Economics of Lightbar and Auto-Guidance GPS Navigation Technologies

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Abstract

To address the economic feasibility of Auto-Guidance and lightbar global positioning system (GPS) navigation technologies, a linear programming model was formulated using data from U.S. Corn Belt farms. Five scenarios were compared: (i) a baseline scenario with foam, disk or other visual marker reference, (ii) lightbar navigation with basic GPS availability (+/-3 dm accuracy), (iii) lightbar with satellite subscription correction GPS (+/-1 dm), (iv) auto-guidance with satellite subscription (+/-1 dm), and (v) auto-guidance with a base station real time kinematic (RTK) GPS (+/-1 cm). Returns from each scenario were compared over incremental management scenarios.

Keywords: auto-guidance, auto-steer, lightbar, GPS navigation

Introduction

Global positioning system (GPS) navigation technologies (NT) such as lightbars (LB) and Auto-Guidance systems (AGS) are commercially available, promising increased efficiency of field operations. Benefits industry claim include 1) reduction in overlap, 2) increased speed of field operations, 3) extension of the workday, 4) greater flexibility in hiring labor and 5) more appropriate placement of inputs. GPS navigation allows more timely field operations improving yields and increasing area farmed with a given equipment set. GPS NT have been used for spatially sensitive practices such as controlled trafficking in compaction prone soils, side-dress nitrogen, and input placement in strip till systems. Comparing GPS NT benefits on compacted soils have been evaluated with at least one study (Watson & Lowenberg-DeBoer, 2003) and the economic feasibility of LBs have been reported (Lowenberg-DeBoer, 1999; Medlin & Lowenberg-DeBoer, 2000). However, it is unclear how GPS NT impact whole-farm returns and to what extent optimal farm size is affected.

A linear programming (LP) model was formulated using PCLP Version 5, Beta Test Version software from Purdue University (Dobbins et al., 2001). PCLP has been used since 1968 in conjunction with the Purdue Top Farmer Crop Workshop and was chosen to conduct this research because more than 7,000 farmers have relied upon, trusted, and inputted their own information over 25,000 times, validating the model (Candler et al., 1970; Doster, 2002; McCarl et al., 1977). PCLP has been used both outside and in the U.S. Corn Belt.

Five scenarios were compared: (i) a baseline scenario with foam, disk, or other visual marker reference method, (ii) addition of LB navigation with basic GPS availability (+/- 3 dm accuracy), (iii) addition of LB with satellite subscription correction GPS (+/- 1 dm), (iv) addition of auto-guidance with satellite subscription (+/- 1 dm), and (v) addition of auto-guidance with a base station real time kinematic (RTK) GPS (+/- 1 cm). Returns from each scenario were compared over incremental management scenarios.

This study focused on GPS NT in single equipment set farms. Disk, foam, or other physical markers meant to serve as visual reference on return passes have been used for many years, are considered status quo technology, and serve as the base for comparison. With marker technology the equipment operator must gauge passes either from markings left by previous passes or by the last pass itself, causing fatigue and human error. Lightbars use GPS to provide an electronic indicator that the operator uses to manually adjust the equipment, potentially lessoning fatigue and human error. Auto-guidance takes GPS NT a step further by steering the equipment to the appropriate location in the field, virtually eliminating fatigue and human error.

GPS NT are being adopted by commercial applicators to make custom applications of fertilizer, pesticides and other crop inputs. Sixty-one percent of U.S. custom applicator services use LBs for ground based applicators, while only 5.3% use AGS when making custom applications (Whipker & Akridge, 2004). GPS guidance has become standard practice on U.S. aerial applicators.

Methods

This study used LP to determine optimal solutions and “shadow values” for factors of production. A shadow value is an estimate of the marginal value of a scarce resource and represents the increase in contribution margin by using the last unit of resource. 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. The base for comparison was a representative sized U.S. Corn Belt farm with a single equipment set (e.g. one planter and one combine) using either marker technology or visual referencing for swathing. The base was modified in a series of LP runs.

Each LP run changes information relative to adding GPS NT benefits or changing farm parameters modeling the extent the farmer makes use of GPS NT. LP objective value results indicate 1) timeliness benefit from adding GPS NT and 2) benefit of increasing farm size without changing equipment sets and still remain timely. Shadow values were examined to ascertain if the change violates timeliness criteria (i.e., if planting or harvesting operations become potentially untimely) by considering the number of time periods with a shadow value (Table 1) and the approximate shadow value level. This methodology has been used since 1968 with the Top Farmer Crop Workshop. If shadow values indicated timeliness was compromised, then the scenario was not accepted.

Table 1. Number of time periods with shadow value on resource.

Resource	Base	Increase Working Rate	Increase Labor Availability	Increase Equipment Hours	Increase Farm Size
			3 dm LB		
Tractor	3	2	1	2	4
Tillage	1	0	1	0	0
Planter	2	2	2	2	2
Harvester	3	3	3	3	4
			1 dm LB		
Tractor	3	1	1	1	4
Tillage	1	1	0	0	0
Planter	2	2	3	3	2
Harvester	3	3	3	3	4
			1 dm AGS		
Tractor	3	1	2	2	4
Tillage	1	1	0	0	0
Planter	2	2	3	3	3
Harvester	3	3	3	3	4
			1 cm AGS		
Tractor	3	2	2	2	4
Tillage	1	0	0	0	0
Planter	2	2	3	3	3
Harvester	3	3	3	3	4

The baseline is a 1214 ha farm that has three tractors, but only one has the GPS NT. Field operations used under GPS NT include chisel and field cultivator. A chisel is a primary tillage implement that minimizes soil inversion while preserving crop residue and the soil surface. A field cultivator is a secondary tillage implement that opens the soil, incorporates crop residue, and controls weeds during spring field preparation. The GPS NT is specific to a single tractor, i.e., an individual GPS NT system is needed for each tractor if it is used. Initially, the tractors and implements can be used 12 hours per day without GPS NT, and increase to 13 and 15 hours per day for LB and AGS, respectively. The farm has one 24-row planter and one eight row combine (220 hp). It is assumed the farm uses a conventional tillage practice and is fall chisel plowed after the corn portion of the rotation and is field cultivated in the spring on all land regardless of rotation. Working rates for field operations used are presented in Table 2. Working rate is the hectares per hour worked and was calculated in a MS Excel spreadsheet, taking into account the speed, size, and field efficiency for the equipment (Schnitkey, 2000).

Table 2. Working rates for select field operations.

	Chisel ha $hour^{-1}$	Field cultivator ha $hour^{-1}$
Base (no GPS NT)	4.2	12.3
3 dm LB	4.5	13.0
1 dm LB	4.6	13.4
1 dm AGS	4.6	13.4
1 cm AGS	4.7	13.6

Analysis

Benefits of GPS NT systems were studied by incrementally changing the model to reflect effects of the technology on working rates, work days, equipment availability and the area that can be farmed in a timely manner. These 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 hours per day that unpaid labor worked, then increasing the number of hours that the equipment were used. Unpaid labor is family labor not paid hourly but compensated out of net farm income. Without GPS NT, the farmer could expect 10% overlap for marker or visual technology. With GPS NT, farmers may expect the level of advertised accuracy to be the overlap. With RTK-AGS, a minimal 0.5% overlap was assumed. The level of overlap affects the working rate calculation. Finally, the amount of land farmed was increased to bring the planter capacity utilization in the latest time period planted to a level similar to the base on condition that other operations could sustain the additional land, i.e., harvester capacity was not adversely affected. Even though the planter is not directly used with GPS NT, planting operations are indirectly affected by more efficient chisel and field cultivator operations. The planting operation hours per period was the metric chosen for which to strive when adding area farmed because planting is a key bottleneck in U.S. Corn Belt production.

Results

Initial LP runs were made with no GPS NT. In the base, a contribution margin of US\$622,319 $farm^{-1}$ was realized (Table 3). Adding a LB with 3 dm accuracy increased the contribution margin by US\$4,895 or US\$4.03 ha^{-1} just from increasing working rates of the chisel and field cultivator (Table 4). When the hours per day that unpaid labor worked and equipment were used increased from 12 to 13 hours per day, the contribution margin increased by US\$5,020 over the base farm or US\$4.14 ha^{-1}. The next higher level technology was a satellite subscription GPS signal used with the LB or AGS to give 1 dm accuracy, an increase of US\$4,923 or US\$4.06 ha^{-1} above base was realized. When labor and equipment time changed to 13 hours per day for 1 dm LB and 15 hours per day for 1 dm AGS, the contribution margin increased by US\$5,033 or US\$4.15 ha^{-1}. RTK-AGS, the highest level of technology tested, increased the contribution margin by US\$4934 or

US$4.06 ha^{-1} for the farm just from increasing timeliness, i.e., reducing yield penalties by increasing working rate. Modeling the workday expansion of unpaid labor working 15 instead of 12 hours per day and increasing the number of hours that implements could be used increased the contribution margin an additional US$5,034 or US$4.15 ha^{-1}.

Table 3. Returns, shadow values, and planter capacity utilization.

	Base	Increase Working Rate	Increase Labor Availability	Increase Equipment Hours	Increase Farm Size
Contribution Margin (US$ $farm^{-1}$)					
3 dm LB	622,319	627,214	627,339	627,339	664,974
1 dm LB	622,319	627,242	627,353	627,352	681,663
1 dm AGS	622,319	627,242	627,353	627,353	681,688
1 cm AGS	622,319	627,253	627,353	627,353	683,807
Contribution Margin minus Land Costs (US$ $farm^{-1}$)					
3 dm LB	244,319	249,214	249,339	249,339	256,734
1 dm LB	244,319	249,242	249,353	249,352	262,083
1 dm AGS	244,319	249,242	249,353	249,353	262,108
1 cm AGS	244,319	249,253	249,353	249,353	263,471
Shadow Value on Land (US$ ha^{-1})					
3 dm LB	376.69	467.03	467.03	467.03	374.02
1 dm LB	376.69	467.05	467.80	467.80	372.41
1 dm AGS	376.69	467.05	467.80	467.80	372.41
1 cm AGS	376.69	467.05	467.80	467.80	372.41
Planter Capacity Utilized May 17 -23 (hours)					
3 dm LB	22.42	22.42	17.99	17.99	22.14
1 dm LB	22.42	22.42	17.11	17.11	22.01
1 dm AGS	22.42	22.42	17.11	17.11	21.13
1 cm AGS	22.42	22.42	17.11	17.11	20.57

Adding AGS to an existing farm not only allows the farmer to conduct field operations in a more timely manner reducing yield penalties, but also to expand the farm size in the same timely manner with the existing equipment set. The planter was used 22.42 hours in the base during the May 17-23 time period, the period when planting operations were completed. When the extra hours per day and equipment time were added associated with GPS NT, the planter was used only 17.99 hours with 3 dm LB and 17.11 hours for the three higher GPS NT levels in this time period. This was the starting point to decide how much land to add to the farm to cause the planter utilization to approach the initial 22.42 hours without violating shadow value criteria on other field operations, i.e. overload harvesters (Table 1). Planter utilization levels after the addition of land to the base farm approached the original value of 22.42; however the resulting levels followed a trend of being lower for the higher level of technology (Table 3). This model added 97 ha for 3 dm

LB, 134 ha for 1 dm LB and AGS, and 136 ha for RTK-AGS (Table 4). The per ha returns for these are US$9.47, US$13.18, US$13.20, and US$14.19 for 3 dm LB, 1 dm LB, 1 dm AGS, and 1 cm RTK-AGS, respectively (Table 4).

Table 4. Incremental changes in whole farm returns above base.

	Increase Working Rate		Increase Labor Availability		Increase Equipment Hours		Increase Farm Size		
	US$ farm^{-1}	US$ ha^{-1}	US$ farm^{-1}	US$ ha^{-1}	US$ farm^{-1}	US$ ha^{-1}	US$ farm^{-1}	US$ ha^{-1}	ha
3 dm LB	4,895	4.03	5,020	4.14	5,020	4.14	12,415	9.47	1311
1 dm LB	4,923	4.06	5,034	4.15	5,033	4.15	17,764	13.18	1348
1 dm AGS	4,923	4.06	5,034	4.15	5,034	4.15	17,789	13.20	1348
1 cm AGS	4,934	4.06	5,034	4.15	5,034	4.15	19,152	14.19	1350

The shadow value on land also 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$376.69 ha^{-1}. As technologies were added, the shadow value on land increased. When the working rate was increased, the shadow value increased to approximately US$467.05 for all GPS NT. The 3 dm LB shadow values were unchanged while the other three GPS NT increased to US$467.80 ha^{-1} when time constraints were loosened. When additional acres were added to make the farm timeliness similar to the base, all land shadow values reverted back down to levels similar to the base. The additional value due to GPS NT could make the difference between a successful land rental bid and being left behind in the competitive U.S. Corn Belt market for farmland.

A partial budget was created from LP results. To calculate annualized costs, a 10 year useful life, 8% discount rate, and no salvage value was used. For example, the annualized costs of RTK-AGS were calculated to be US$4.67 ha^{-1} assuming a US$35,000 initial investment (Table 5). Annualized per hectare costs were calculated and then subtracted from returns to the GPS NT. Table 5 concludes with returns to fixed costs above GPS NT. When farm size was not expanded, the 3 dm LB NT was most profitable, followed by 1 dm LB, 1 dm AGS, and no GPS NT. RTK-AGS was less profitable than no GPS NT when the farmer did not take full advantage of benefits by expanding farm size. When the farmer makes complete use of GPS NT by expanding farm size to remain as timely planting as the base, the 1 dm LB becomes the most profitable level of GPS NT. Not only does RTK-AGS become profitable, it out ranks 3 dm LB when farm size expands.

Table 5. GPS navigation technology costs and returns.

	3 dm LB	1 dm LB	1 dm AGS	1 cm AGS
Navigation Technology (NT) Costs US$				
Initial investment	3,000	5,000	18,000	35,000
Annualized cost farm $^{-1}$	540	900	3,240	6,300
Annualized cost ha^{-1}	0.44	0.74	2.67	5.19
Annualized cost ha^{-1} with added ha	0.41	0.67	2.40	4.67
Annual subscription fee	0	800	800	0
Subscription fee ha^{-1}	0.00	0.66	0.66	0.00
Subscription fee ha^{-1}with added ha	0.00	0.59	0.59	0.00
Total cost farm^{-1}	540	1700	4040	6300
Total cost ha^{-1}	0.44	1.40	3.33	5.19
Total cost ha^{-1} with added ha	0.41	1.26	3.00	4.67
Returns to fixed costs above base US$				
Returns (no added land)	4.14	4.15	4.15	4.15
Returns (added land)	9.47	13.18	13.20	14.19
Returns to fixed costs minus GPS NT above base US$				
Returns (no added land)	3.69	2.75	0.82	-1.04
Returns (added land)	9.06	11.92	10.20	9.52

Conclusion and Implications

Results of this study suggest that GPS NT is promising for farmers who can devote a tractor to field operations that typically overlap. Making complete use of GPS NT by expanding farm size is important to the profitability potential of the technology. With a fixed farm size, LB technology is most profitable. AGS becomes a competitive option when farm size is allowed to adjust. Other studies suggest that RTK AGS is profitable when spatially sensitive practices like controlled traffic and strip tillage show substantial yield benefits.

The worldwide implications of this research for adoption of GPS NT depend on cost and availability of capital and labor, as well as on potential for farm expansion. For instance, in countries such as the U.S. and European Union, labor costs are very high relative to capital costs so labor management effects of GPS NT are valuable. In South Africa, many farm workers experienced in combine and tractor operations have been lost to the AIDS epidemic (Nell, 2004). In response, some South African owner-operators are considering purchasing AGS to replace years lost in driver skill. Conversely, in areas such as Brazil and Argentina where labor is relatively cheap and readily available compared to capital, reducing skip or overlap and operating at faster field operations dominate economics. The farm expansion scenarios may be more plausible in the U.S. due to the active land rental market and larger U.S. farm sizes than Europe.

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