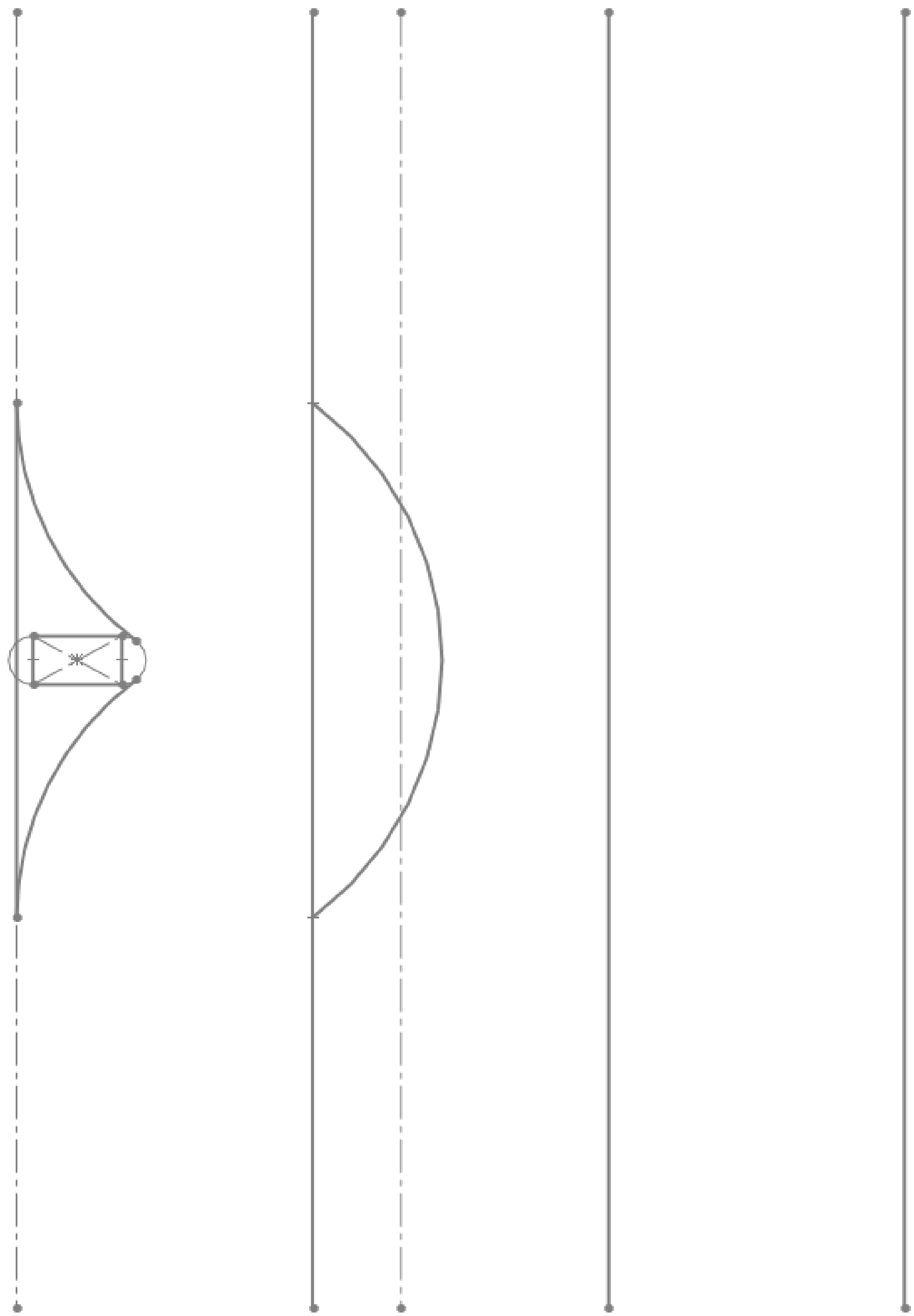

Figure A-6. Scenario 1, H-frame, 60 ft.

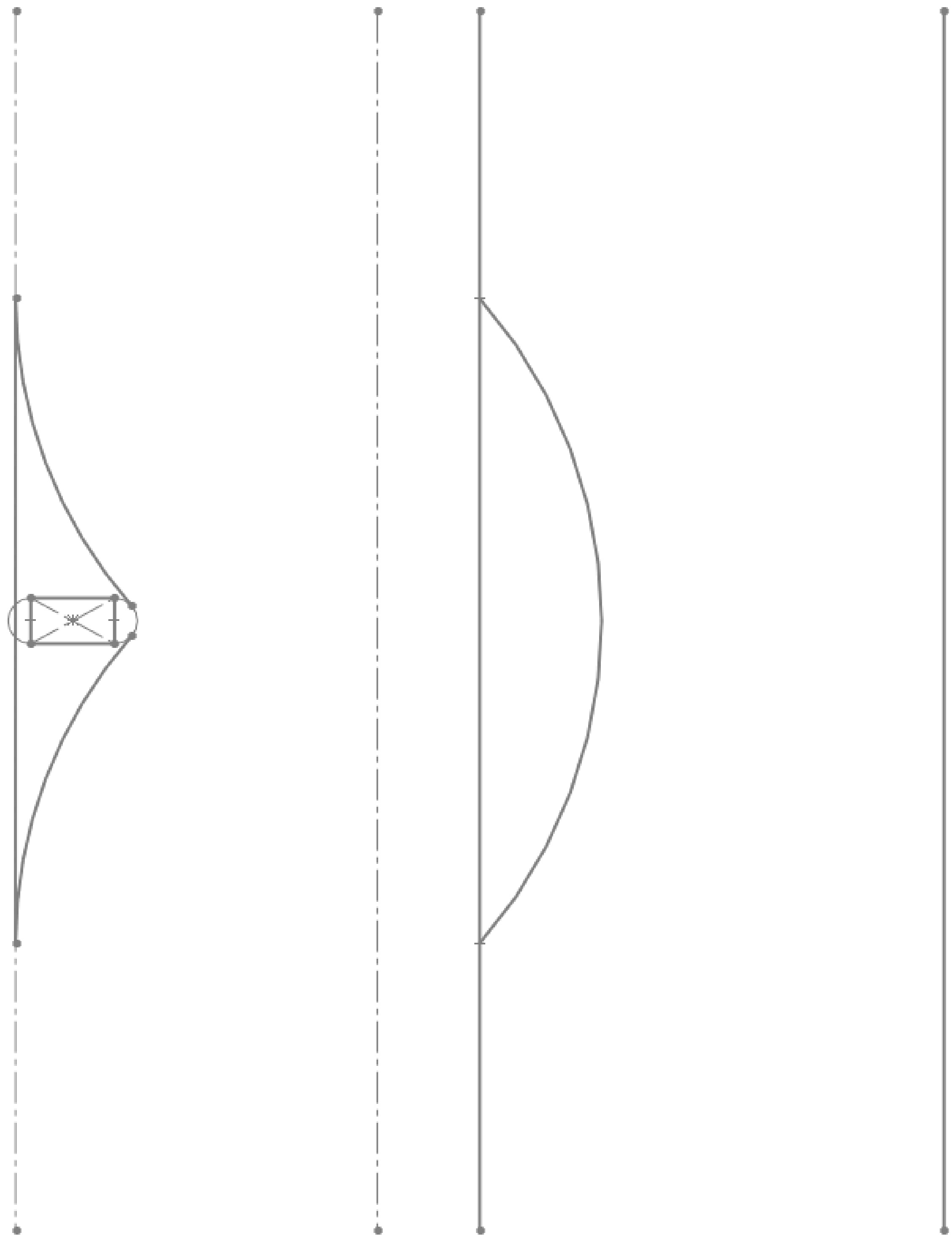

Figure A-7. Scenario 1, H-frame, 100 ft.

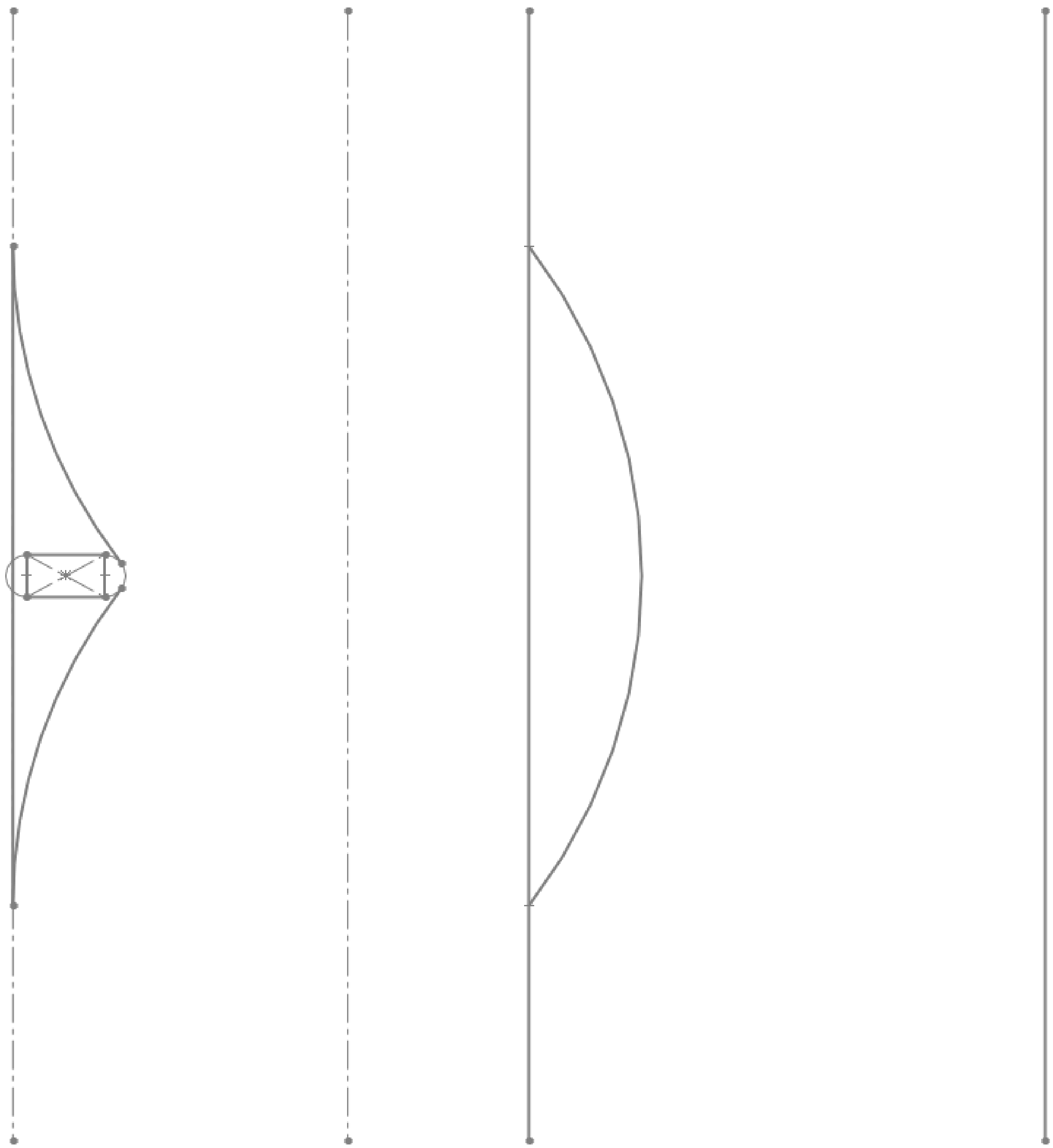

Figure A-8. Scenario 1, H-frame, 120 ft.

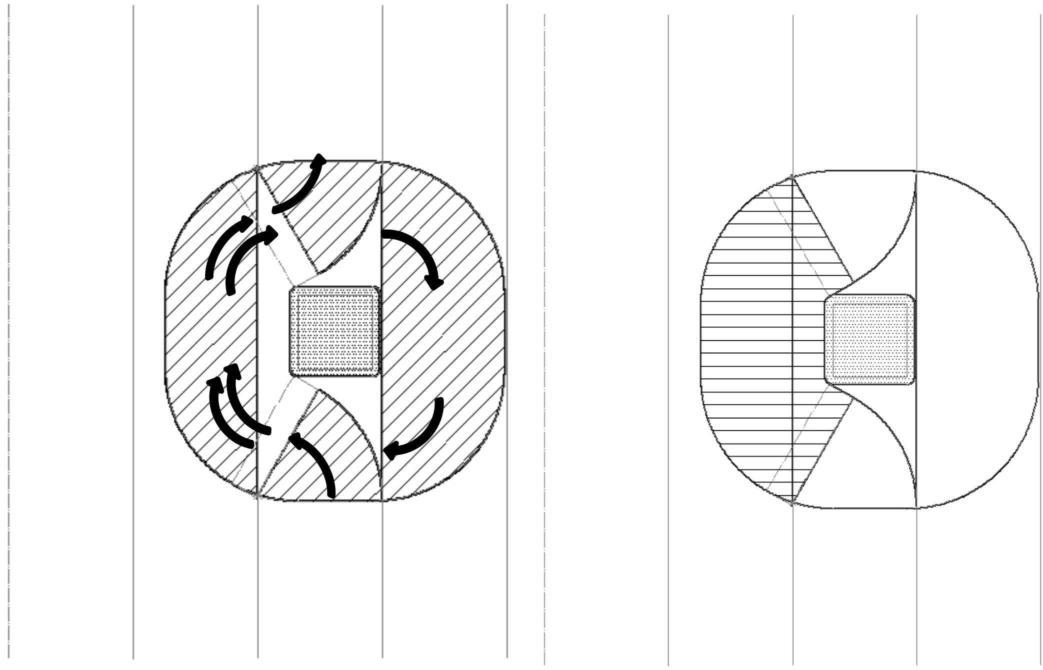

Figure A-9. Scenario 1, steel tower, 50 ft, with examples of footprint area (dotted) and overlap areas (hashed) on completing field passes, Left, and transport area (horizontal lines) on the Right.

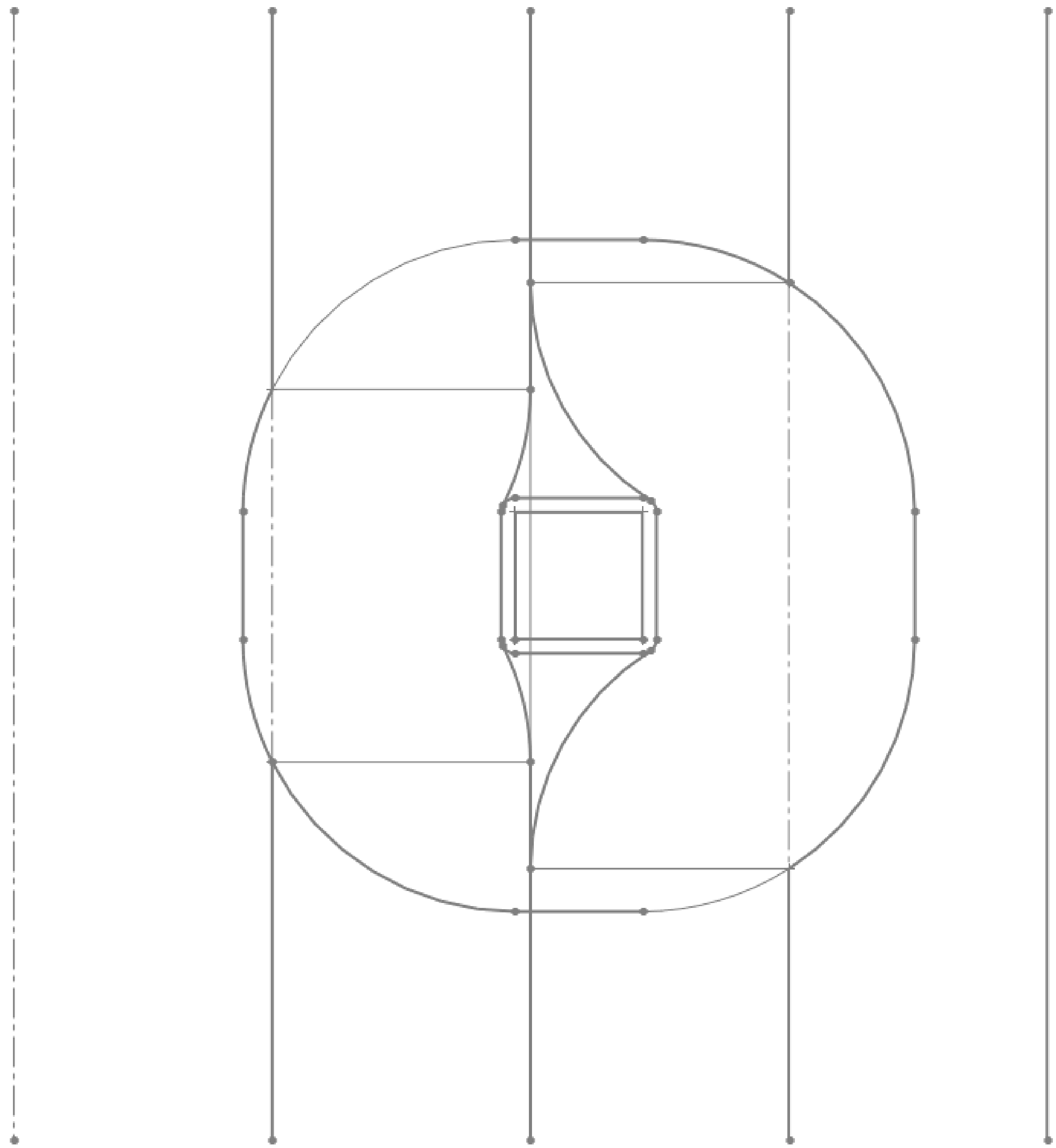

Figure A-10. Scenario 1, steel tower, 60 ft.

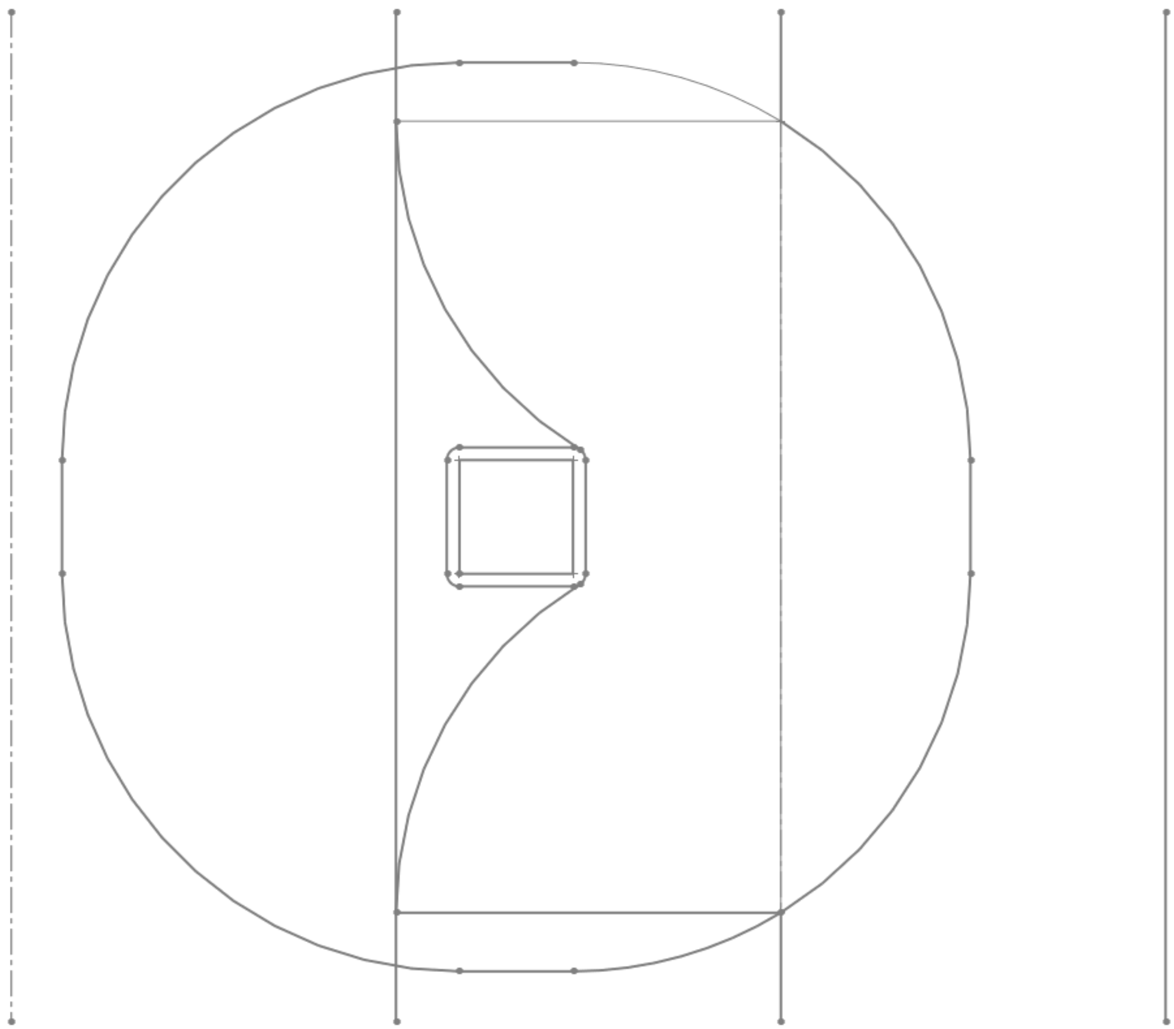

Figure A-11. Scenario 1, steel tower, 100 ft.

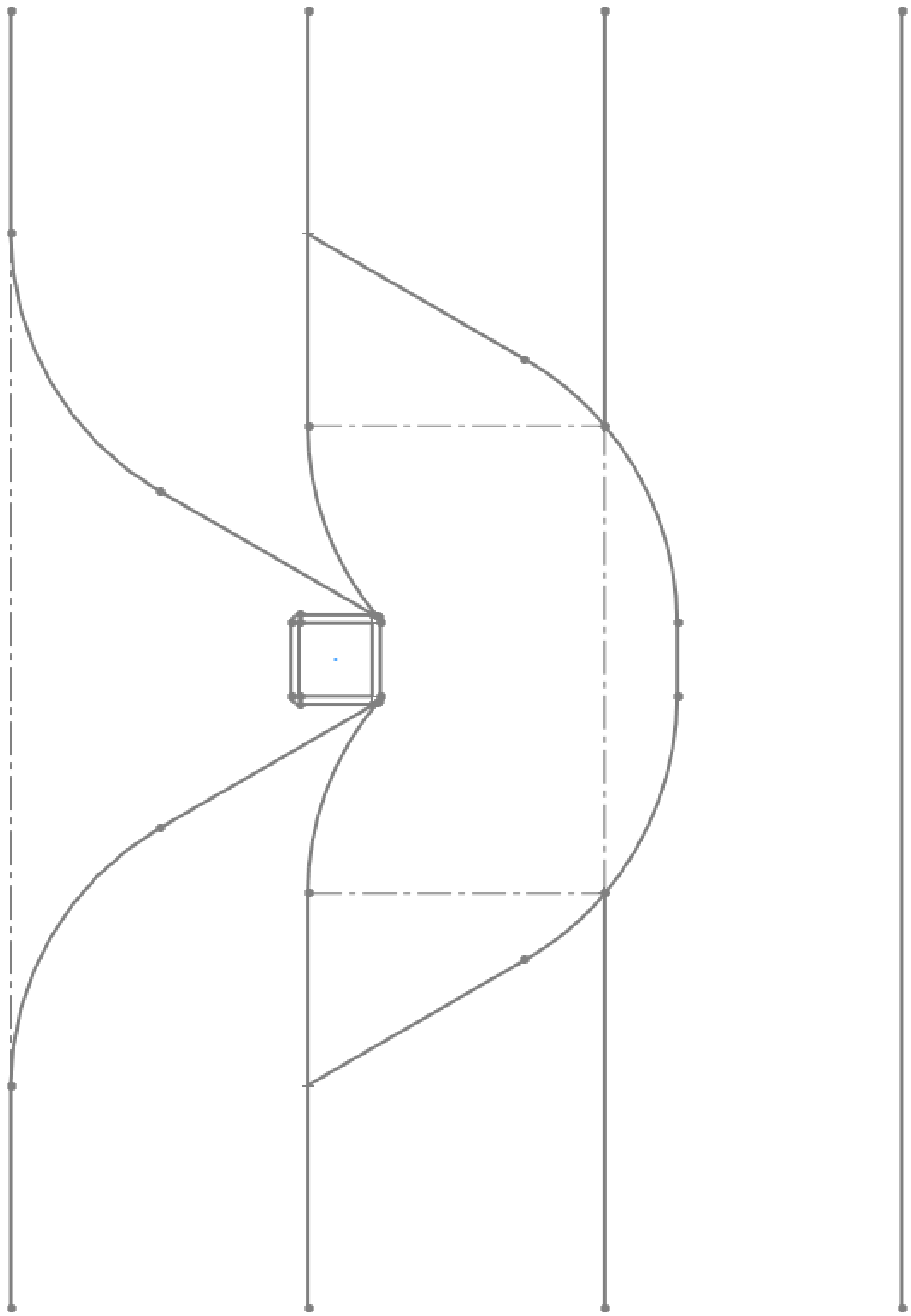

Figure A-12. Scenario 1, steel tower, 120 ft.

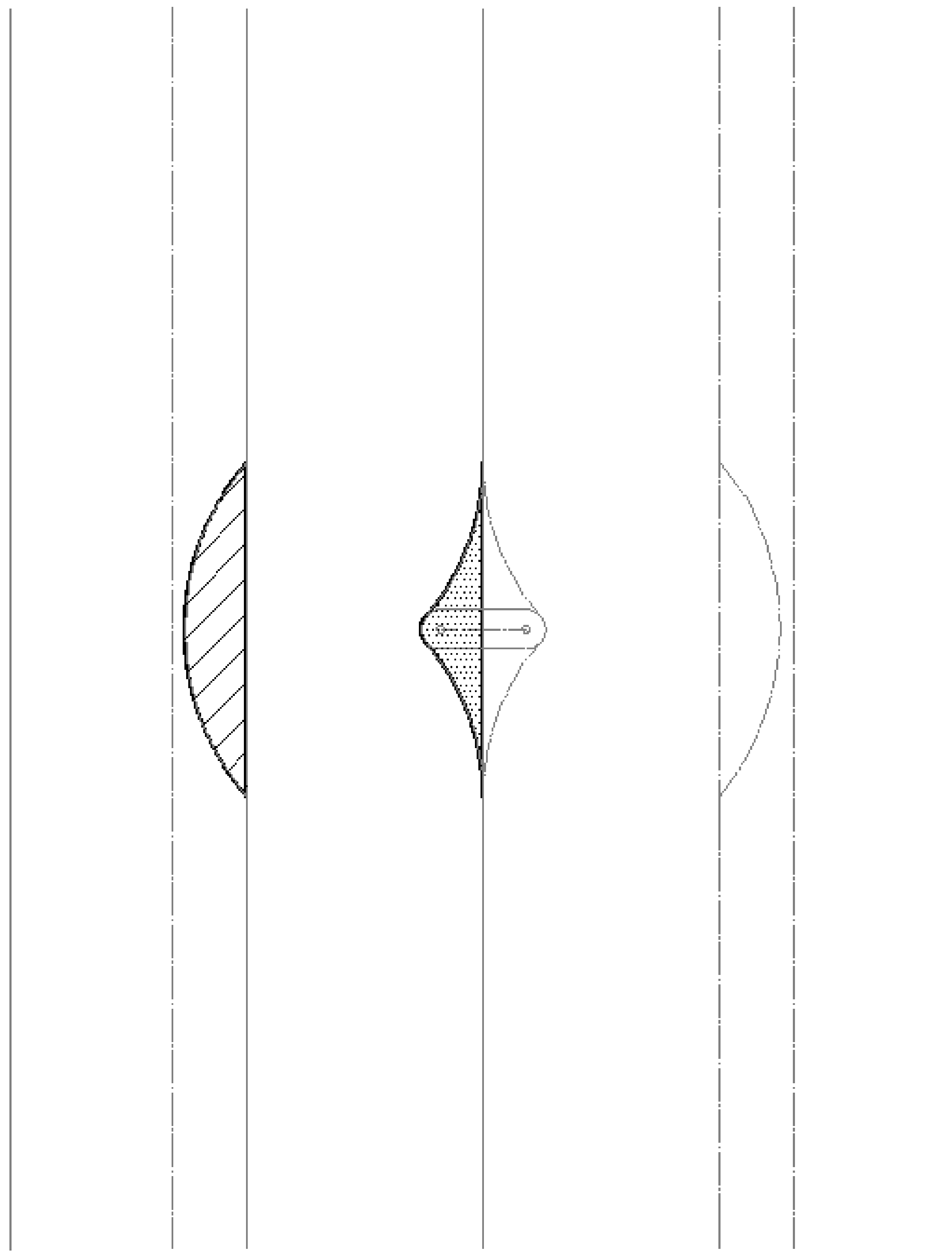

Figure A-13. Scenario 2, H-frame, 50 ft, with examples of footprint area (dotted) and overlap areas (hashed) on completing field passes.

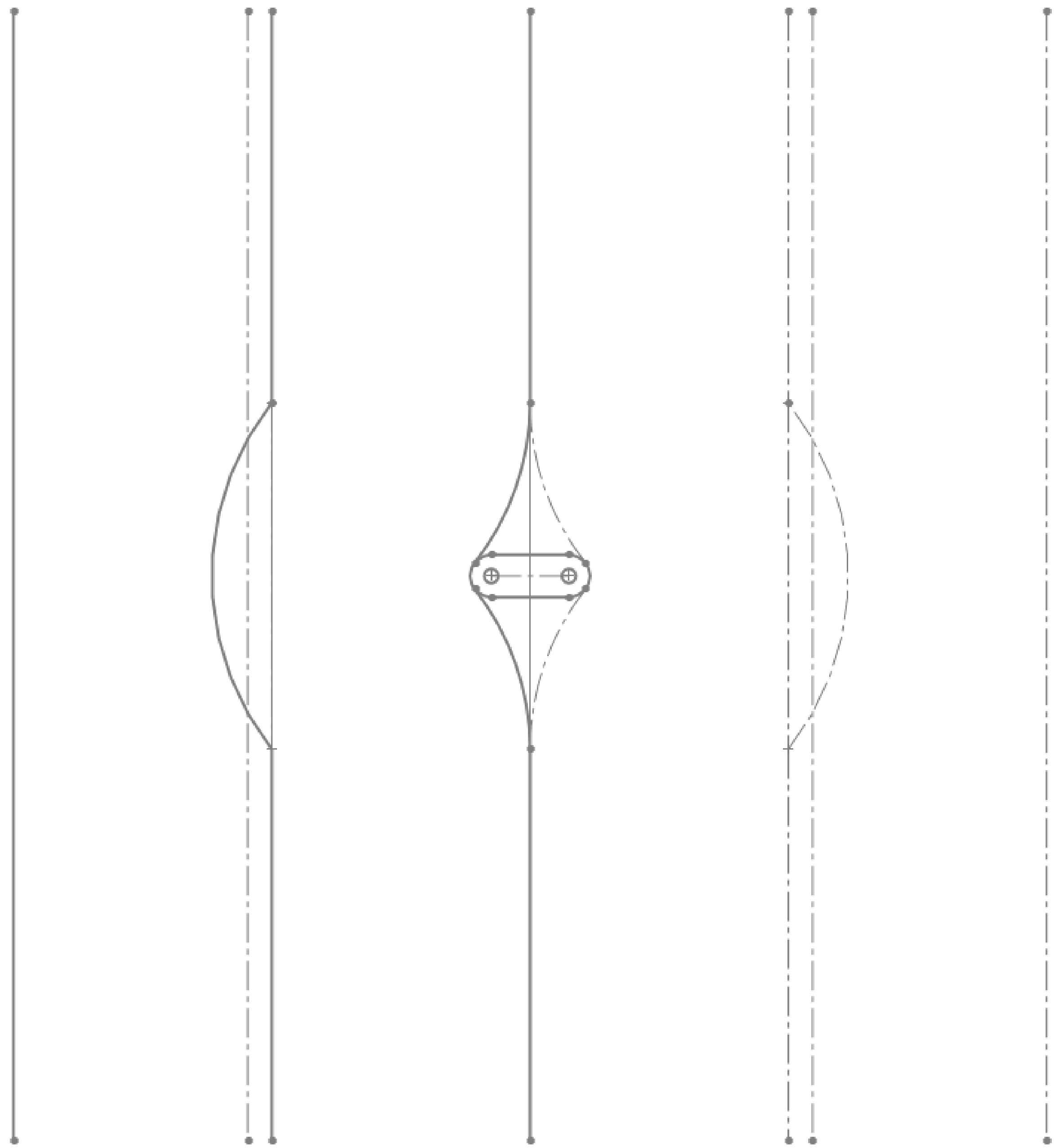

Figure A-14. Scenario 2, H-frame, 60 ft.

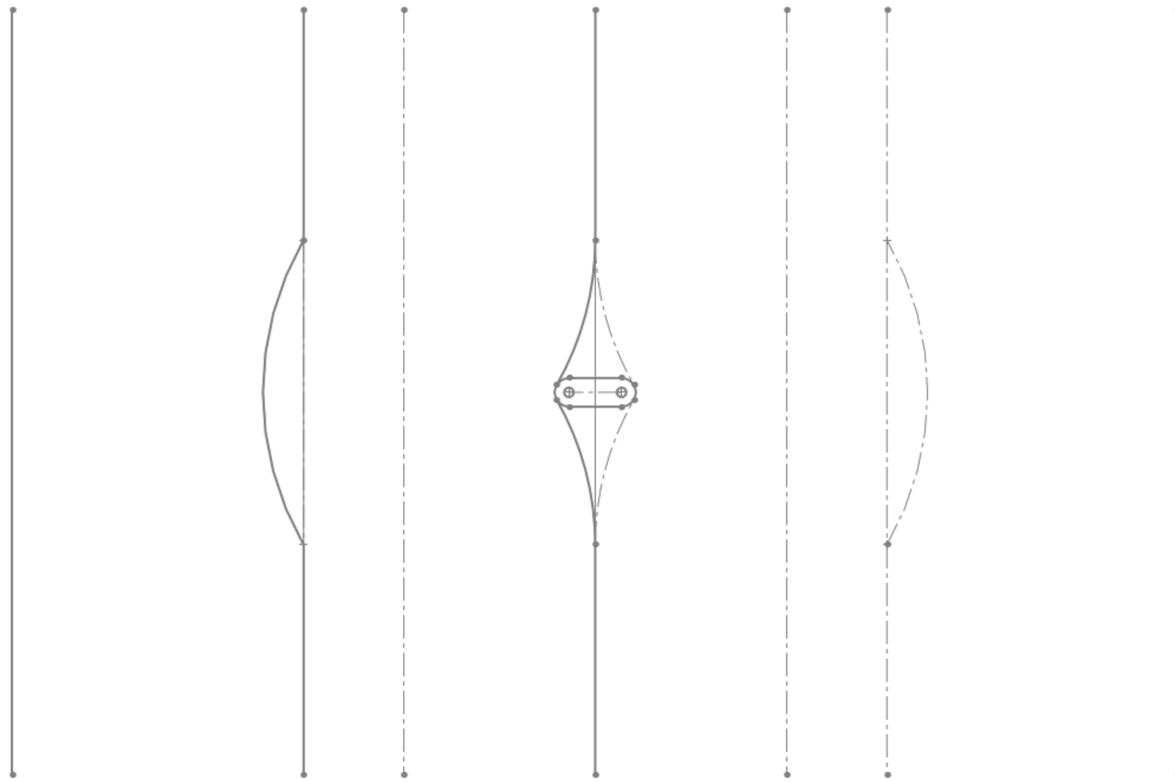

Figure A-15. Scenario 2, H-frame, 100 ft.

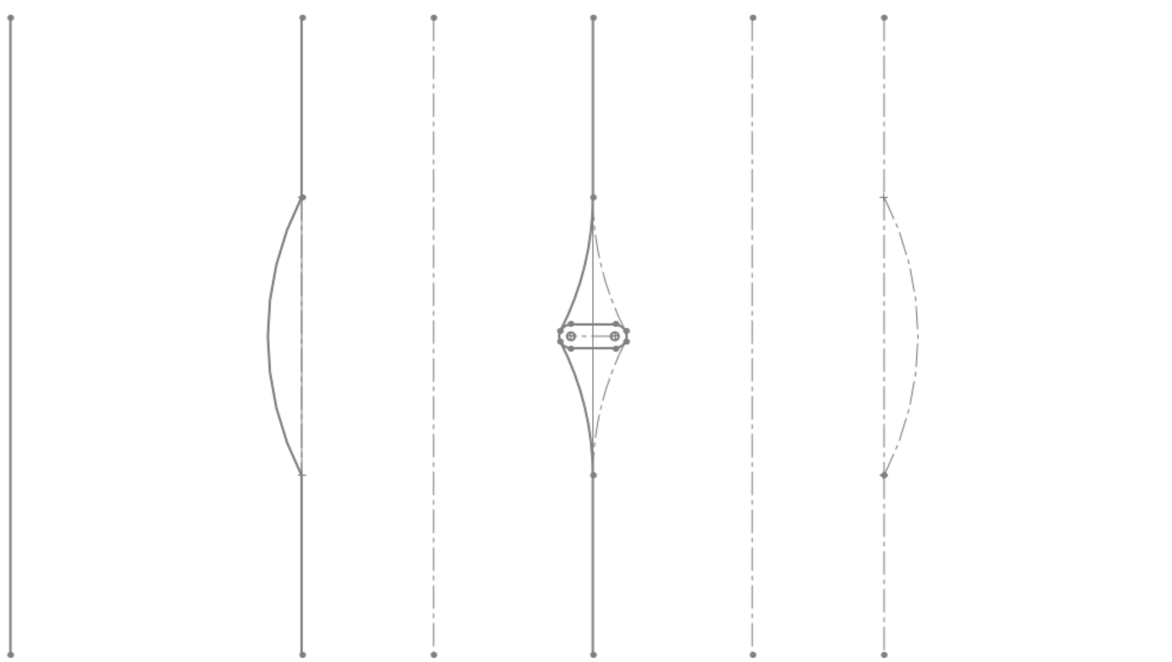

Figure A-16. Scenario 2, H-frame, 120 ft.

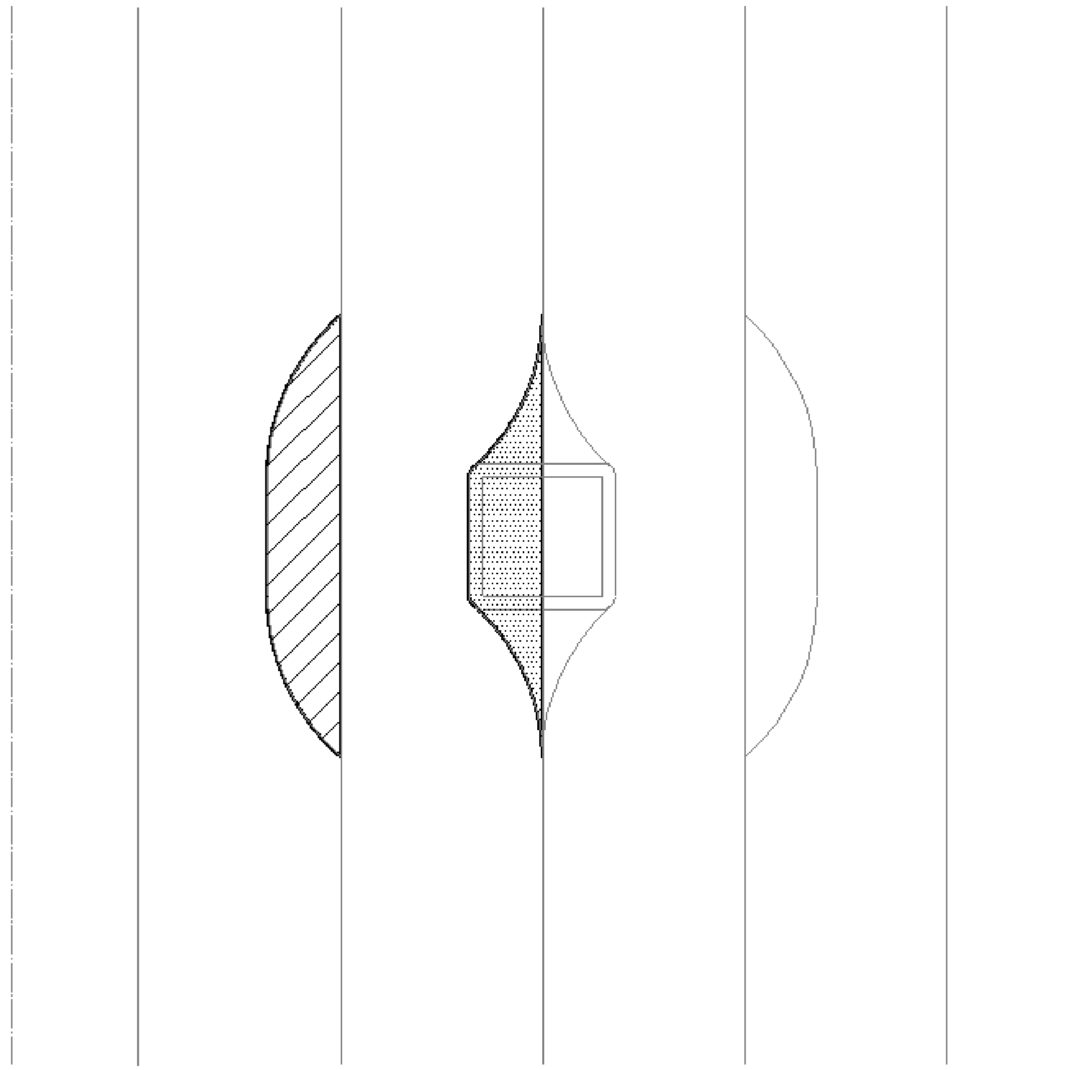

Figure A-17. Scenario 2, steel tower, 50 ft, with examples of footprint area (dotted) and overlap areas (hashed) on completing field passes.

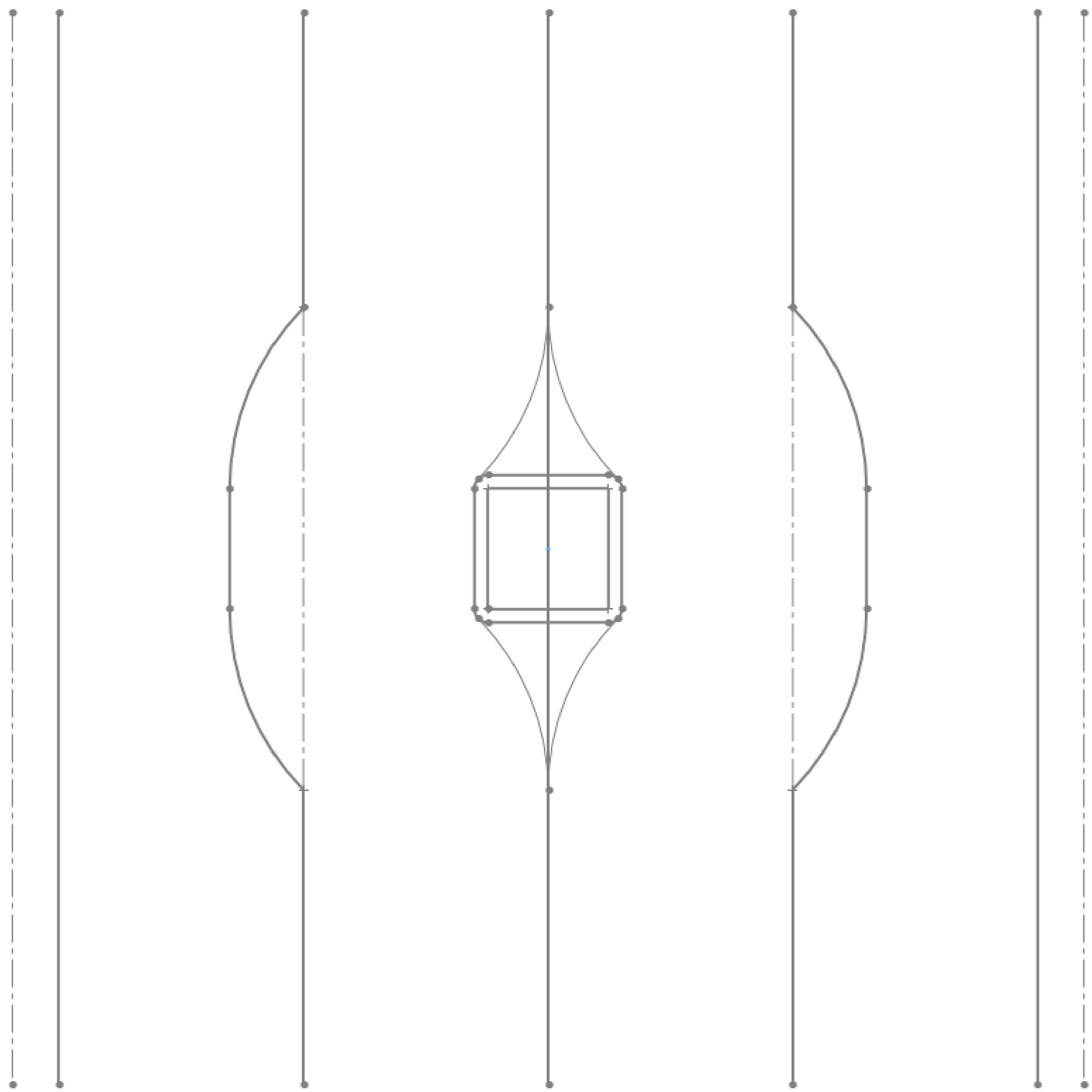

Figure A-18. Scenario 2, steel tower, 60 ft.

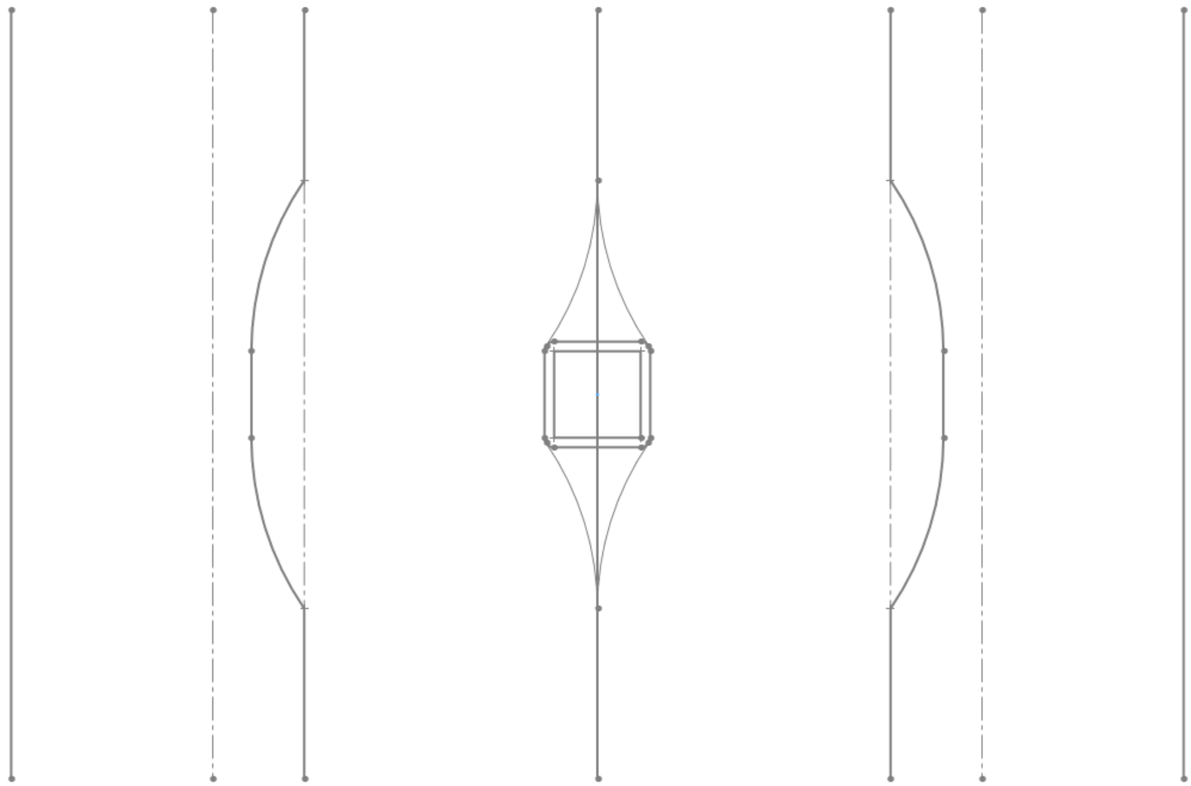

Figure A-19. Scenario 2, steel tower, 100 ft.

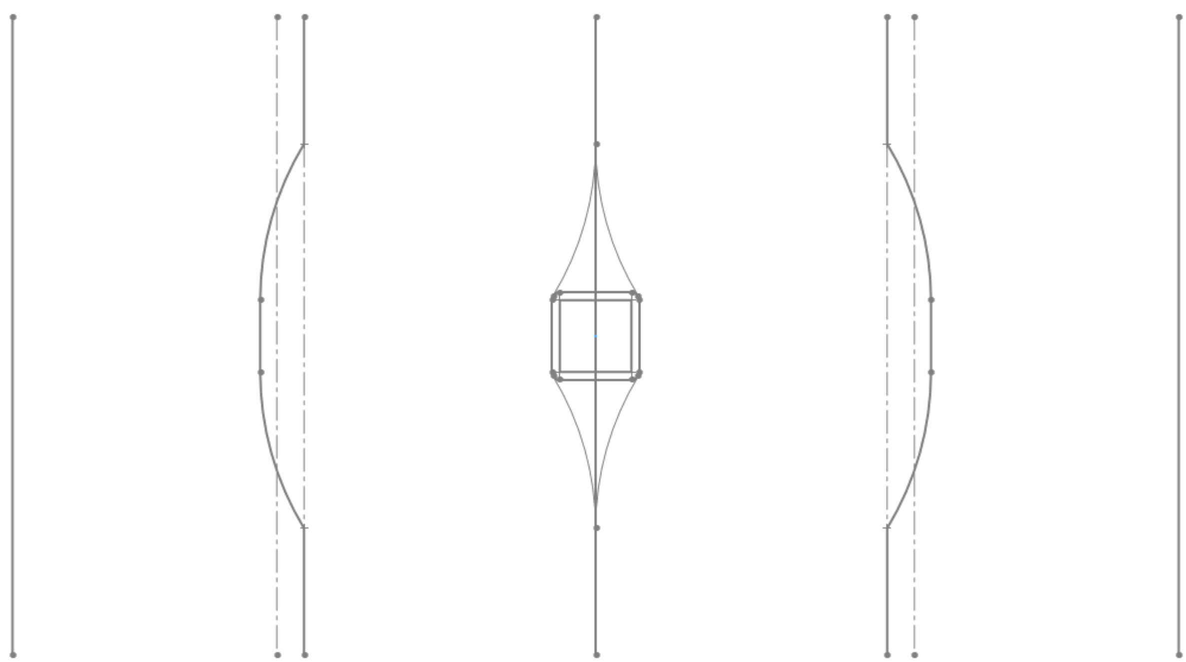

Figure A-20. Scenario 2, steel tower, 120 ft.

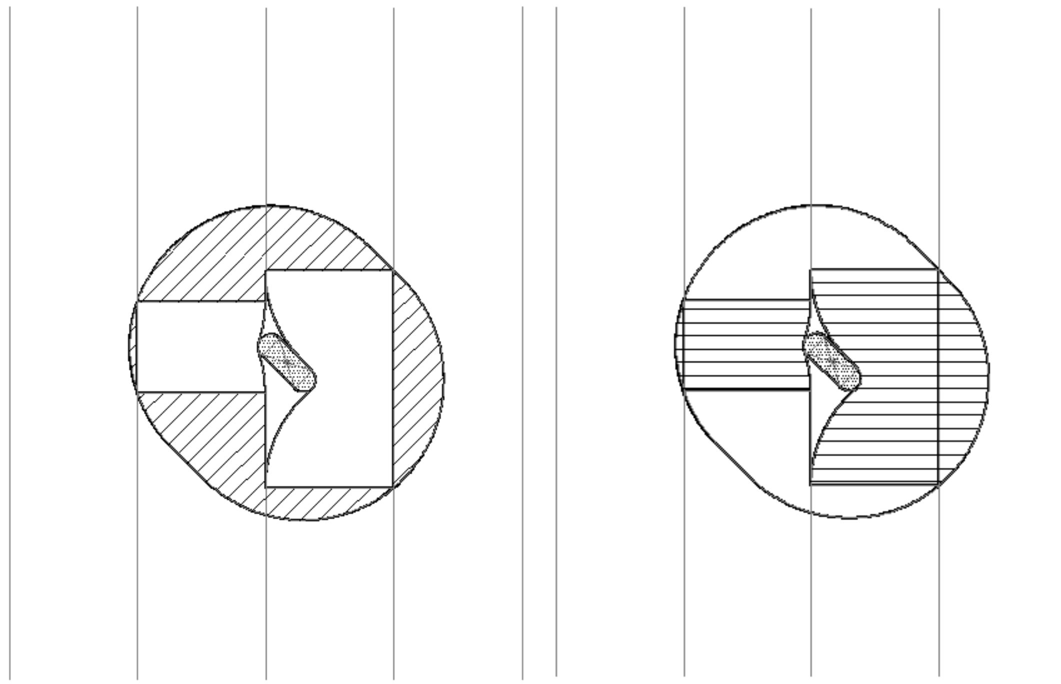

Figure A-21. Scenario 3, H-frame, 50 ft, with examples of footprint area (dotted) and overlap areas (hashed), Left, and transport area (horizontal lines), Right, on completing field passes.

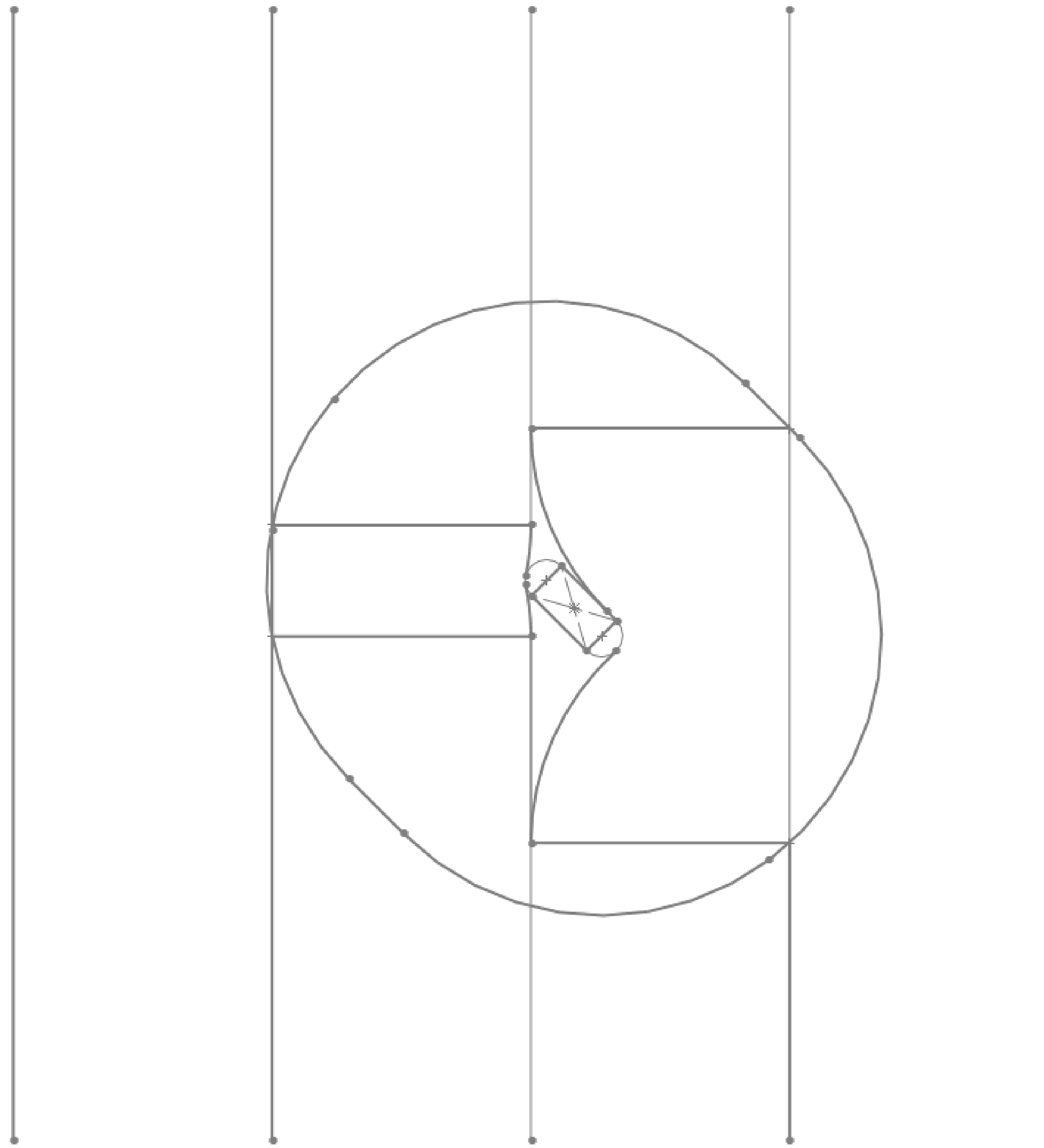

Figure A-22. Scenario 3, H-frame, 60 ft.

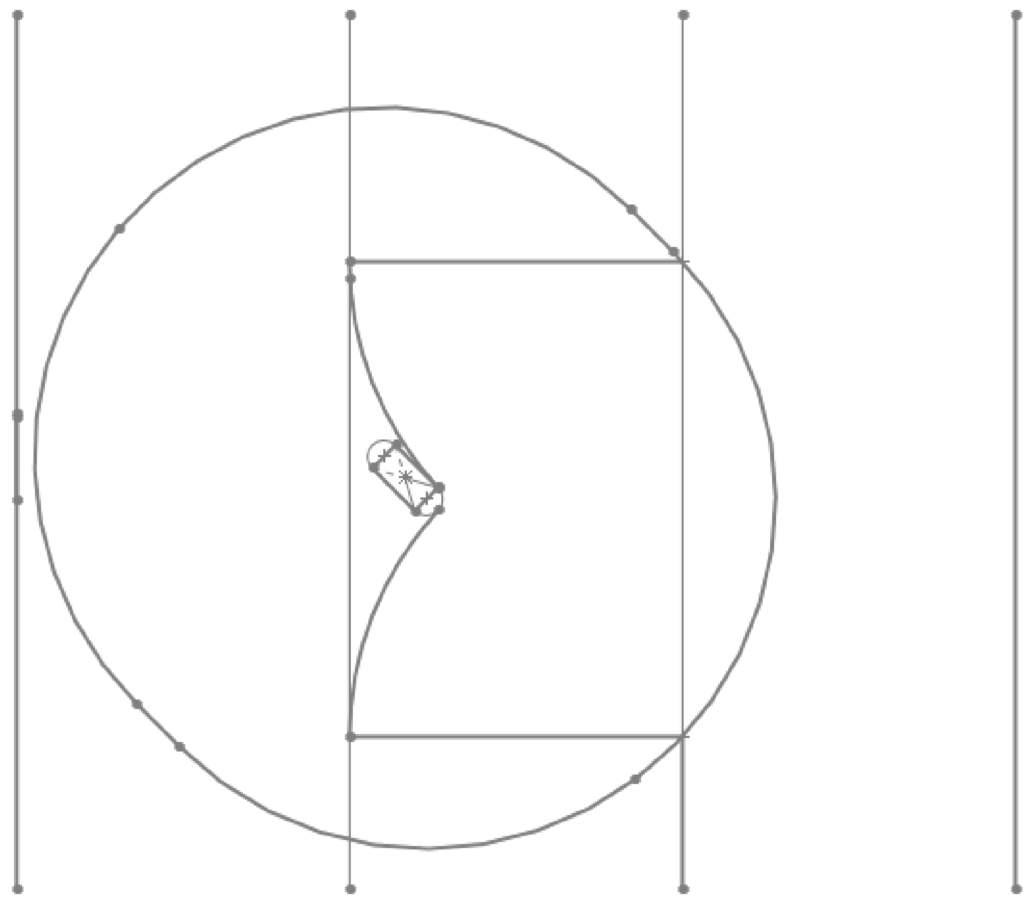

Figure A-23. Scenario 3, H-frame, 100 ft.

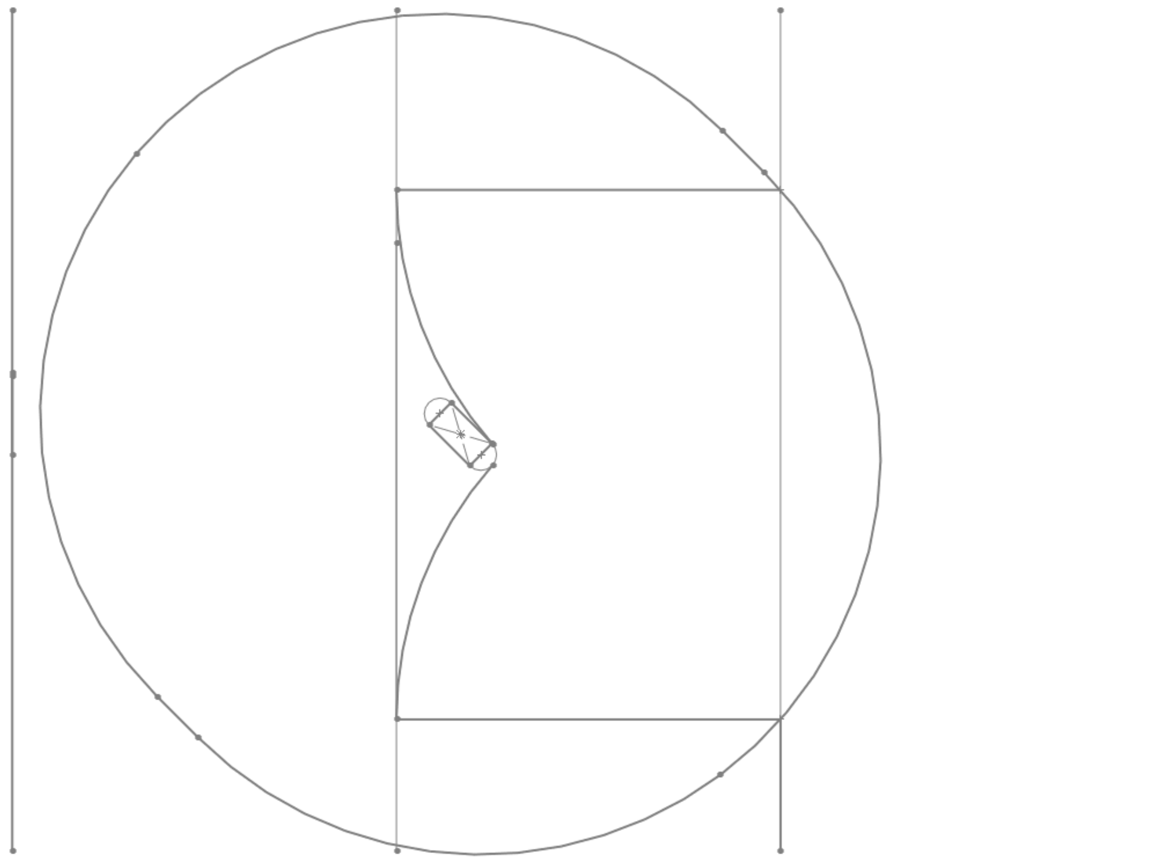

Figure A-24. Scenario 3, H-frame, 120 ft.

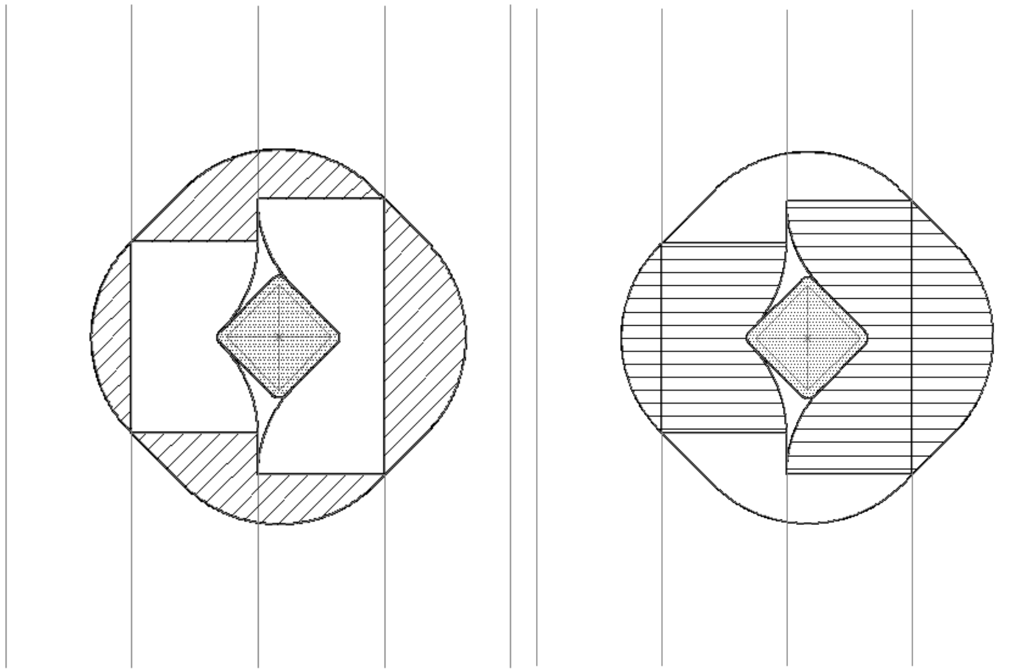

Figure A-25. Scenario 3, steel tower, 50 ft, with examples of footprint area (dotted) and overlap areas (hashed), Left, and transport area (horizontal lines), Right, on completing field passes.

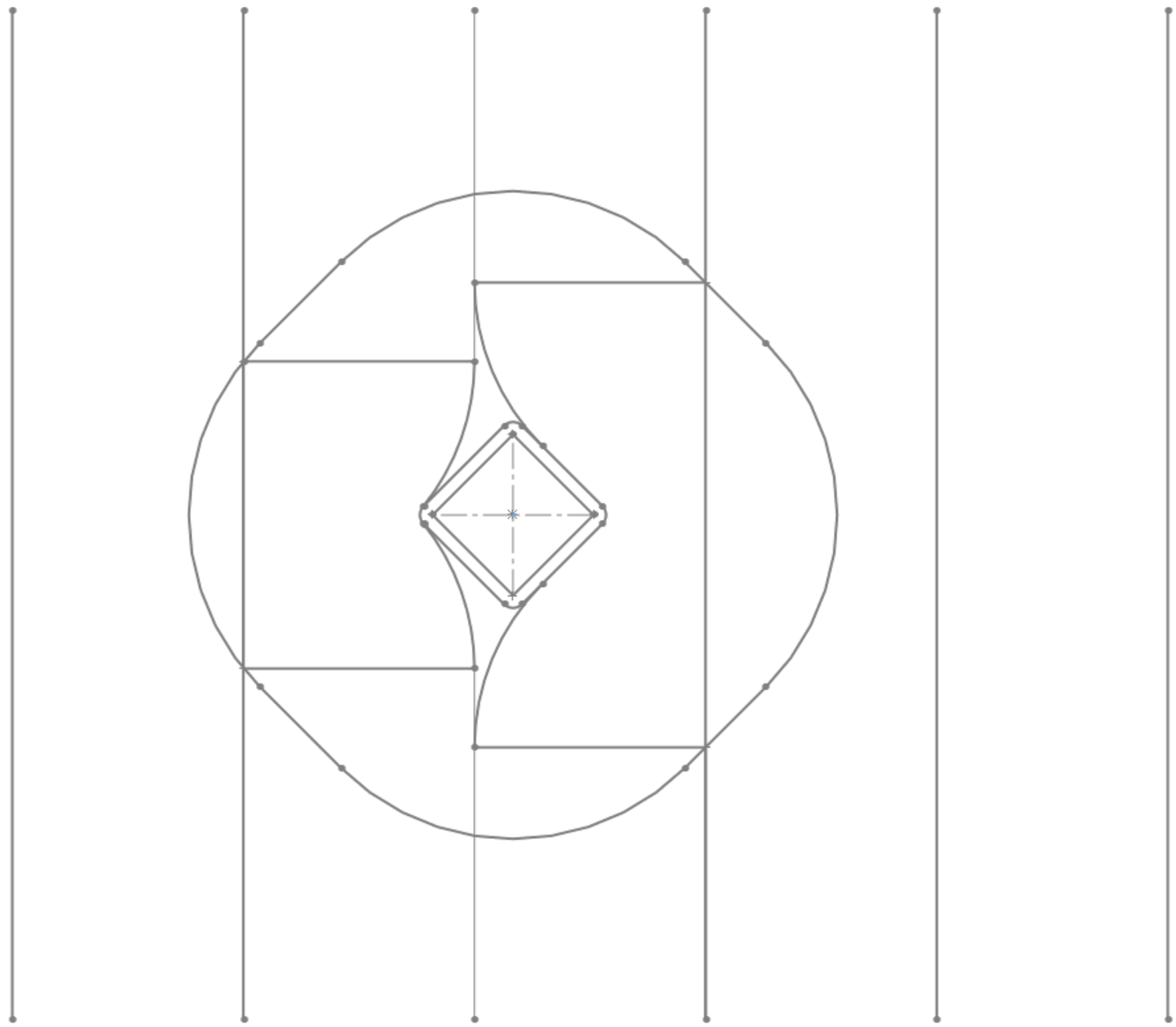

Figure A-26. Scenario 3, steel tower, 60 ft.

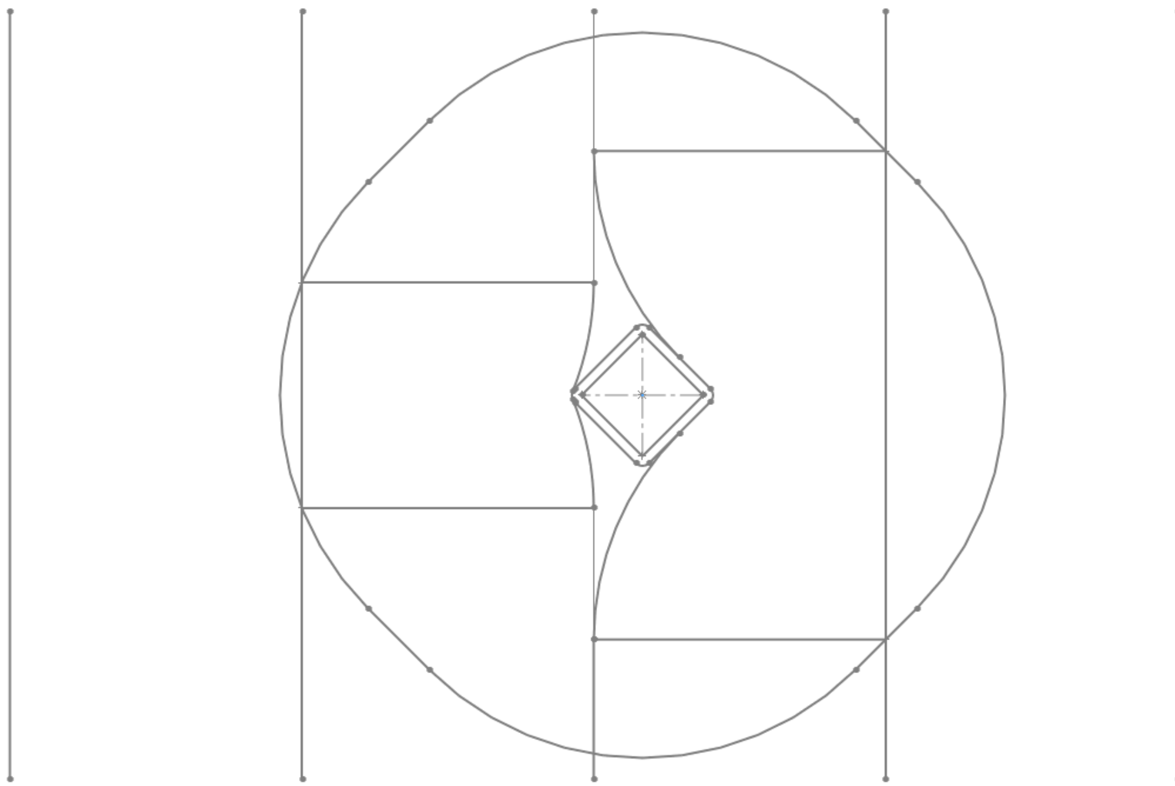

Figure A-27. Scenario 3, steel tower, 100 ft.

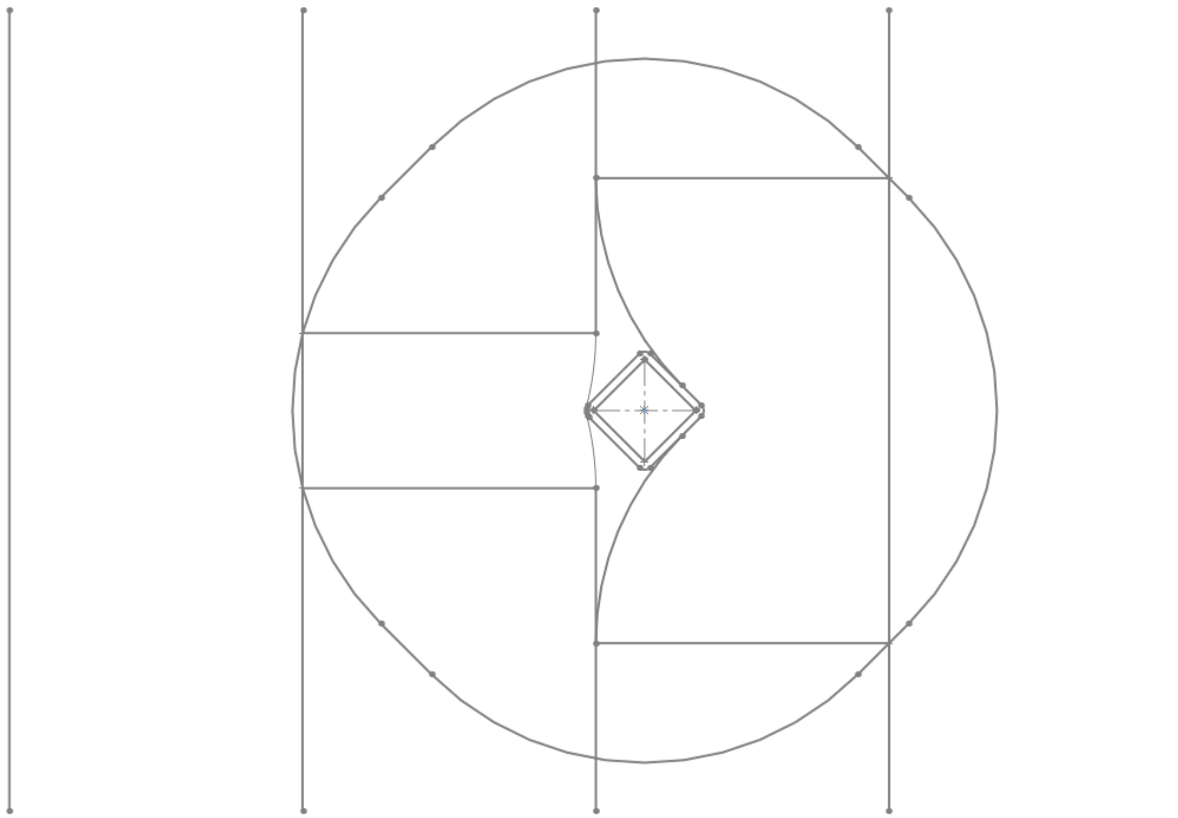

Figure A-28. Scenario 3, steel tower, 120 ft.

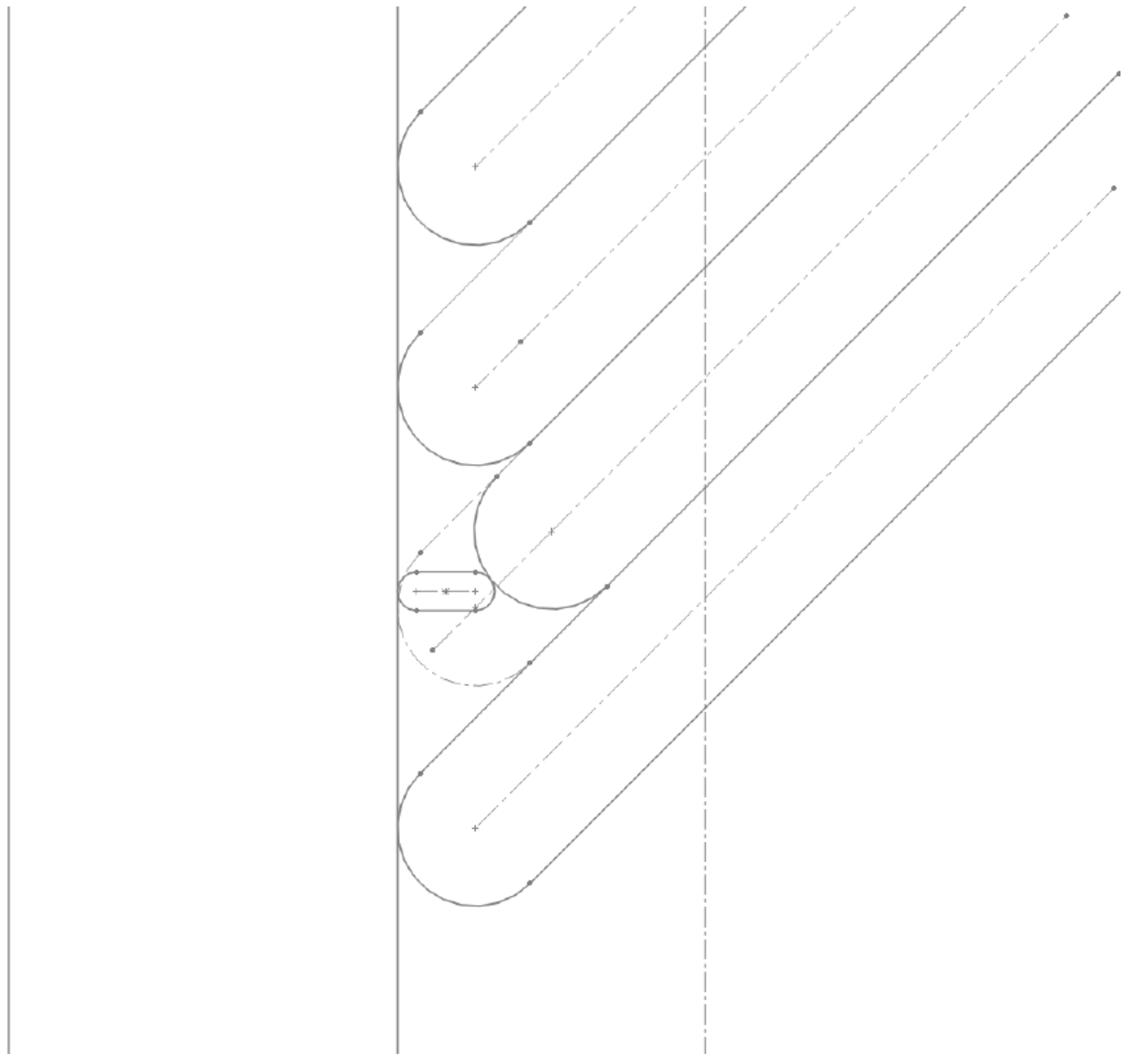

Figure A-29. Scenario 1, Manure, H-frame, 20 ft.

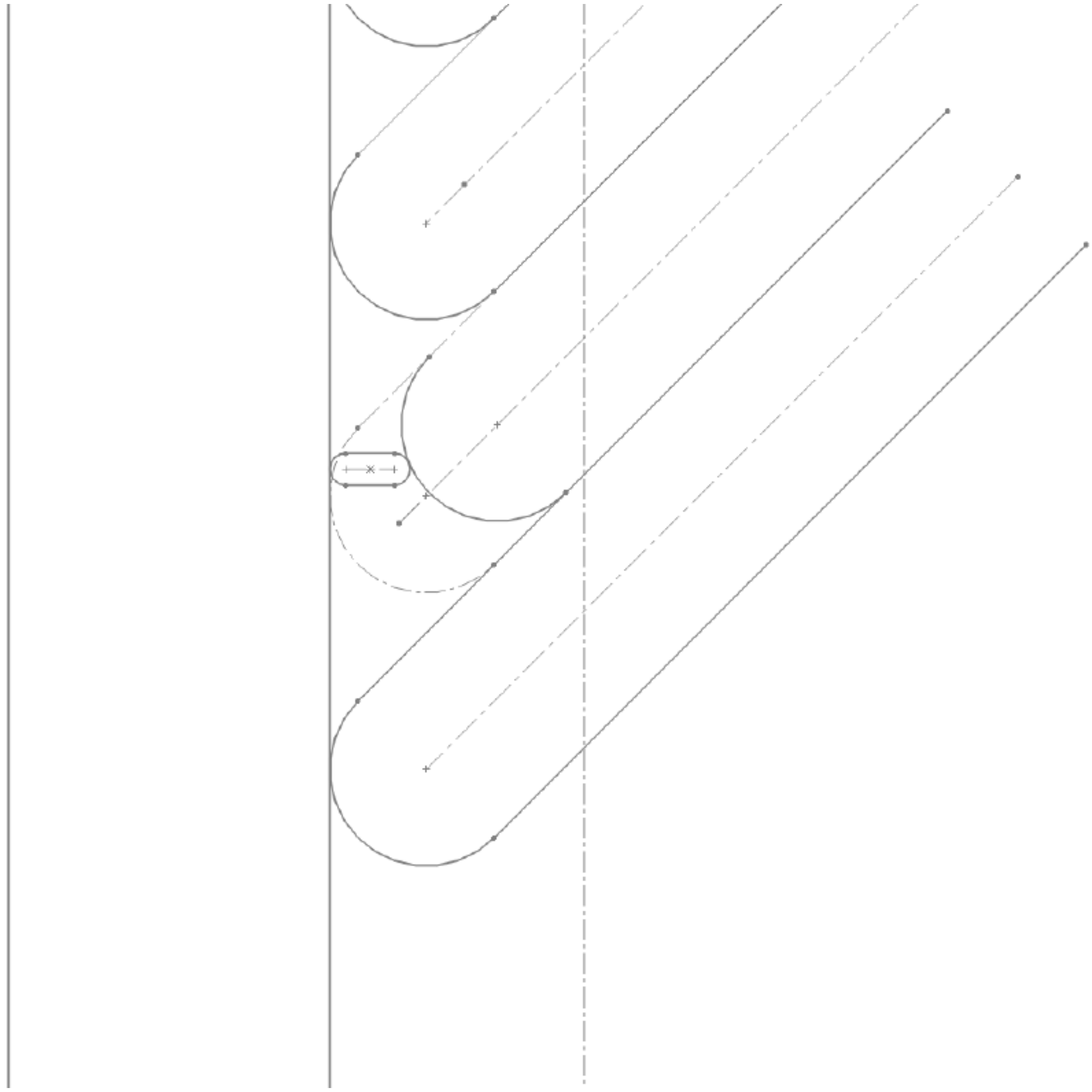

Figure A-30. Scenario 1, H-frame, 30 ft.

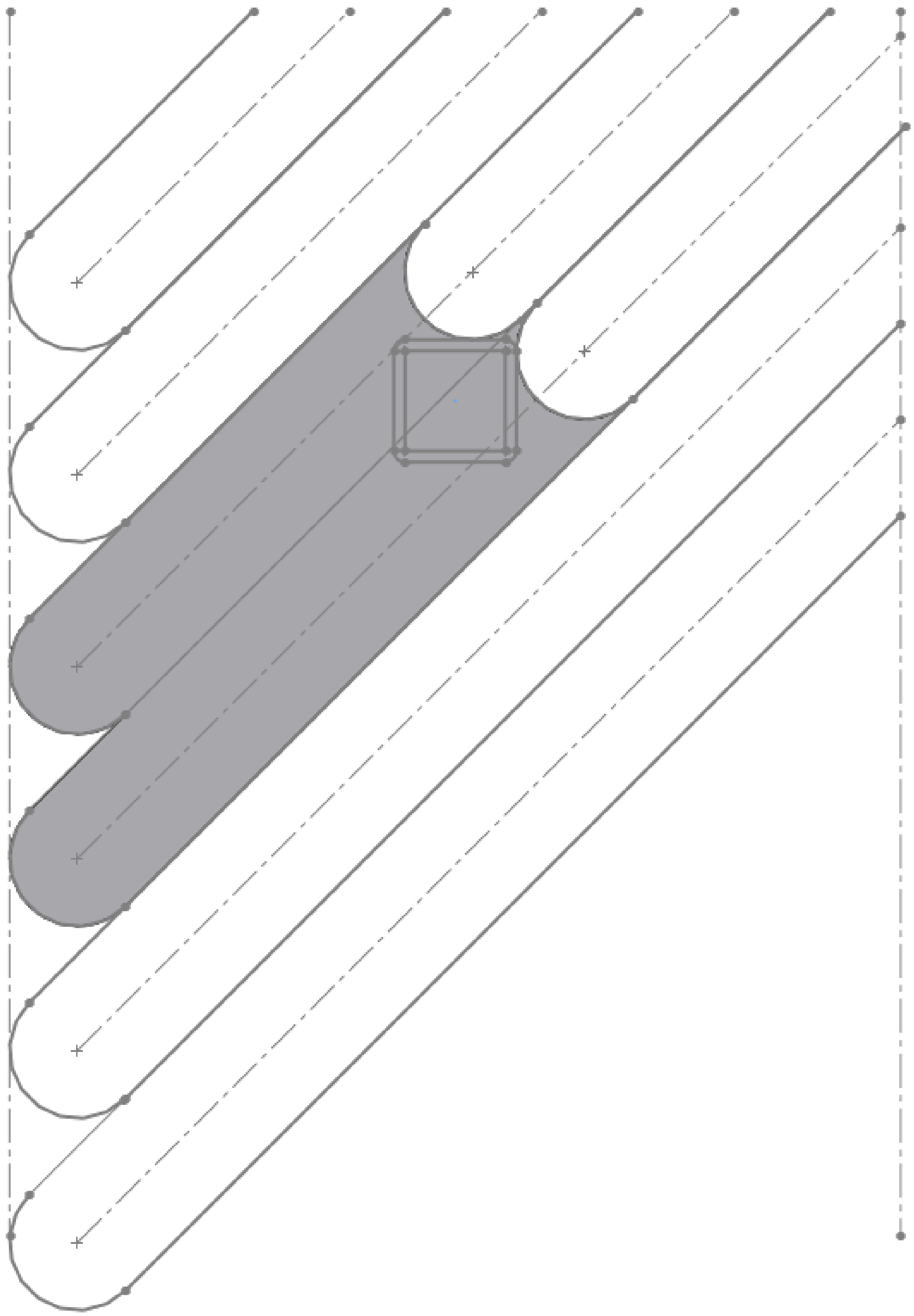

Figure A-31. Scenario 1, Manure, steel tower, 20 ft, with examples of footprint area and overlap areas on completing field passes.

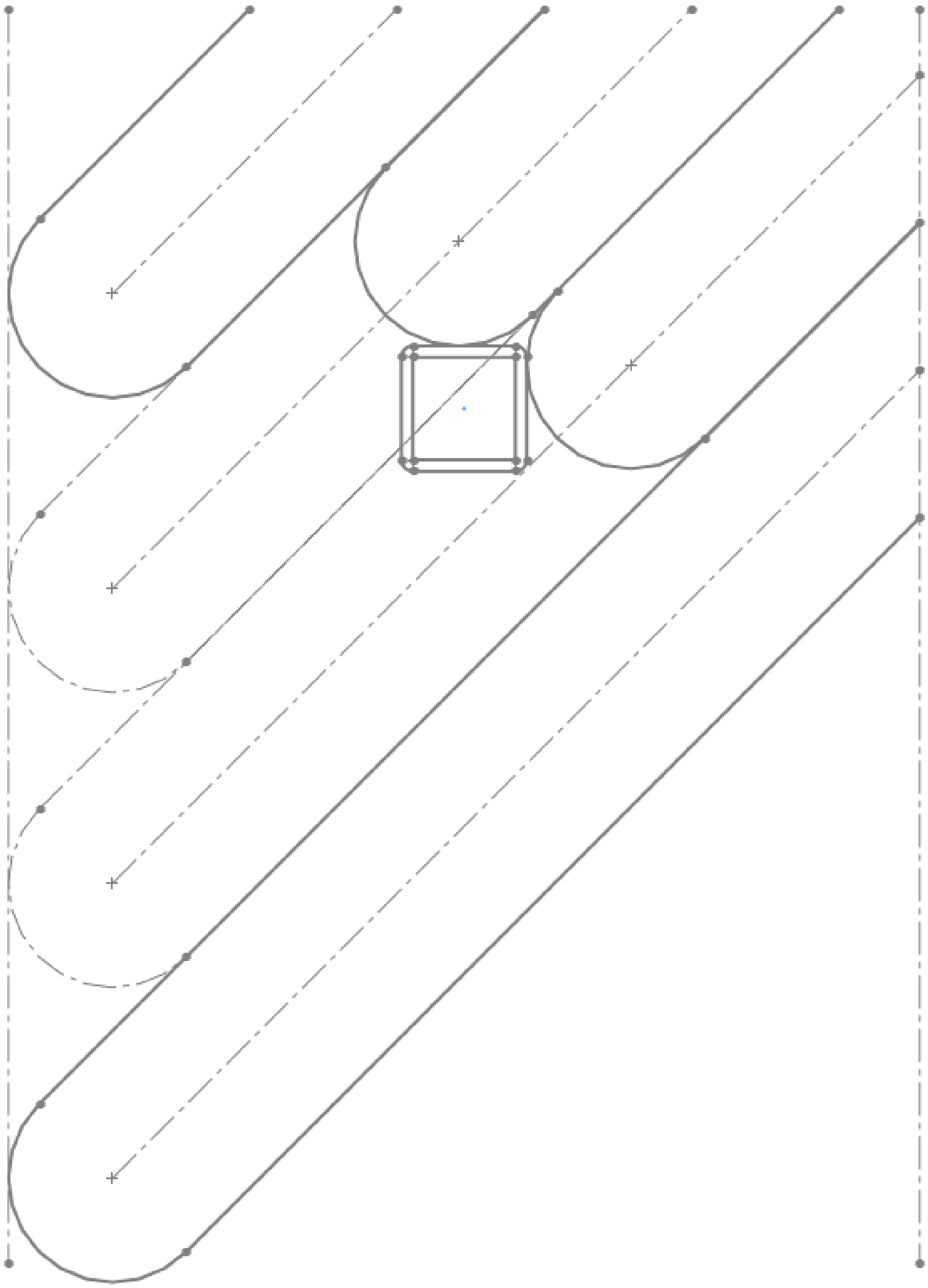

Figure A-32. Scenario 1, Manure, steel tower, 30 ft.

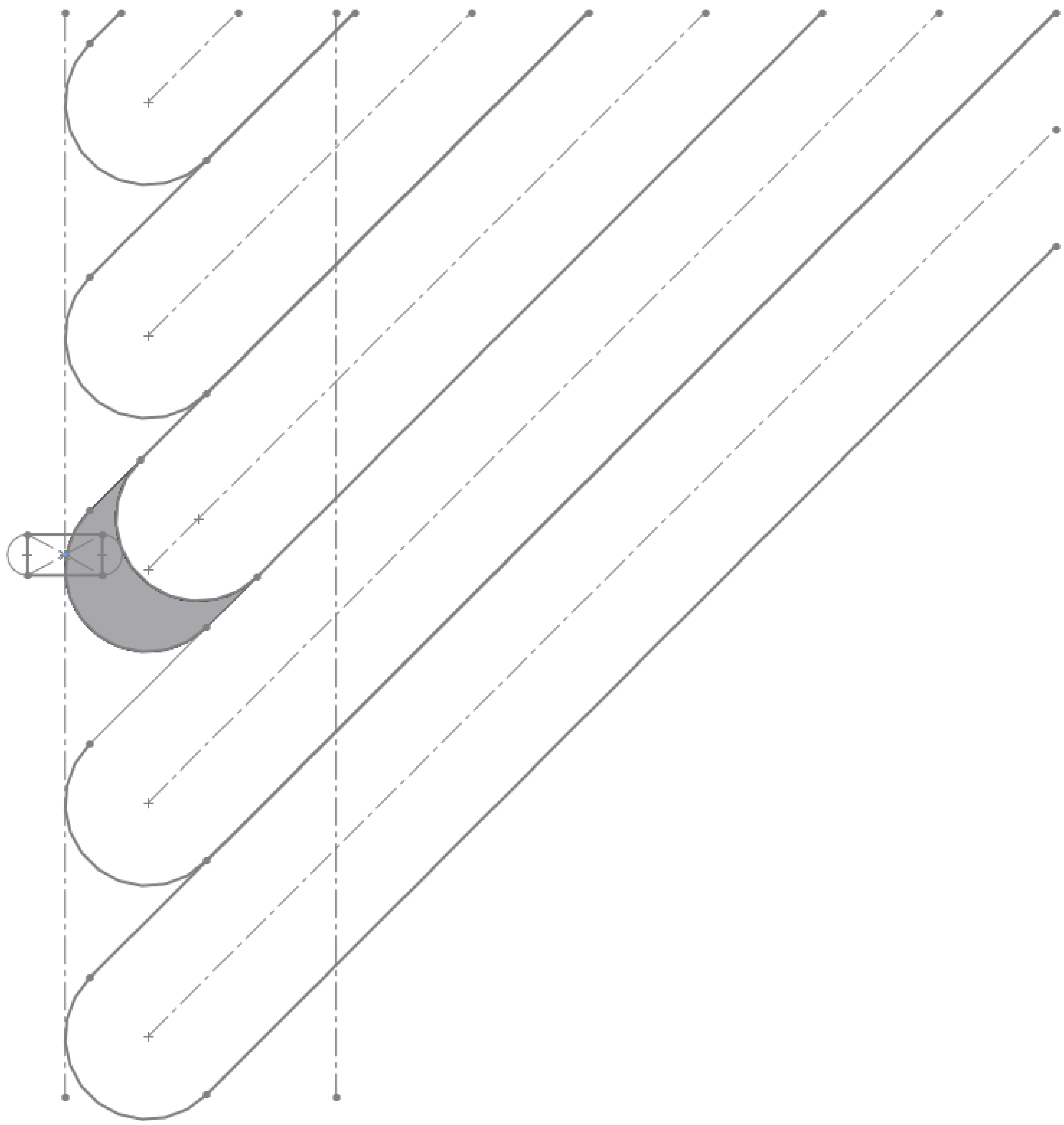

Figure A-33. Scenario 2, Manure, H-frame, 20 ft, with examples of footprint area and overlap areas on completing field passes.

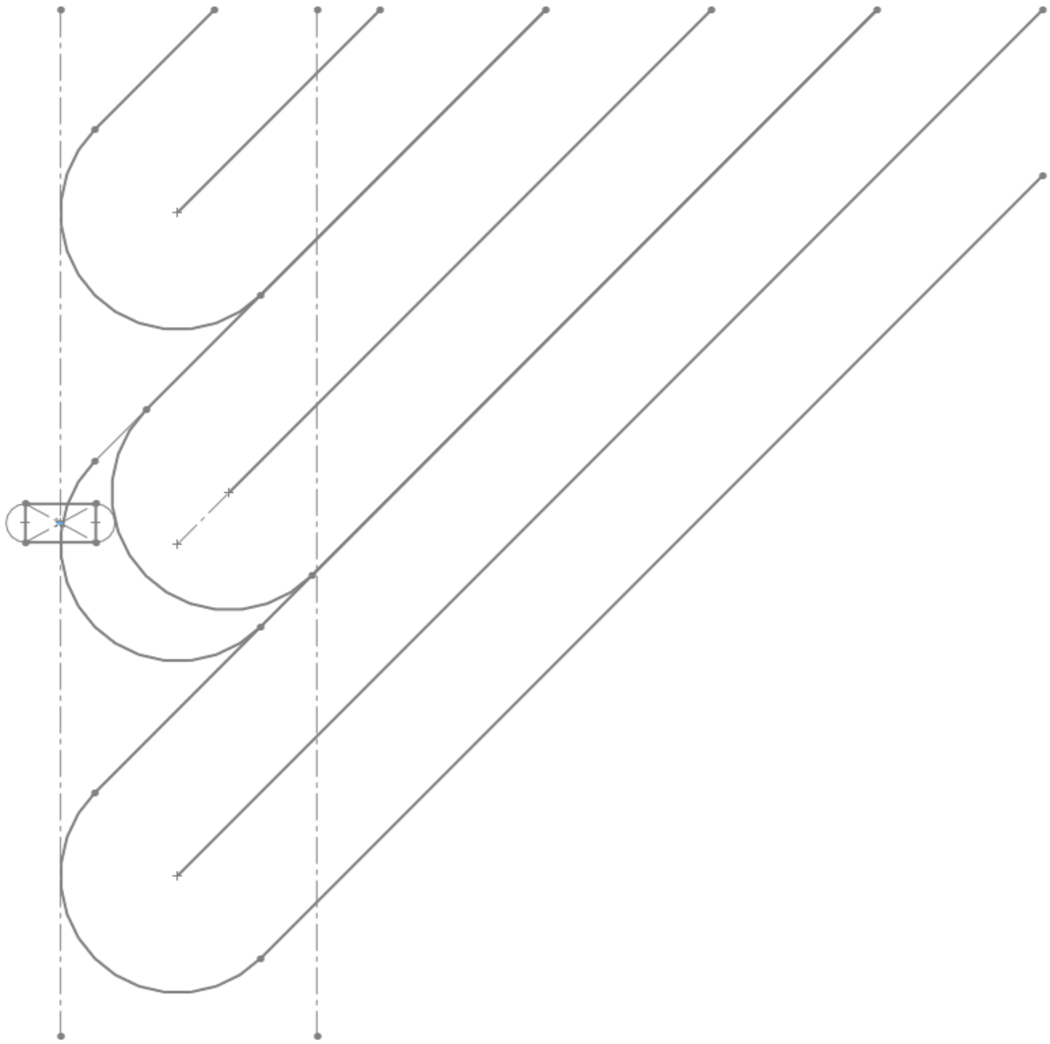

Figure A-34. Scenario 2, Manure, H-frame, 30 ft.

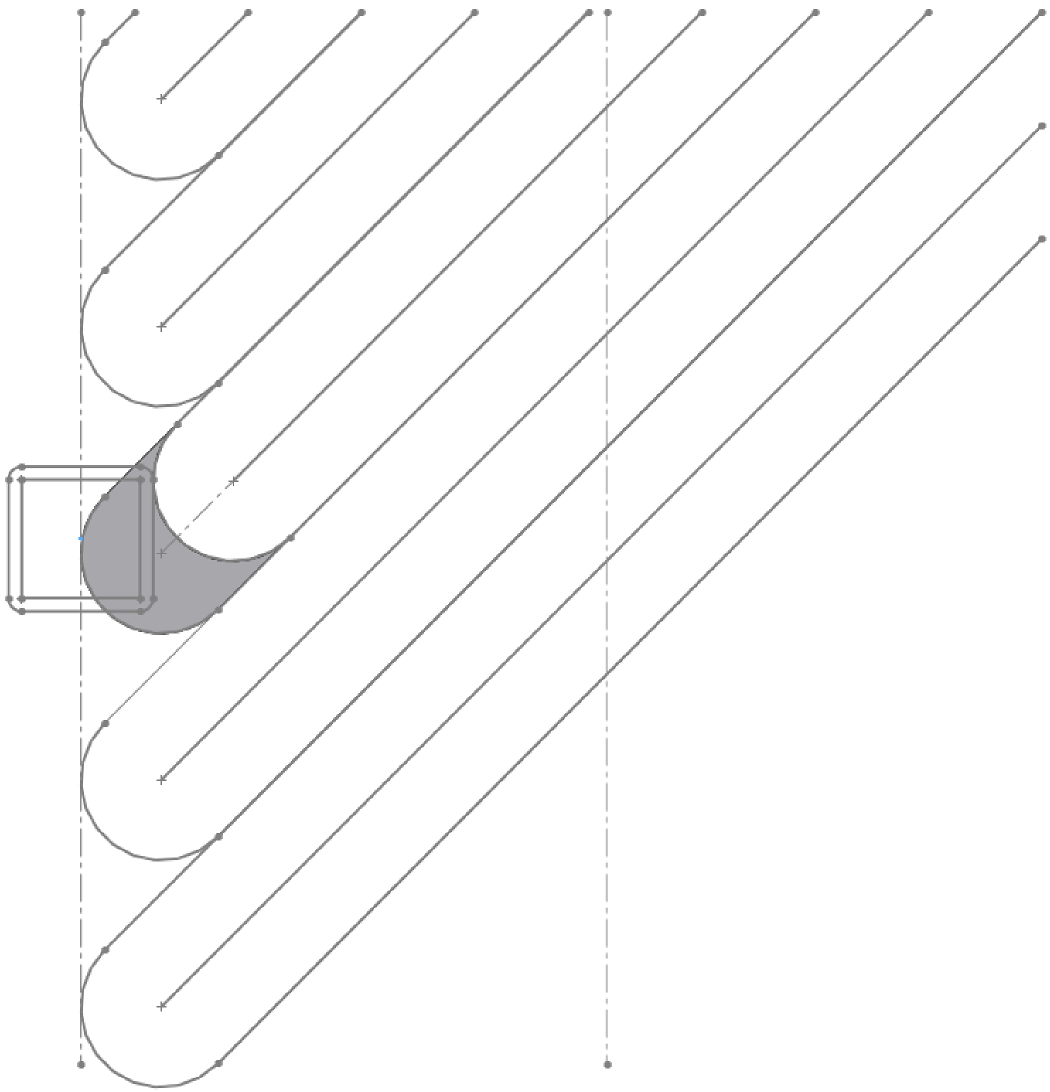

Figure A-35. Scenario 2, Manure, steel tower, 20 ft, with examples of footprint area and overlap areas on completing field passes.

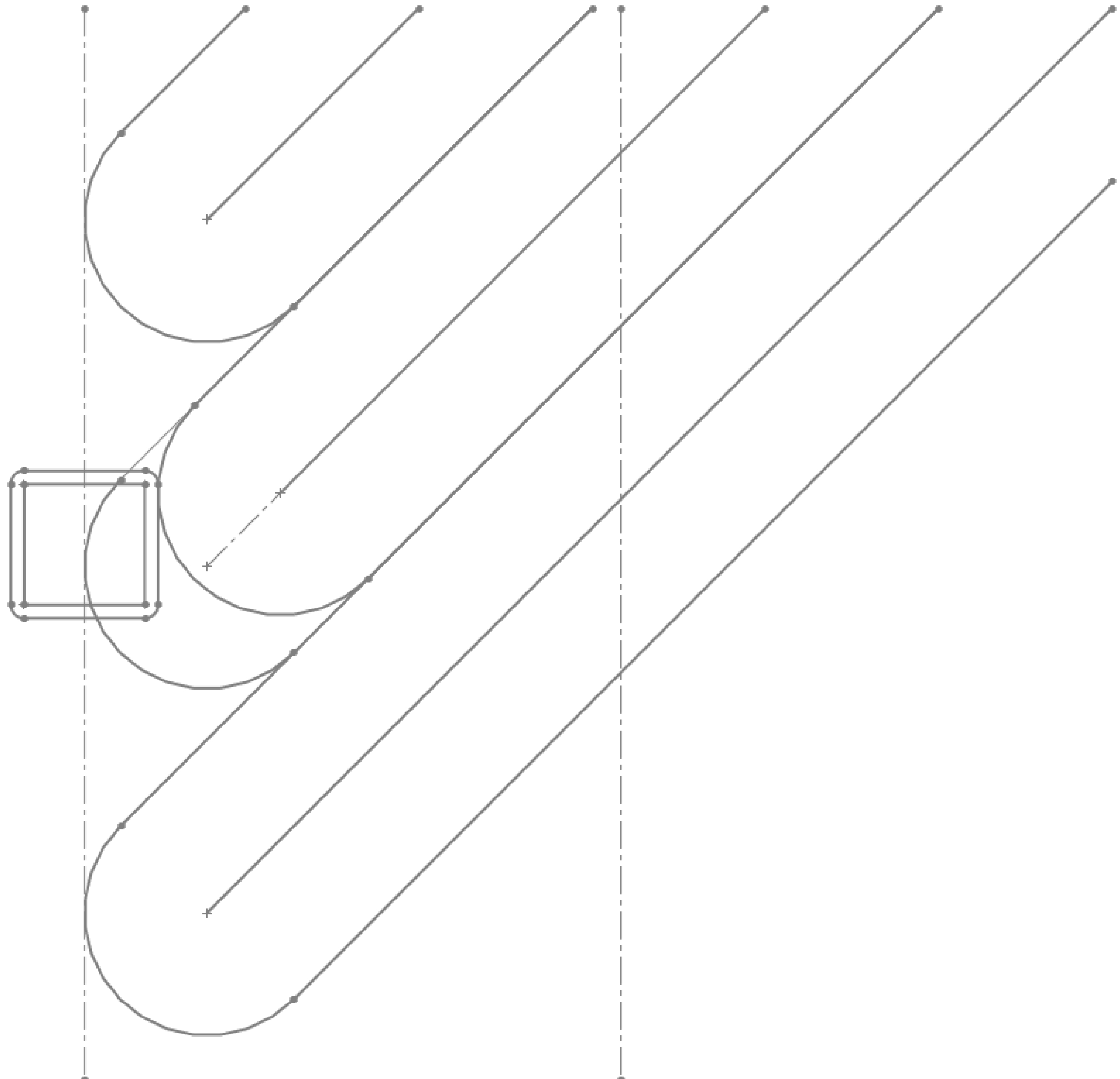

Figure A-36. Scenario 2, Manure, steel tower, 30 ft.

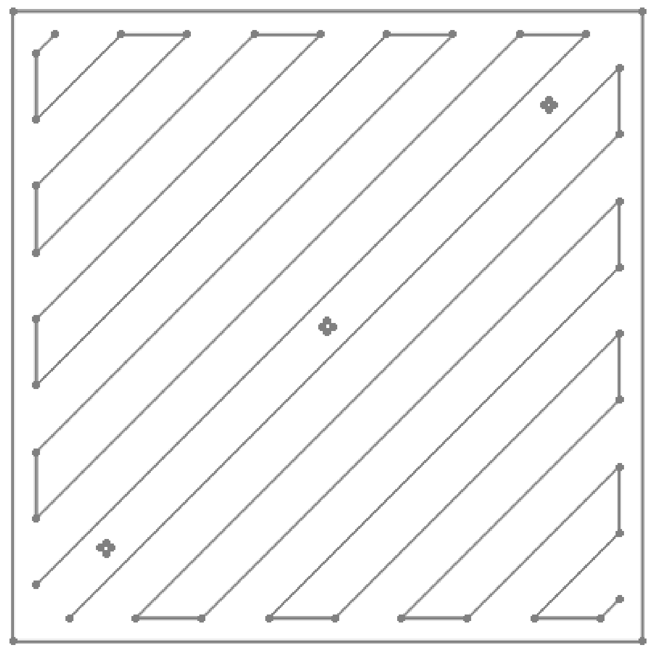

Figure A-37. Scenario 3, general manure drag hose pattern.

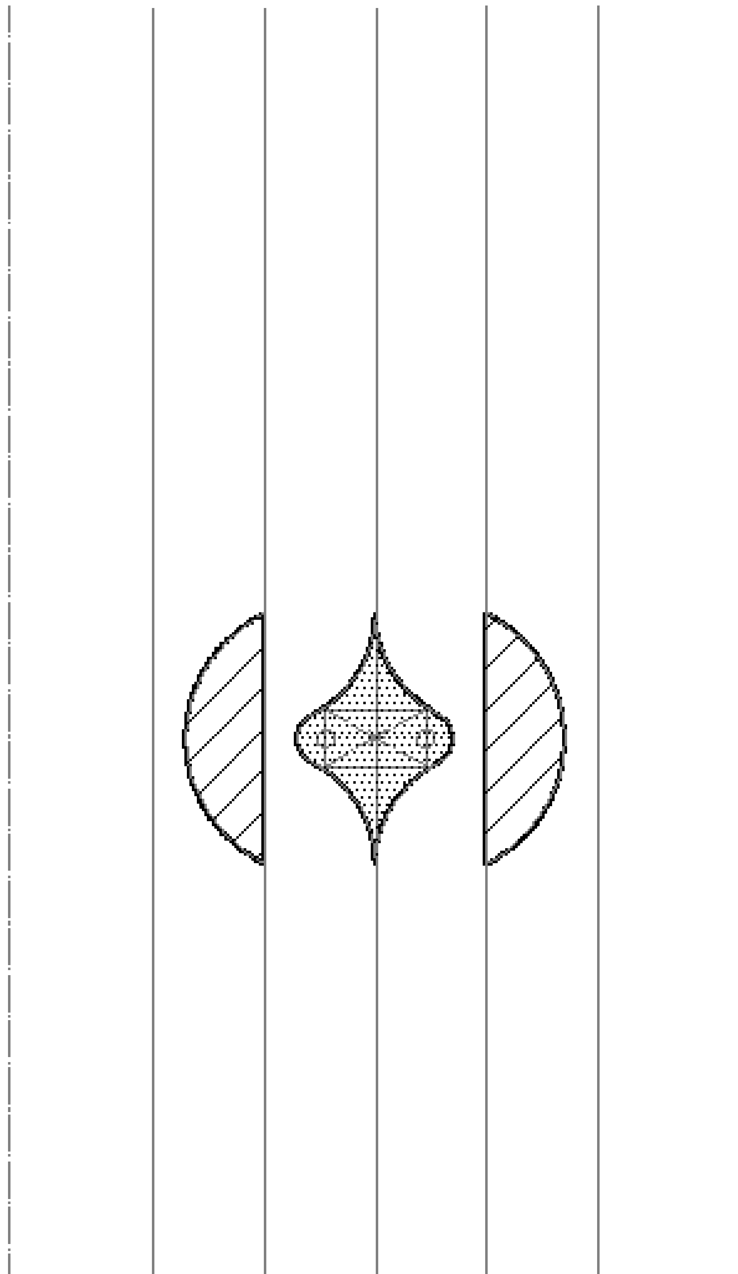

Figure A-38. Scenario 3, Manure, H-frame, 20 ft, with examples of footprint area (dotted) and overlap areas (hashed) on completing field passes.

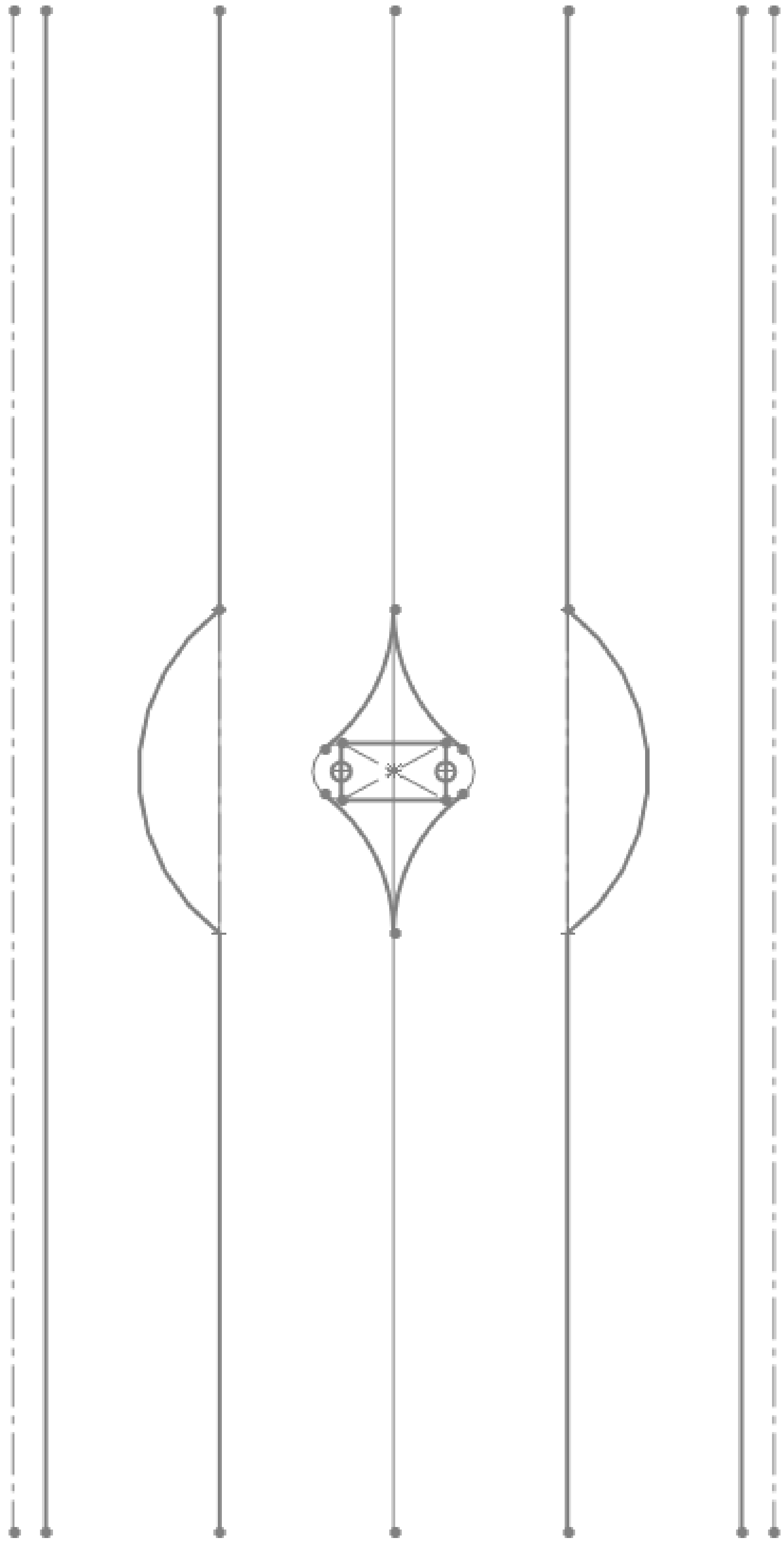

Figure A-39. Scenario 3, Manure, H-frame, 30 ft.

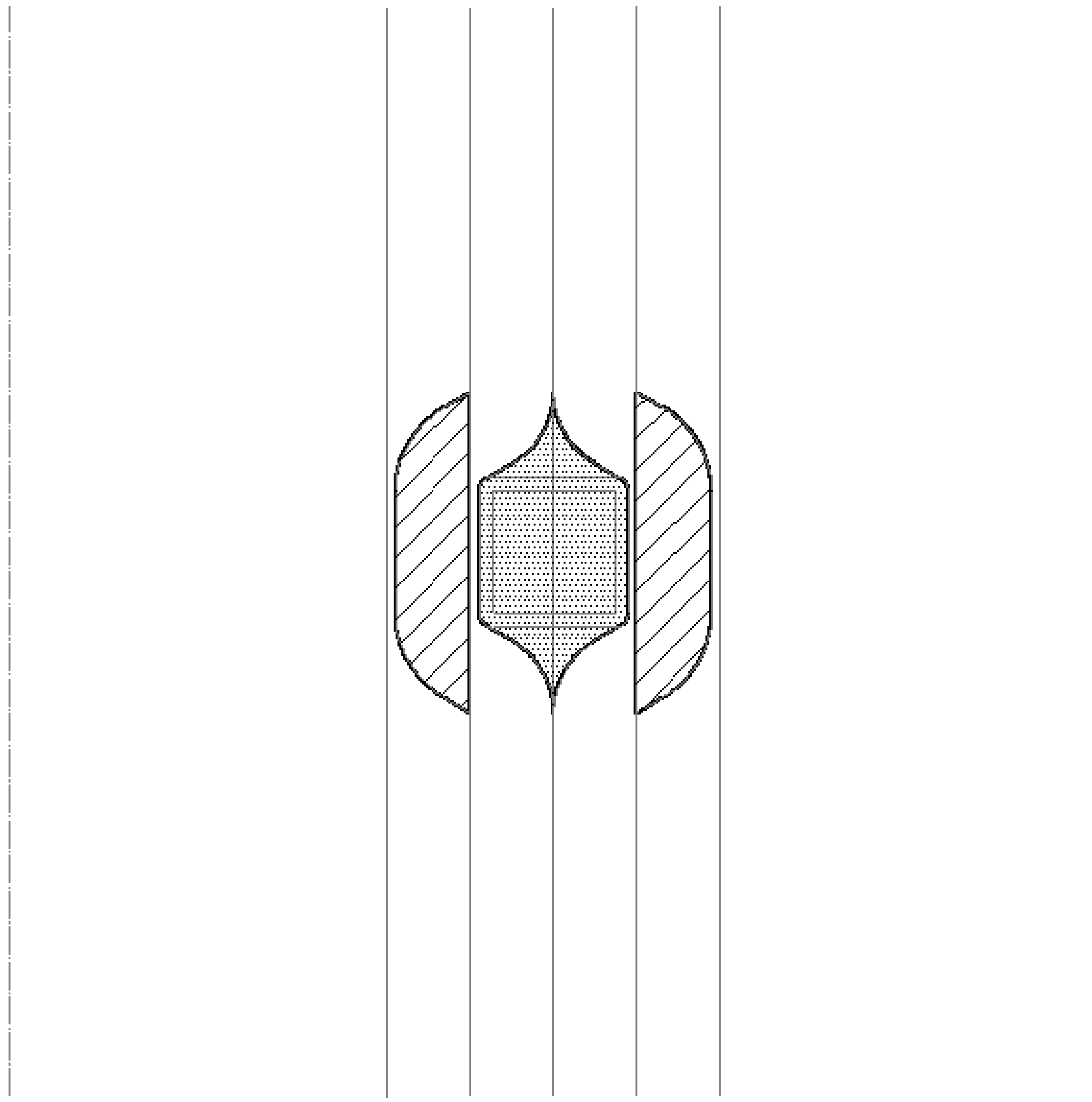

Figure A-40. Scenario 3, Manure, H-frame, 20 ft, with examples of footprint area (dotted) and overlap areas (hashed) on completing field passes.

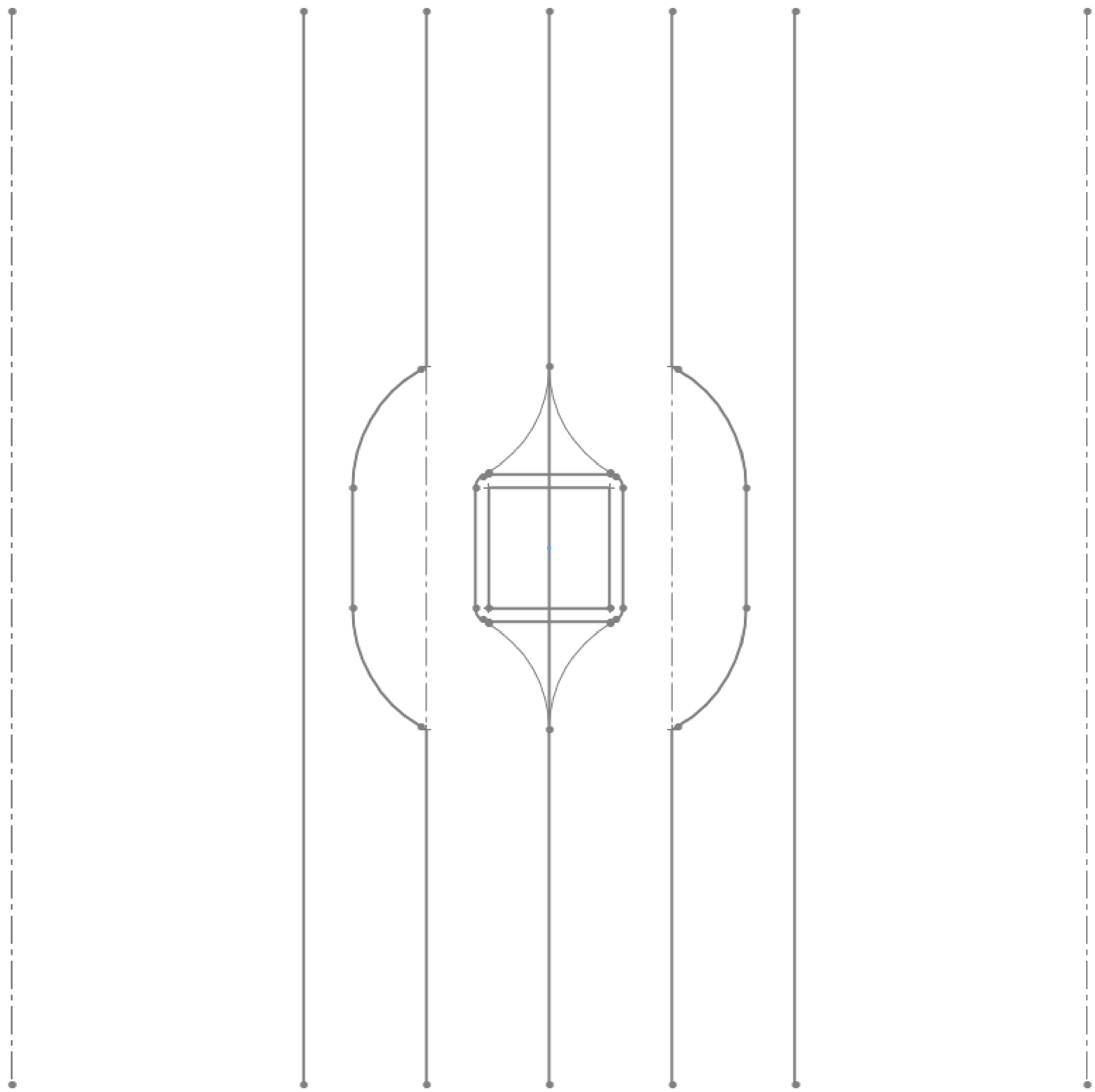

Figure A-41. Scenario 3, Manure, H-frame, 30 ft.

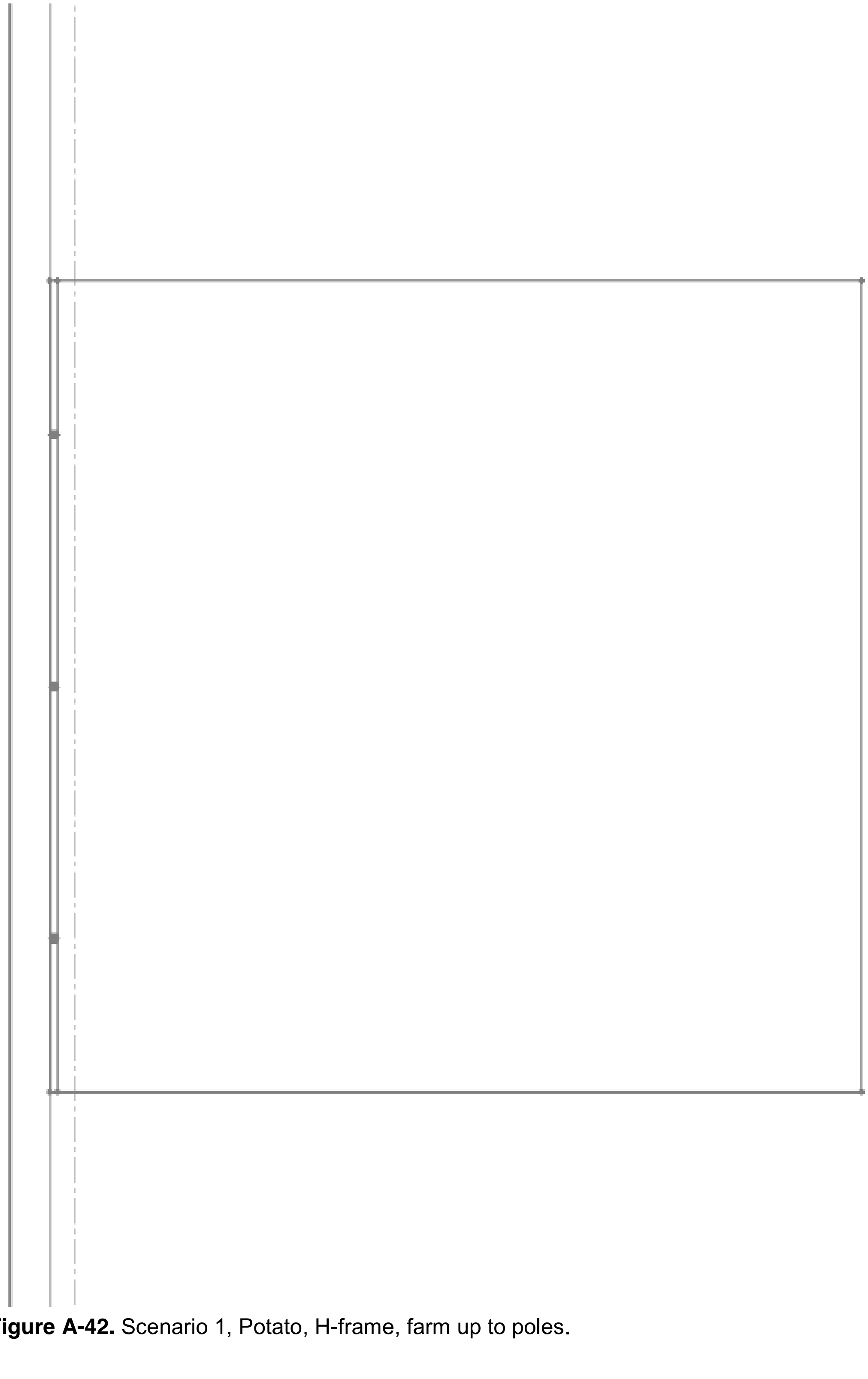

Figure A-42. Scenario 1, Potato, H-frame, farm up to poles.

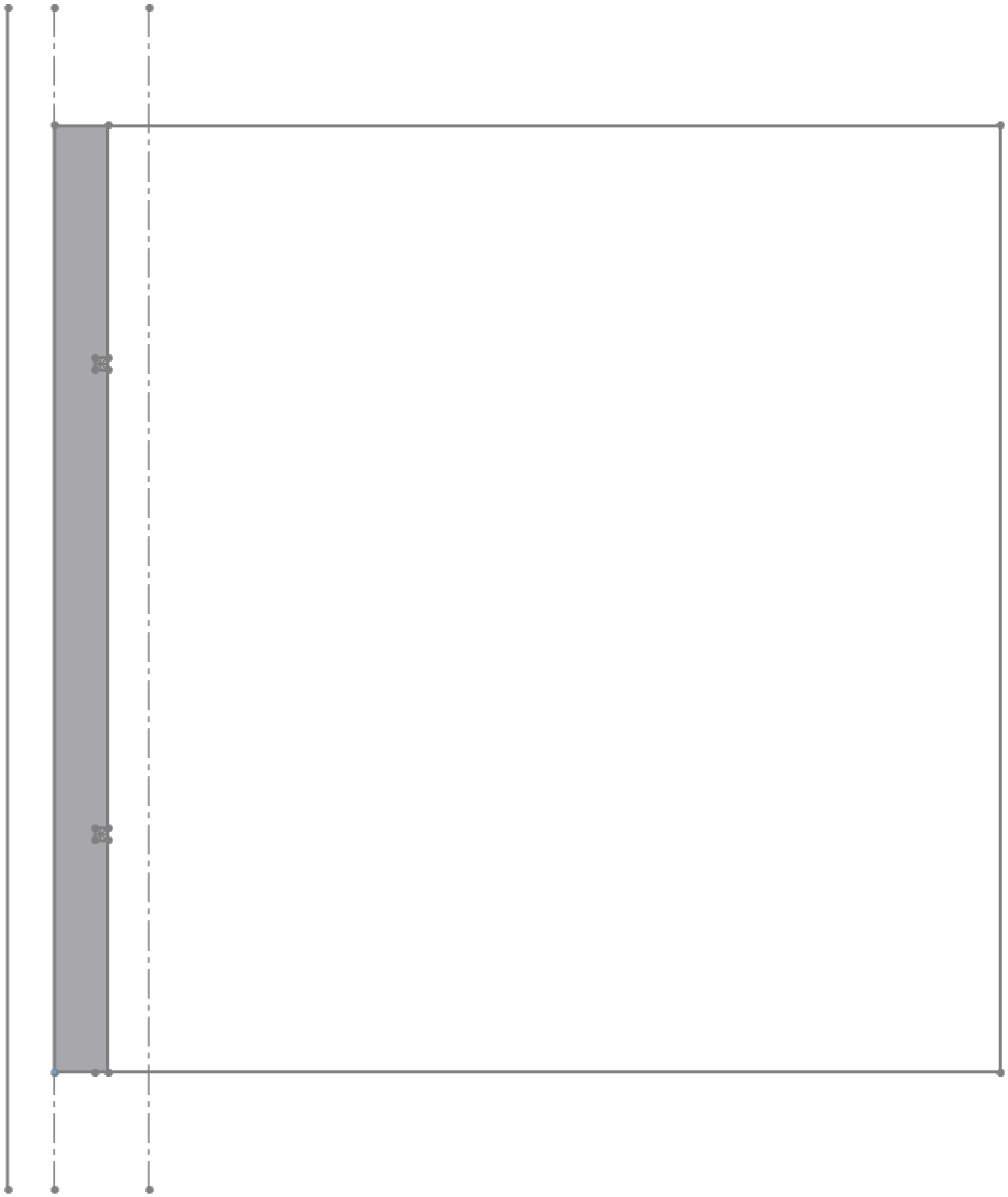

Figure A-43. Scenario 1, Potato, steel tower, farm up to poles.

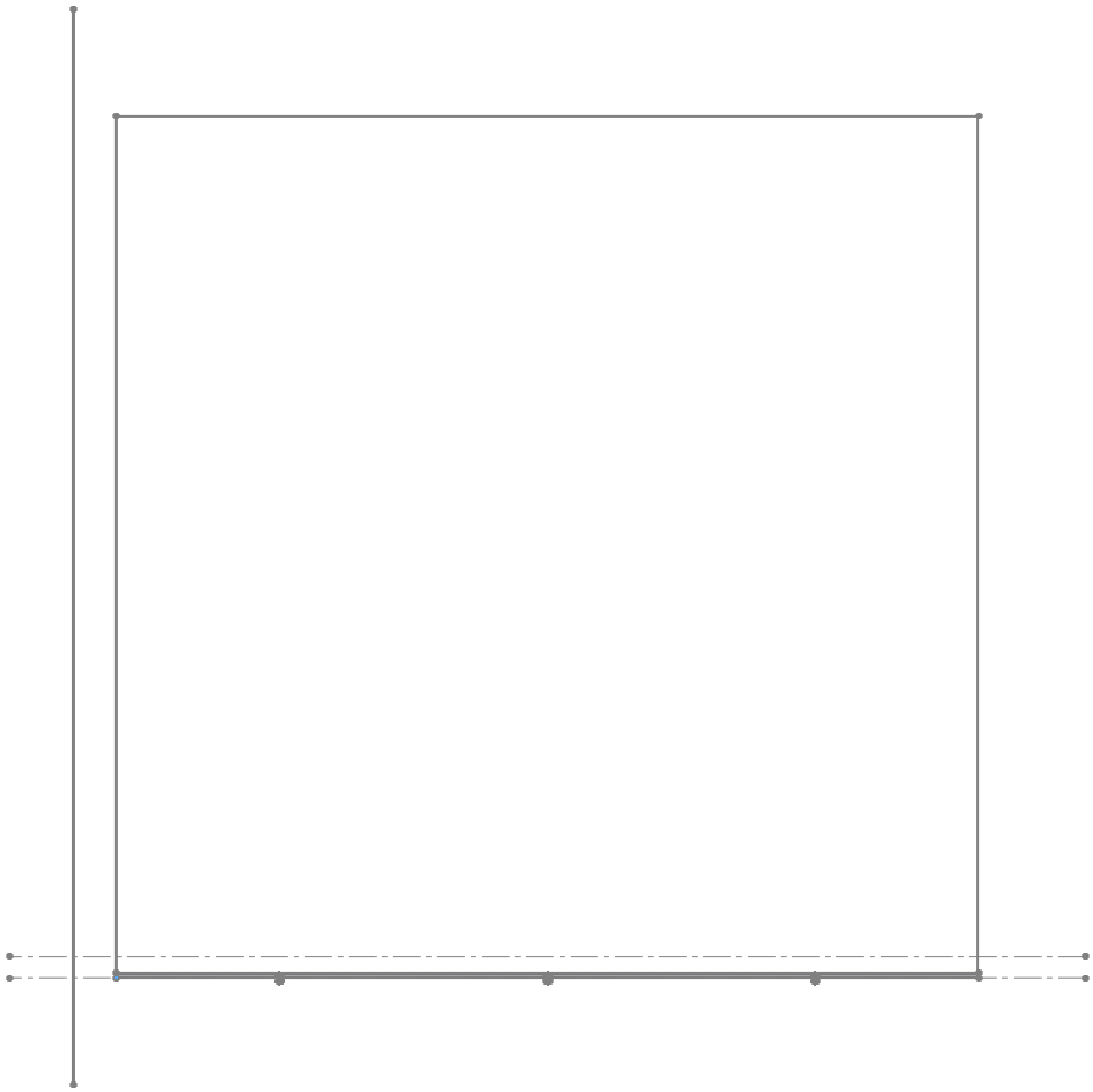

Figure A-44. Scenario 2, Potato, H-frame, farm up to poles.

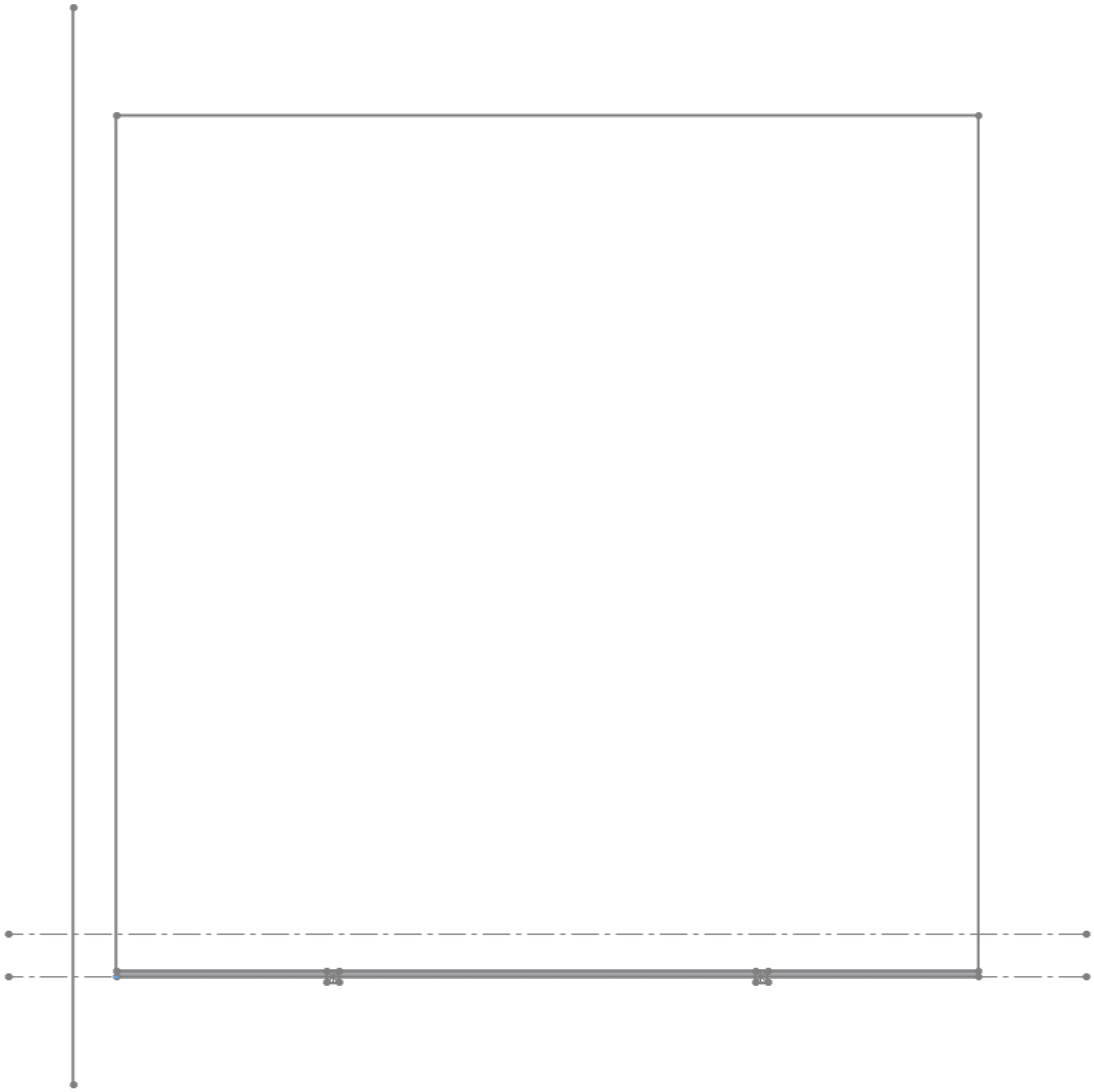

Figure A-45. Scenario 2, steel tower, Potato, farm up to poles.

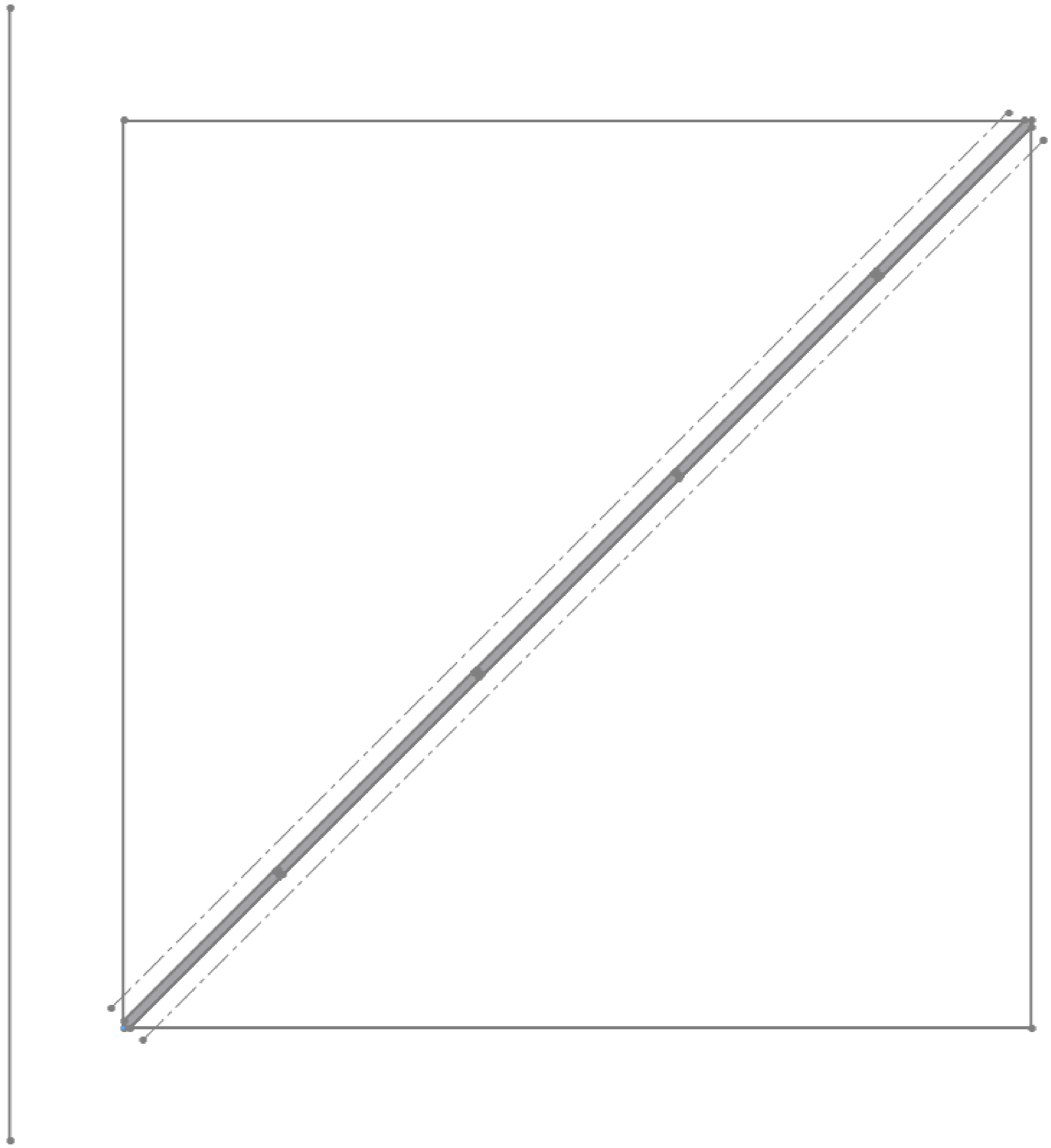

Figure A-46. Scenario 3, H-frame, Potato, farm both sides of poles.

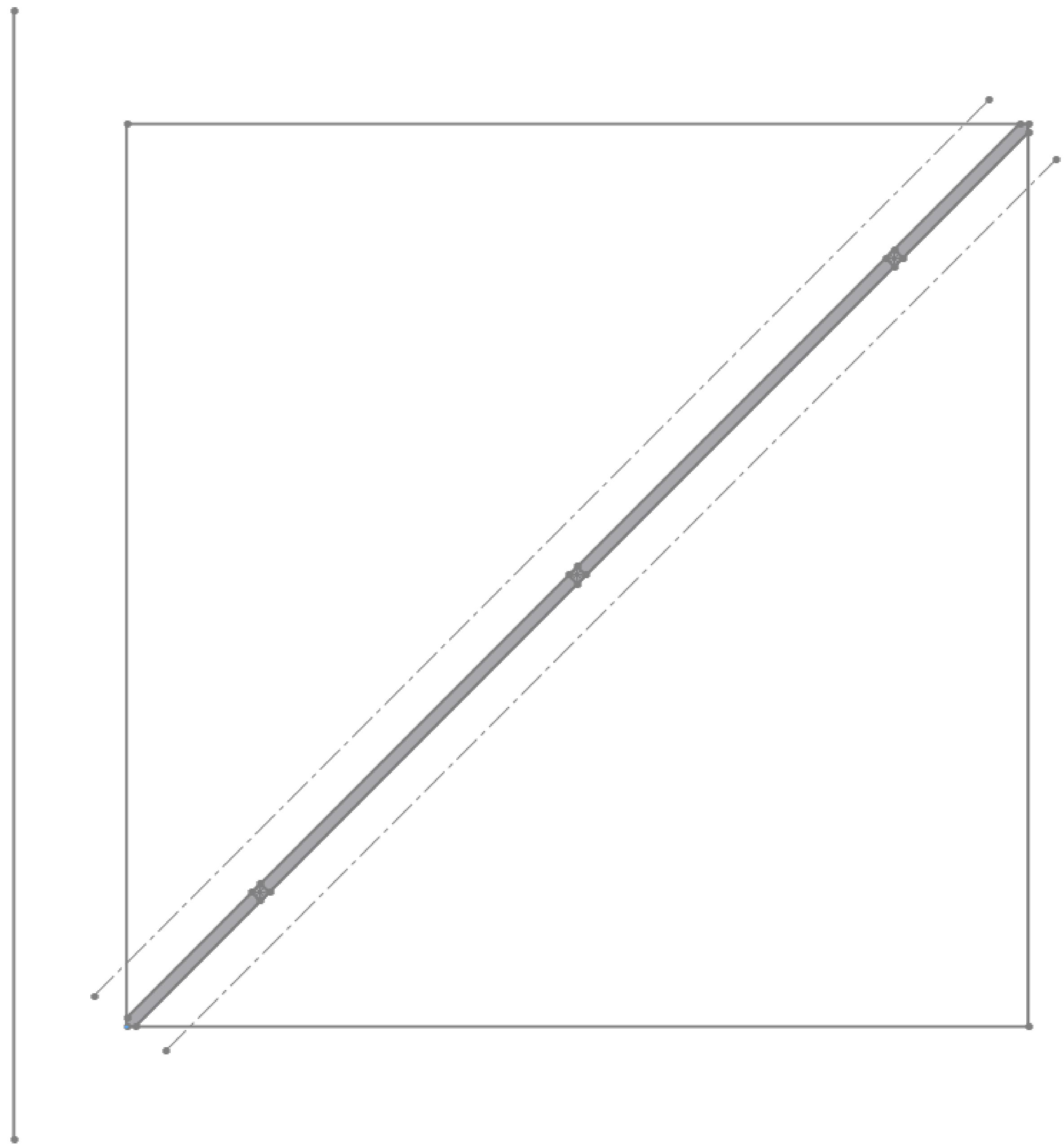

Figure A-47. Scenario 3, Potato, steel tower, farm both side of poles.

Appendix C

Multiplication Factors

Table 5. Multiplication factors used for general crop production considerations.

Crop Production (except potatoes)							
Support Structure	**Scenario**	**Implement Width**	**% Area Overlap**	**% Area Unused**	**% Area Transport**	**% Easement Unaffected by Lines**	**% of Field Unaffected by Lines**
H-frame	**1 (Roadside)**	15.2 m (50')	4.07%	1.26%	0.00%	94.67%	99.84%
		18.3 m (60')	4.50%	1.41%	0.00%	94.09%	99.83%
		30.5 m (100')	5.86%	1.50%	0.00%	92.64%	99.78%
		36.6 m (120')	6.44%	2.09%	0.00%	91.47%	99.75%
	2 (Mid-Section Line)	15.2 m (50')	1.77%	0.60%	0.00%	97.63%	99.94%
		18.3 m (60')	2.13%	0.72%	0.00%	97.15%	99.93%
		30.5 m (100')	2.76%	0.92%	0.00%	96.32%	99.91%
		36.6 m (120')	3.00%	1.00%	0.00%	96.00%	99.90%
	3 (On Diagonal)	15.2 m (50')	7.73%	0.24%	6.25%	85.78%	99.02%
		18.3 m (60')	11.69%	0.24%	7.61%	80.46%	98.65%
		30.5 m (100')	34.14%	0.24%	14.80%	50.82%	96.60%
		36.6 m (120')	47.69%	0.24%	20.47%	31.60%	95.27%
Steel	**1 (Roadside)**	15.2 m (50')	5.26%	0.37%	2.41%	91.96%	99.20%
		18.3 m (60')	3.29%	0.37%	3.01%	93.33%	99.34%
		30.5 m (100')	11.32%	0.37%	7.70%	80.61%	98.07%
		36.6 m (120')	6.18%	5.62%	7.06%	81.14%	98.12%
	2 (Mid-Section Line)	15.2 m (50')	1.33%	0.59%	0.00%	98.08%	99.90%
		18.3 m (60')	1.42%	0.62%	0.00%	97.96%	99.90%
		30.5 m (100')	1.70%	0.71%	0.00%	97.58%	99.88%
		36.6 m (120')	1.83%	0.76%	0.00%	97.42%	99.87%
	3 (On Diagonal)	15.2 m (50')	3.06%	0.39%	3.22%	93.34%	99.09%
		18.3 m (60')	3.98%	0.39%	4.11%	91.52%	98.84%
		30.5 m (100')	9.90%	0.39%	8.09%	81.63%	97.48%
		36.6 m (120')	14.62%	0.39%	10.04%	74.95%	96.56%

Table 6. Multiplication factors used for livestock manure injection line considerations.

Livestock Manure Injection Line							
Support Structure	**Scenario**	**Impleme nt Width**	**% Area Overlap**	**% Area Unused**	**% Area Transport**	**% Easement Unaffecte d by Lines**	**% of Field Unaffected by Lines**
H-frame	**1 (Roadside)**	6 m (20')	0.00%	1.68%	0.00%	98.32%	99.95%
		9 m (30')	0.00%	2.85%	0.00%	97.15%	99.92%
	2 (Mid-Section Line)	6 m (20')	0.00%	1.30%	0.00%	98.70%	99.97%
		9 m (30')	0.00%	2.06%	0.00%	97.94%	99.95%
	3 (On Diagonal)	6 m (20')	0.84%	0.35%	0.00%	98.81%	99.92%
		9 m (30')	1.03%	0.53%	0.00%	98.45%	99.89%
Steel	**1 (Roadside)**	6 m (20')	0.00%	4.36%	0.00%	95.64%	99.57%
		9 m (30')	0.00%	6.13%	0.00%	93.87%	99.39%
	2 (Mid-Section Line)	6 m (20')	0.00%	0.59%	0.00%	99.41%	99.97%
		9 m (30')	0.00%	0.89%	0.00%	99.11%	99.96%
	3 (On Diagonal)	6 m (20')	0.68%	0.49%	0.00%	98.82%	99.84%
		9 m (30')	0.77%	0.53%	0.00%	98.70%	99.82%

Table 7. Multiplication factors used for irrigated potato farming considerations.

Irrigated Potato Farming						
Support Structure	**Scenario**	**% Area Overlap**	**% Area Unused**	**% Area Transport**	**% Easement Unaffected by Lines**	**% Easement Unaffected by Lines**
H-frame	Scenario 1 (23.75 m easement)	0.00%	31.58%	0.00%	68.42%	99.07%
	Scenario 2 (40 m easement)	0.00%	21.24%	0.00%	78.76%	99.47%
	Scenario 3 (40 m easement)	0.00%	21.52%	0.00%	78.48%	98.51%
Steel	Scenario 1 (80 m easement)	0.00%	56.85%	0.00%	43.15%	94.35%
	Scenario 2 (80 m easement)	0.00%	13.75%	0.00%	86.25%	99.32%
	Scenario 3 (80 m easement)	0.00%	14.03%	0.00%	85.97%	98.08%

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