Cost Sensitivity Analysis on the Optimal Location of Technology Providers In Kentucky

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Abstract

A warehouse location model was utilized in order to expand upon previous research. The aim was to more accurately depicting the optimal location for an agribusiness firm providing precision agriculture technologies in the state of Kentucky. It was determined that the optimal solution was Muhlenberg County.

Keywords: warehouse location model, precision agriculture, agribusiness

Introduction

Throughout the southern United States, precision agriculture has been utilized in crop production for many years. With the progression of the precision agriculture industry, expansion of firms providing precision agriculture services is inevitable. As a result, potential agribusinesses entering the precision agriculture industry are in need of a more complete set of information to aid in the decision making process. Due to the spatial variability of the utilization of precision agriculture, one problem faced by agribusiness is where to locate a firm in order to minimize costs (e.g. construction costs and transportation costs). Previous research by Shockley et al. (2007) provides insight to the locational problem faced by agribusinesses in the precision agriculture industry, as observed throughout the state of Kentucky.

The purpose of this study is to expand on Shockley et al.'s (2007) optimization model-- specifically a warehouse location model-- in order to more accurately depict the optimal location for an agribusiness firm providing precision agriculture technologies in the state of Kentucky. The precision agriculture technologies evaluated in this study include: grid soil sampling, variable rate application of fertilizer and lime, and field mapping. Previous studies have determined the optimal location of a precision agriculture service provider based solely upon minimization of total miles traveled. In order to expand upon this idea, costs associated with the concrete location of an agribusiness are introduced into the previous study. It is then possible to determine the optimal location of an agribusiness firm, a location that will minimize the total costs incurred by an agribusiness. Additionally, other evaluations can determine the loss associated with locating in counties other than the determined optimal location. Finally, results from both studies are compared to evaluate any changes of the optimal solution that may occur.

Literature Review

Precision agriculture adoption studies can be very useful for agribusinesses in determination of an ideal location. Specifically, logit models have been conducted to identify characteristics that influence the adoption of these technologies (e.g. Daberkow and McBride (2003), Roberts et al. (2002) and Shockley et al. (2006)) Such studies were used by Shockley et al (2007) in order to determine any prospective counties for the location of a precision agriculture agribusiness. These potential locations were chosen because they have a greater than 50% expected probability of adopting a precision agriculture technology such probabilities were also used in previous publications as a weighted measure for the possible agribusiness locations.

An optimization model was developed in order to determine the most favorable county in Kentucky for agribusiness location, so that precision agriculture services could be provided to all of Kentucky's possible demand centers. Based solely on minimizing total travel distance it was determined that an agribusiness should locate in Muhlenberg County, which resulted in an optimal round trip distance of 8151.10 miles and cost of $3,307.06. This base model was expanded by incorporating the expected probabilities of adopting sub-groupings of precision agriculture technologies for the respected counties in question. Again, it was determined that Muhlenberg County was the optimal solution for all of the precision agriculture sub-groupings. The costs determined in the study by Shockley et al (2007) were tabulated from the standard mileage rate given by the United States Department of Treasury, not actual costs incurred by the agribusiness.

In order to expand upon initial studies, those costs associated with locating an agribusiness in Kentucky are needed. One of the costs introduced in this study was that associated with the construction of an agribusiness. Logsdon and Debertin (2004) conducted a study in which they developed a business model, specifically a cash flow statement responsible for determining the profitability of a firm selling precision agriculture technology services. They concluded that a firm centrally located in the Purchase and mid-Western regions of Kentucky could be successful and have a payback period of three years. The base start-up cost (included construction and a two acre parcel of land) determined in the cash flow statement by Logsdon and Debertin (2004) was $117,500. Thus, the start-up cost determined by Logsdon and Debertin (2004) is employed in this study.

In order to expand Shockley et al's (2007) study, a warehouse location model will again be used to determine the optimal location of an agribusiness providing grid soil sampling, variable rate application of fertilizer and lime, and field mapping. The objective of the warehouse location model is to minimize total transportation costs plus the cost of building and operating the warehouse (Feldman et al., 1966). Accordingly, the warehouse location model will be the basis for this study.

Data and Methods

Critical to this study is the previous research conducted on the optimal location of precision technology providers by Shockley et al (2007). Their study determined the optimal location of an agribusiness providing different sub-groupings of precision agriculture technologies using mathematical programming by minimizing the total miles traveled in order to supply all the demand centers with these technologies. This study expands Shockley et al's (2007) optimal location model to encompass more parameters, specifically the costs incurred by the agribusiness, than just total distance to the demand centers. This will in turn, determine the optimal location of an agribusiness providing only one grouping of precision agriculture technologies and those are: grid soil sampling, variable rate application of fertilizer and lime, and field mapping. A warehouse location model was used to determine the optimal location for an agribusiness. According to McCarl and Spreen (1997), a general warehouse location model formulation is as follows.

$$\text{Min} \quad \sum_k F_k V_k + \sum_i \sum_k C_{ik} X_{ik} + \sum_k \sum_j D_{kj} Y_{kj} + \sum_i \sum_j E_{ij} Z_{ij}$$

$$\begin{aligned}
\text{s.t.} \quad & \sum_k X_{ik} + \sum_j Z_{ij} \le S_i \quad \text{for all i} \\
& \sum_k Y_{kj} + \sum_i Z_{ij} \ge D_j \quad \text{for all j} \\
& -\sum_i X_{ik} + \sum_j Y_{kj} \le 0 \quad \text{for all k} \\
& -CAP_k V_k + \sum_j Y_{kj} \le 0 \quad \text{for all k} \\
& \sum_k A_{mk} V_k \le b_m \quad \text{for all m} \\
& V_k = 0 \text{ or } 1, \quad X_{ik}, \quad Y_{kj} \quad Z_{ij} \ge 0 \quad \text{for all i, j, k}
\end{aligned}$$

The objective function depicts total cost minimization where total cost includes warehouse costs plus shipping costs. The warehouse costs include such expenses as cost of the land and construction of the facility. The shipping costs include such expenses as the travel cost associated with providing services to the demand centers and the on farm cost of the service being provided. The first constraint balances outgoing shipments with available supply for supply points. The second constraint makes sure you meet the demand requirements from the demand centers and requires a minimum level of incoming shipments to supply location. The third constraint requires outgoing shipments at a warehouse location not to exceed incoming shipments to that warehouse. The next constraints both involve the zero-one warehouse variables imposing warehouse capacity. The last constraint limits warehouse construction through configuration constraints. This general model must be configured to address the problem in this study, which is, where to locate an agribusiness that provides precision agriculture technologies so that it minimizes costs associated with the location decision.

To adjust the model to be appropriate for this study and to expand on Shockley's et al. (2007) previous study, a few modifications need to be made. McCarl and Spreen's (1997) warehouse location model contains intermediate shipments into the warehouse from supply points (X_{ij}). In this study, we are not considering these intermediate shipments because our warehouse is an agribusiness that will be providing all of the services and these services are already on site. Since this study is not considering shipments from supply points, Z_{ji} will also not be used. Therefore, the modified warehouse location model that is used in this study is as follows:

$$\text{Min} \quad \sum_k F_k V_k + \sum_k \sum_j D_{kj} Y_{kj}$$

$$\text{s.t.} \quad \sum_k V_k = 1$$

$$V_k - M_{kj} \leq 0$$

$$V_k = 0 \text{ or } 1, \qquad Y_{kj},\ M_{kj} \geq 0 \text{ for all j, k}$$

where,

V_k - a zero-one indicator variable indicating whether the agribusiness located in county k is constructed;

Y_{kj} – a continuous variable indicating the precision technologies provided by agribusiness located in county k to demand point j;

The demand points in this case were the county seats of Kentucky's counties with probabilities greater than 50% of adopting the above technologies. Figure 1 shows the location of the demand centers in Kentucky's various counties. In turn these counties also represent possible counties where an agribusiness providing precision agriculture technology services should locate.

The parameters for this model include: the variable cost of constructing an agribusiness in county k (F_k) and the variable cost of agribusiness k servicing demand point j (D_{kj}). The variable cost associated with agribusiness k servicing demand point j (D_{kj}) is a function of travel costs and distance from agribusiness k to demand point j (M_{kj}). The objective function for this study attempts to minimize the cost of constructing the agribusiness plus the travel costs associated with servicing all demand points. The first constraint in the model forces the model to chose only one of the k^{th} counties to construct the agribusiness and the second constraint insures that if an agribusiness locates in county k that is serves all demand points j.

Previous research conducted by Shockley et al. (2007) only minimized the travel distance from agribusiness k to demand point j (M_{kj}). They did not consider the variable cost to serve demand point j (D_{kj}) nor did they consider the variable cost of constructing the agribusiness in county k (F_k). For that reason, this research introduces cost into the model to evaluate any changes of the optimal location that may occur.

The cost associated with constructing an agribusiness in county k (F_k) was calculated by adjusting the base cost from the study by Logsdon and Debertin (2004) by the varying counties average per acre dollar value of land and buildings provided by the USDA Census of Agriculture (2002). This included the construction of the building, along with the cost of two acres of land to build on. On the other hand, the cost associated with servicing the demand centers,

$$D_{kj} = D_{kj}\ (M_{kj}\ , P_{kt}, A_j, R_t, W, MPG, G)$$

where,

M_{kj} – the travel distance (in miles) from agribusiness k to demand point j, which was gathered from Map Quest on the World Wide Web;

P_{jt} – probability of demand point j adopting precision agriculture technologies t, which was collected from the previous study by Shockley et al. (2006);

A_j – total adjusted acres to be served in demand point j, provided by USDA Census of Agriculture (2002);

R_t – performance rate of a precision agriculture technology t, collected from previous research from Gandonou et al. (2006);

W – number of hours worked per day (assumed 8 hrs per day);

MPG – average miles per gallon for mode of transportation (assumed 20 MPG);

G – average gas price in Kentucky collected from AAA on the World Wide Web (Average Kentucky Regular Unleaded Gas Price = 2.150);

Finally, GAMS (General Algebraic Modeling System) can be used to determine the optimal county for an agribusiness providing precision agriculture technologies to locate by minimizing the associated costs.

Results

General Algebraic Modeling System (GAMS) was applied in order to solve the optimization model, specifically the warehouse location model. After introducing both construction and travel costs associated with the multiple locations in Kentucky (counties), results indicated that Muhlenberg County was the optimal solution, which in turn minimized costs. The optimal cost for locating in Muhlenberg County was $658,414.33. This cost includes construction costs (i.e. building costs and a two acre parcel of land) and multiple round trip travel costs, which are needed to service all the demand points shown in Figure 1. In order to service an entire county, multiple trips must be made in order to complete the precision task. The number of required trips was quantified by analyzing the following variables: the total acres in the county that must be serviced, the performance rate of the technology being utilized, and the number of hours worked per day. Surprisingly, the majority of the cost incurred by locating in Muhlenberg County was from travel costs, which accounted for almost 90 percent of total location cost Construction costs (i.e. land values) do vary throughout Kentucky's counties. However when compared to the significant travel costs, these deviations prove to be rather insignificant.

Also evaluated were the expected losses associated with locating in a less-than-optimal county. Rather than placement in Muhlenberg, the prospect of locating to one of its seven bordering counties was analyzed. The expected losses are illustrated in Figure 2. From Figure 2, we see that the two counties with the smallest expected loss are directly west of Muhlenberg. Whereas, the two counties with the largest expected losses are north of Muhlenberg. This correlates with the density of the demand centers. The majority of demand centers are located in Western Kentucky. Accordingly, an agribusiness would lose less profit by locating west, rather than north of Muhlenberg. At this location, a business would still be in close proximity to the heaviest concentration of demand points.

Along with the comparison of the losses associated with locating an agribusiness in a county other than the optimal, the results of this study were compared with the results from Shockley et al.'s (2007) previous study and are presented in Table 1. It can be inferred from Table 1 that the optimal location results are consistent throughout the three models, concluding that Muhlenberg County is the optimal location for an agribusiness to supply services to all the demand points. When comparing the results from both studies, there exists a significant difference in estimated costs. The less recent study did not include multiple trips nor did it consider the initial investment needed to start an agribusiness, parameters that the current study has corrected for. Addition of these variables resulted in substantial increases in costs. Even though there is a substantial difference in the costs associated with locating in any particular county, results show that travel costs are much more weighted than construction costs in regards to determination of an optimal location. .

Another notable result is seen when comparing the dollar cost of the base model (with probabilities) with the advanced model: McLean County. In the base model it was the 5th most expensive place to locate out of the seven Muhlenberg-bordering counties, and was the 2nd most expensive county in the advanced model. This is again attributed to the number of trips needed to serve the other nearby demand points. In order to minimize travel costs, an agribusiness ought to locate in a county which demands numerous trips because service cost to itself is relatively small (nil in this model), which McLean County lacks. For this reason, the costs associated with locating in McLean County are larger than that of the base model by Shockley et al. Overall, it can be concluded that, to minimize costs associated with introduction and management of an agribusiness that supplies precision agriculture service to demand points around Kentucky, Muhlenberg County is the optimal choice.

Summary and Conclusion

In this study, mathematical programming was used to solve an optimization model, specifically a warehouse location model, which determined the optimal county in Kentucky to locate an agribusiness providing precision agriculture services can supply all of Kentucky's demand points. The purpose of the study was to expand upon the previous research conducted by Shockley et al. (2007), which determined the optimal location of an agribusiness providing precision agriculture services solely based on minimizing the distance to supply all demand centers. This study introduced variable costs into the model and evaluated any changes to the initial base model optimal solution determined by Shockley et al. (2007).

The optimal solution of the expanded model was determined by minimizing the variable costs associated with located in a county in Kentucky using GAMS. The variable costs that were used in the warehouse location model were construction costs and travel costs. It was determined that the optimal solution to the expanded model when these variable costs were introduced was the same as the previous base model—Muhlenberg County. Muhlenberg County shows an optimal cost of $658,414.33, which includes the cost of constructing the agribusiness building along with the purchase of two acres of land. Also included are the multiple round trip costs associated with providing grid soil sampling, variable rate application of fertilizer and lime, and computerized field mapping to all the demand points in Kentucky. This study could provide very valuable information to either potential agribusiness firms that are looking to locate in Kentucky or firms already established in Kentucky that are looking to re-locate. In both cases, businesses could face the complications of trying to find a favorable location. These results provide insight for the firm's decision-making process by providing an estimated cost minimizing optimal location.

This study provides an expansion to previous research, which utilized the warehouse location model in determining the optimal location for an agribusiness providing precision agriculture services to Kentucky's counties. The opportunity exists to expand this model even further to evaluate an agribusiness that provides a different grouping of precision agriculture services. Also, additional costs could be considered to more accurately depict the costs associated with an agribusiness providing precision agriculture services. Finally, the purpose of this technique is to minimize costs associated with a location problem and is not limited to only Kentucky. Rather, it can be expanded to evaluate any location and/or any type of business.

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Table 1. Comparison of Shockley et al. (2007) Base Models with the Advanced Model of This Study

	Base Model ($0.405/mile)	Base Model with Probabilities of Tech's (in dollars - $0.405/mile)	Advanced Model with construction costs and travel costs ($)
Optimal County	Muhlenberg County	Muhlenberg County	Muhlenberg County
Optimal Value	$3,301.16	$5,567.73	$658,414.33
Optimal Location Bordering Counties			
Ohio County	$3,367.29	$6,123.71	$742,523.53
Butler County	$3,366.12	$6,326.05	$734,175.68
Logan County	$3,649.33	$6,411.76	$728,291.24
Todd County	$3,681.86	$6,190.07	$729,249.71
Christian County	$3,636.50	$5,793.26	$700,593.05
Hopkins County	$3,479.36	$5,699.27	$701,211.51
McLean County	$3,466.07	$5,897.28	$741,113.77

Figure 1. The Possible Counties in Kentucky where an Agribusiness can locate, as well as the demand centers that must be serviced (Shockley et al. 2006).

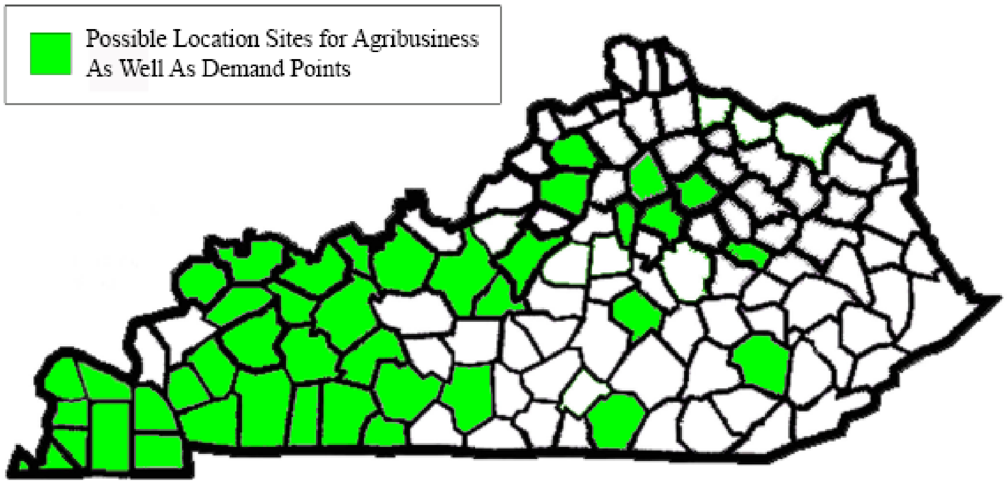

Figure 2. Expected losses when locating agribusiness counties that border Muhlenberg