# THE COST OF DEPENDENCE UPON GPS-ENABLED NAVIGATION TECHNOLOGIES

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## ABSTRACT

The adoption of global positioning system (GPS) technology to fine-tune agricultural field operations over the last decade has been unprecedented relative to other agricultural technologies. As agricultural machinery size and capacity increased, field operations have become much more precise due to the synergistic relationship between farm machinery and GPS-enabled guidance technology. Now that the farm-level benefits re better understood, the risks associated with becoming dependent upon GPS technology are estimated. This question is addressed by estimating the economic cost of reverting from GPS-enabled navigation technologies, such as manual lightbar (LB) assistance and automated guidance, to traditional visual marker (VM) references. For the purposes of this scenario, economic cost will be defined by the summation yield penalties associated with being forced to revert to status quo VM technology. This analysis illustrates the strengths of GPS adoption as well as highlights key pitfalls. In the U.S. Cornbelt alone, multi-million dollar impacts are possible and more than one-half of one billion dollars is possible.

**Keywords:** GPS guidance, lightbar, automated guidance, economics, regional, cost, outage

## INTRODUCTION

This study builds upon previous work of Griffin et al. (2005, 2008) and Griffin (2009) by estimating the economic loss of reverting from GPS-enabled navigation technologies back to visual marker references. By summing the estimated farm-level value of adopting GPS navigation technologies for an existing farm across a region, a proxy for the cost of a regional GPS outage was determined.

## METHODS

To address the economic feasibility of GPS navigation technologies, a mathematical linear programming (LP) model was formulated for a representative

1,214 hectare U.S. Cornbelt farm. Several scenarios were compared: 1) a baseline scenario with foam, disk or other visual marker reference without GPS navigation; 2) LB navigation with basic GPS availability of +/- 3 dm accuracy; 3) automated guidance with satellite subscription correction; and 4) automated guidance with a base station (RTK) and +/- 1 cm accuracy. Evaluation of whole-farm returns over incremental management scenarios builds upon previous research by evaluating the changes to inputs costs. This study is of interest to farmers considering the best use of precision technology, agricultural industry marketing the technology, university researchers searching for optimal management of technology, and agricultural and international policy makers.

Linear programming (LP) was used to determine optimal solutions to contribution margins and "shadow values" for factors of production. LP is a mathematical tool for optimizing an objective function (Dantzig, 1949) such as maximizing contribution margin with respect to a set of whole-farm constraints on land, labor, and capital under a given weather regime (Boehlje and Eidman, 1982). Contribution margin is total crop sales revenue minus total direct costs, and can be considered returns to resources or fixed costs such as land, labor, and machinery. A shadow value is an estimate of the marginal value of a scarce resource and represents the change in contribution margin by using the last unit of resource. The base for comparison was a representative sized Corn Belt farm with a single equipment set (e.g. one planter and one harvester) using only VM technology for swathing. The base was modified in a series of LP runs to model the NT scenarios.

Five scenarios were compared: (i) a baseline foam, disk, or other VM (10% overlap), (ii) addition of LB with basic GPS availability (+/-3 dm accuracy), (iii) addition of LB with satellite subscription (+/-1 dm), (iv) addition of AG with satellite subscription (+/-1 dm), and (v) addition of AG with a base station real time kinematic (RTK) GPS (+/-1 cm). It is assumed VM NT costs are incurred in all scenarios plus any GPS NT costs, i.e. disk markers are installed on the planter.

***The Mathematical Linear Programming Model***

The optimization problem was specified as a linear programming model in the standard summation notation and written as in Boehlje and Eidman (1982, p. 404-405) as:

$$Max\ \Pi = \sum_{j=1}^{n} c_j X_j \qquad \text{eq. 1}$$

subject to:

$$\sum_{j=1}^{n} a_{ij} X_j \le b_i \text{ for } i = 1 \ldots m \qquad \text{eq. 2}$$

$$X_j \ge 0 \text{ for } j = 1 \ldots n \qquad \text{eq. 3}$$

where:

$X_j$ = the level of the $j$th production process or activity,
$c_j$ = the per unit return to the unpaid resources ($b_i$'s) for the $j$th activity,
$a_{ij}$ = the amount of the $i$th resource required per unit of the $j$th activity,
$b_i$ = the amount of the $i$th resource available.

Each LP run within a GPS NT scenario changed information relative to adding or changing the extent the technology was used. LP objective value results indicate 1) timeliness benefit from adding GPS NT and 2) benefit of increasing farm size without changing equipment sets while still remaining timely. Shadow values were examined to ascertain if the change violated timeliness criteria (i.e., if planting or harvesting became untimely) by considering the magnitude of and the number of time periods with a shadow value. Increases in the number of time periods with relatively large shadow values indicate compromised timeliness and the scenario were rejected as not a solution a rational farmer would accept. Time periods are generally one week in length during field operation periods.

***Hypothetical Model Farm Scenario***

The 1,214 ha baseline farm has three tractors, but only two have GPS-enabled NT. Field operations were based on conventional tillage production systems reported in Cain (2006). Field operations benefiting from GPS NT include the 7.3 m chisel plow, the 12.8 m field cultivator, 9.8 m tandem disk, 9.1 m grain drill and 18.3 m planter (Table 1); therefore the chisel, cultivator, and disk overlap were reduced with each subsequent improvement of GPS accuracy. Although planter overlap and speed were not impacted by NT, GPS-enabled planting operations were included to model farmer behavior based on their desire for straight and parallel rows; however GPS NT allowed planter to be used for additional hours per day. This combination of equipment was chosen because of potential overlap reduction benefits. A chisel is a primary tillage implement that minimizes soil inversion while preserving crop residue. A field cultivator is a secondary tillage implement that incorporates crop residue. A disk is a primary tillage implement that incorporates crop residue while stirring the soil. GPS NT is specific to two tractors, i.e., the farm has two individual GPS NT systems. With VM NT, tractors and implements could be used 12 hrs day$^{-1}$, and increased to 13 and 15 hrs day$^{-1}$ for LB and AG, respectively. The farm has two each of the chisel, disk and field cultivator and one 24-row planter and one combine (370 hp) with a 12-row corn head on 0.76 m row spacing and 9.1 m soybean head. The conventional tillage practice was to disk, chisel plow, and field cultivate prior to planting corn and disk and field cultivate prior to planting soybean. Equipment working rate is ha hr$^{-1}$ worked taking into account speed, size, and field efficiency (Table 1 and Table 2). The planter working rate was a constant 12.9 ha hr$^{-1}$ regardless of GPS NT.

Table 1. Implement size, field efficiency and working rates without GPS NT.

| Implement | Width (m) | Field efficiency (%) | Working Rate (ha hr$^{-1}$) |
|---|---|---|---|
| Disc | 9.8 | 80 | 6.6 |
| Chisel plow | 7.3 | 85 | 5.3 |
| Field cultivator | 12.8 | 85 | 11.4 |
| Boom sprayer | 36.6 | 55 | 36.4 |
| Drill (soybean) | 9.1 | 70 | 6.4 |
| Planter (corn) | 18.3 | 70 | 12.9 |
| Harvester (corn) | 9.1 | 85 | 4.8 |
| Harvester (soybean) | 9.1 | 85 | 4.8 |

For LP models, not only were the absolute price values important but also the price ratios. LP models are typically used for long term planning horizons and not for a single year, therefore prices and yields representative across several years were chosen. Corn and soybean prices were \$0.197 kg$^{-1}$ and \$0.456 kg$^{-1}$, respectively, for a price ratio of 2.48. Corn and soybean base yields were expected to be 11.80 Mg ha$^{-1}$ and 3.97 Mg ha$^{-1}$, respectively, when planted and harvested in the optimal time periods. Per hectare variable costs were \$ 963.71 USD and \$ 481.86 USD for corn and soybean, respectively. Yield and variable cost ratios were 0.31 and 0.50 for corn and soybean, respectively.

## ANALYSIS

Benefits of GPS NT systems were evaluated by incrementally changing the model to reflect effects that each NT had on working rates, workday, equipment availability and area farmed in a timely manner. Changes to the model were cumulative. Each change was added to the model using parameters from the previous step. This was done by initially changing the working rate, then increasing the number of hrs $day^{-1}$ that unpaid labor worked, then increasing equipment use hrs. Unpaid labor is family labor compensated from net farm income. With VM NT, 10% overlap is assumed, the level of advertised GPS accuracy was assigned to be the overlap for GPS NT, and 0.05 m overlap for RTK-AG (Table 2), affecting working rate calculations. Finally, farm size was increased to bring planter capacity utilization during the last time period to a level

Table 2. Working rates and overlaps for field operations benefiting from GPS NT.

| | 9.8 m tandem disk | | 7.3 m chisel plow | | 12.8 m field cultivator | |
|---|---|---|---|---|---|---|
| GPS NT | WR (ha $hr^{-1}$) | Overlap (m) | WR (ha $hr^{-1}$) | Overlap (m) | WR (ha $hr^{-1}$) | Overlap (m) |
| VM NT | 6.86 | 0.98 | 5.23 | 0.73 | 11.33 | 1.28 |
| 3 dm LB | 7.41 | 0.3 | 5.57 | 0.3 | 12.29 | 0.3 |
| 1 dm LB | 7.55 | 0.1 | 5.71 | 0.1 | 12.50 | 0.1 |
| 1 dm AG | 7.55 | 0.1 | 5.71 | 0.1 | 12.50 | 0.1 |
| 1 cm AG | 7.60 | 0.05 | 5.76 | 0.05 | 12.53 | 0.05 |

WR= working rate

similar to the base, conditional upon other operations not being adversely affected, i.e., harvester capacity as measured by the number and magnitude of shadow values (Table 3). Timeliness was measured by the hrs of planting for each time period. A farm remains timely if planting is completed by a base number of hrs $period^{-1}$.

### *Mathematical Model Results*

Initial LP runs were made with no GPS NT. In the base, a contribution margin of $1,452,173 farm$^{-1}$ was realized (Table 3). Adding a LB with 3 dm accuracy increased the contribution margin by $34,530 (Table 3) or US$28.44 ha$^{-1}$ just from increasing working rates of the chisel and field cultivator. When the hrs day$^{-1}$ that equipment was used increased from 12 to 13 hrs day$^{-1}$, the contribution margin increased by $49,478 over the base farm or $40.16 ha$^{-1}$ (Table 4). The next higher level NT was a satellite subscription GPS signal used with the LB or AG to give 1 dm accuracy, yielded an increase of $36,773 (Table 3) or US$30.29 ha$^{-1}$ (Table 4) above base when only working rates were changed. When workday was expanded to 13 and 15 hrs day$^{-1}$ for 1 dm LB and AG, contribution margin increased by $51,513 or $42.43 ha$^{-1}$. RTK-AG, the highest level of technology tested, increased the contribution margin by $37,364 or $30.78 ha$^{-1}$ for the farm just from increasing timeliness, i.e., reducing yield penalties by increasing working rate. Increasing the number of hours that implements are used increased the contribution margin an additional $57,802 (Table 3) or $47.61 ha$^{-1}$ (Table 4).

Table 3. Change in returns, shadow values, and planter capacity utilization.

| GPS NT | Increased Working Rate | Increase Equipment Hours | Increase Farm Size |
|---|---|---|---|
| Contribution Margin (US$ farm-1) (Base = $1,452,173) [after land costs] | | | |
| 3 dm LB | 34,530 | 49,478 | 196,619 [128,619] |
| 1 dm LB | 36,773 | 51,513 | 219,799 [143,299] |
| 1 dm AG | 36,773 | 57,802 | 387,360 [251,360] |
| RTK AG | 37,364 | 57,802 | 389,062 [253,062] |
| Shadow Value on Land (US$ ha-1) (Base=$438) | | | |
| 3 dm LB | 541 | 543 | 37 |
| 1 dm LB | 542 | 545 | -10 |
| 1 dm AG | 542 | 668 | 336 |
| RTK AG | 543 | 668 | 337 |

The shadow value on land changed as GPS NT benefits were added. The shadow value is the amount the farmer would be willing to pay for one additional unit of resource or in this case one ha of land. Without GPS NT, the shadow value on land was US$438 $ha^{-1}$ (Table 3). As NT were added, the shadow value on land increased. When the working rate increased, the shadow value increased to approximately $980 for all GPS NT, or a difference of $541 to $543 (Table 3). The shadow values in both LB scenarios were unchanged while AG NT increased to $1,106 $ha^{-1}$ when time constraints were relaxed. When additional acres were added to make the farm as timely as the base, all land shadow values reverted to levels similar to the base. This decrease in land shadow value results from a constant harvester capacity with increased equipment set utilization, reducing the value of the next unit of land. The additional value due to GPS NT could make the difference between a successful land rental bid and being left behind in the competitive Corn Belt market for farmland.

***Economic Partial Budget Analyses***

A partial budget was created from LP results. Annualized costs were calculated using a 10 year useful life, 8% discount rate and no salvage value for GPS NT. For example, the annualized costs of RTK-AG were $5.19 $ha^{-1}$ assuming a $35,000 initial investment (Table 4). Annual subscription fees for 1 dm DGPS correction were assumed to be $1,500, while the 3 dm accuracy had no annual fee. It was assumed that conventional VM NT were still present, therefore the fixed costs of VM were not deducted from the costs of GPS NT. Annualized $ha^{-1}$ GPS NT costs were subtracted from returns to the respective GPS NT (Table 4). When farm size was not expanded, the 1 dm AG NT was most profitable, followed by RTK AG, 1 DM LB, 3 DM LB and VM. All GPS NT were more profitable than VM in all cases. When full benefits of GPS NT were made by expanding farm size, RTK AG became the most profitable GPS NT. Economic ranking differs from earlier studies (Griffin et al., 2005) due to differences in crop prices and GPS NT cost ratios.

Table 4. GPS navigation technology costs and returns relative to visual markers.

| | 3 dm LB | 1 dm LB | 1 dm AG | RTK AG |
|---|---|---|---|---|
| Potential farm size expansion by adding GPS NT (Base farm size 1,214 ha) | | | | |
| Change in farm size (ha) | 162 | 182 | 324 | 324 |
| Navigation Technology (NT) Costs (US$) | | | | |

| | | | | |
|---|---|---|---|---|
| Initial investment US$ | 3,000 | 5,000 | 18,000 | 35,000 |
| Annualized cost farm $^{-1}$ | 540 | 900 | 3,240 | 6,300 |
| Annual subscription fee | 0 | 1,500 | 1,500 | 0 |
| Total annual cost farm$^{-1}$ | 540 | 2,400 | 4,740 | 6,300 |
| Total annual cost ha$^{-1}$ | 0.44 | 1.98 | 3.90 | 5.19 |
| Total annual cost ha$^{-1}$ with added ha | 0.39 | 1.72 | 3.08 | 4.10 |
| Returns to fixed costs above base (US$ ha$^{-1}$) | | | | |
| Returns (no added land) | 40.76 | 42.43 | 47.61 | 47.61 |
| Returns (added land) | 93.47 | 102.65 | 163.43 | 164.54 |
| Returns to fixed costs minus GPS NT above base (US$ ha$^{-1}$) | | | | |
| Returns (no added land) | 40.31 | 40.46 | 43.71 | 42.42 |
| Returns (added land) | 93.08 | 100.93 | 160.35 | 160.44 |

***Financial Depreciation Analysis***

It is unclear whether precision agriculture technologies such as GPS NT are to be depreciated similar to the associated field machinery or depreciated over a shorter horizon used for computer technology. The preceding analyses assumed a 10 year depreciation schedule. Four additional straight-line depreciation schedules were examined to determine the sensitivity of the relative ranking of GPS accuracy. In all cases, all four GPS NT dominated VM NT (Table 5).

In the event that the GPS NT investment must be completely paid the first year and without the opportunity for expanded farm size, the 3 dm LB scenario was the most profitable followed by 1 DM LB, 1 DM AG, and RTK AG (Table 5). When farm size was able to change, the 1 dm AG dominated followed by 1 dm LB, RTK AG, and 3 DM LB. This quick payback period is one reason that LB was so readily adopted by both agricultural service providers and farmers.

Table 5. Sensitivity of depreciation schedules on relative ranking of GPS NT

| | 3 dm LB | 1 dm LB | 1 dm AG | 1 cm AG |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| | Depreciated over 1 year | | | |
| Returns (no added land) (US$ $ha^{-1}$) | 38.09 | 36.75 | 30.36 | 16.48 |
| Returns (expanded acreage) (US$ $ha^{-1}$) | 91.12 | 97.71 | 149.82 | 139.96 |
| | Depreciated over 3 years | | | |
| Returns (no added land) (US$ $ha^{-1}$) | 39.73 | 39.49 | 40.25 | 35.70 |
| Returns (expanded acreage) (US$ $ha^{-1}$) | 92.57 | 100.09 | 157.62 | 155.13 |
| | Depreciated over 5 years | | | |
| Returns (no added land) (US$ $ha^{-1}$) | 40.06 | 40.04 | 42.23 | 39.54 |
| Returns (expanded acreage) (US$ $ha^{-1}$) | 92.86 | 100.57 | 159.18 | 158.17 |
| | Depreciated over 7 years | | | |
| Returns (no added land) (US$ $ha^{-1}$) | 40.21 | 40.28 | 43.07 | 41.19 |
| Returns (expanded acreage) (US$ $ha^{-1}$) | 92.99 | 100.78 | 159.85 | 159.47 |
| | Depreciated over 10 years | | | |
| Returns (no added land) (US$ $ha^{-1}$) | 40.31 | 40.46 | 43.71 | 42.42 |
| Returns (expanded acreage) (US$ $ha^{-1}$) | 93.08 | 100.93 | 160.35 | 160.44 |

It is expected that GPS NT will be given more than one year to generate a positive return on investment. Computer equipment is typically depreciated over a three year period. In the case of a three year depreciation schedule, the 1 dm AG dominated the 3 dm and 1 dm LB and RTK alternatives. The same relative rankings exist for the three year, five year and seven year depreciation schedules.

Although a 10-year deprecation schedule may be too long, it remains the most commonly used in the literature. The 1 dm AG was the most profitable when farm size was held constant followed by RTK AG, 1 DM LB, and 3 dm LB. When farm size could expand, RTK AG dominated 1 dm AG, 1 dm LB and 3 dm LB.

### *Estimated Willingness-to-Pay for Subscription Correction Fees*

The majority of farmers using automated guidance employ satellite correction services. Annual subscription fees currently range from $0 to $1,500 depending upon the service provider and accuracy level. Breakeven analyses were conducted to estimate how much the farmer would be willing to pay for the next higher accuracy level.

Given the situation where the farm size is not able to expand, the breakeven subscription fee for 1 dm LB was equal to $1,675 (Table 6). When the fee was greater than $1,675, the farmer would opt to use the 3 dm LB that does not require a paid subscription service. When the fee was less than $1,675, the farmer would opt to adopt the 1 dm LB system. The breakeven subscription fee for 1 dm automated guidance was equal to $3,060. At this fee, the farmer is indifferent between remaining with the 1 dm AG or moving to the 1 cm RTK system. When the fee is greater than $3,060, then the optimal choice would be to adopt RTK rather than use the subscription corrected GPS.

When the farm situation allows for acreage expansion, the breakeven fees were $12,458 for moving to the 1 dm LB and $1,358 for moving from 1 dm AG to 1 cm RTK AG (Table 6). These values are very similar to the range of subscriptions fees commanded by service providers. The most commonly charged annual subscription fees are $800 and $1,500.

Table 6. Estimated willingness-to-pay for annual subscription correction

| Farm size allowed to increase | no | yes |
|---|---|---|
| Breakeven between 3 dm LB and 1 dm LB | $1,675 | $12,458 |
| Breakeven between 1 dm AG and 1 cm RTK-AG | $3,060 | $1,358 |

Table 7. Regional Farm-level Costs of GPS Outage

| GPS-NT | Farm Value of GPS-NT | farms with GPS-NT (%) | Farms affected | Regional loss (USD) |
|---|---|---|---|---|
| 3 dm LB | 49,478 | 40.5 | 10,894.50 | $539,038,071 |
| 1 dm LB | 51,513 | 40.5 | 10,894.50 | $561,208,379 |
| 1 dm AG | 57,802 | 21.3 | 5,729.70 | $331,188,119 |
| RTK AG | 57,802 | 21.3 | 5,729.70 | $331,188,119 |

*Based on 26,900 farms with more than $500K in sales in North Central region

### Regional Cost of GPS Outage

Regional costs of GPS outage can be estimated by a simple summation of the farm-level losses for all affected farms and can be as complex as including other direct and indirect economic impact using community analysis methodology. Assumptions concerning the number of farmers making use of GPS and the value of production for the average farm must be made. The USDA Census of Agriculture states that there were 26,900 farms in Illinois, Indiana, Iowa, and Ohio all in the North Central Region of the U.S. that have more than $500USD in annual sales. According to estimates from Whipker and Akridge (2009), 40.5 percent of farms using lightbars and 21.3 percent use automated guidance. Using the farm-level value of GPS-enabled navigation technologies presented in Table 4, the regional economic loss due to GPS outage is presented in Table 7. Summing the farm-level losses of a GPS outage across the North Central region of the U.S. could reduce farm gate values by more than a half billion USD.

## SUMMARY AND CONCLUSIONS

Analyses presented here assume that the farmer has the option of reverting back to some visual marker reference such as row markers, foam makers or other technology considered status quo. Once farmers adopt and rely upon GPS technology, it is unlikely that they will possess or maintain row markers, especially for large planters such that row markers may cost more than $20K USD.

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