

REDUCING HARVEST COSTS THROUGH COORDINATED SUGARCANE HARVEST AND TRANSPORT OPERATIONS IN LOUISIANA

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ABSTRACT

Harvest costs represent a major cost item for sugarcane production in Louisiana and other sugarcane producing regions in the United States. Projected costs for sugarcane production in Louisiana for 2007 show harvest costs account for 32.5 percent of total production costs. One factor which can have a significant influence on harvest cost is the impact of time spent waiting for trucks returning from the mill to arrive at the farm. As the number of trucks arriving at a mill to unload harvested sugarcane in a given time period increases, the time required for a truck to be sampled, unload and return to the farm increases. A study was conducted to estimate the cost of waiting time on harvest cost and to develop a framework for coordinating harvest and transport of sugarcane to minimize waiting time. This required the development of a mathematical programming model which could coordinate harvest and delivery schedules to minimize truck waiting time at the mill. Waiting time was estimated to increase farmers harvest cost at a rate of \$1.30 per minute. Mathematical programming model results illustrate the ability to coordinate harvest and delivery schedules can reduce truck waiting time at the mill.

INTRODUCTION

Harvest costs represent the single largest farm cost item associated with producing sugarcane in Louisiana. A breakdown of estimated variable and total sugarcane production costs by phase of production are shown in Table 1. Variable cost for the sugarcane production phases listed includes expenses for seed cane, fuel, labor, fertilizer, chemicals, custom application, repair and maintenance, and interest on operating capital. Total cost includes variable costs plus fixed costs, the depreciation and interest expense on machinery and equipment used in production. Some production operations may have a very high cost per hectare, but are conducted over a relatively small number of hectares. For example, the planting of cultured seed cane, which has an estimated total cost of \$1,361 per hectare to purchase and load the seed cane and another \$763 per hectare cost to hand plant the seed cane in the field, is the most expensive sugarcane farm operation on a per hectare basis, but is conducted on only a small number of hectares each year. Harvesting, on the other hand, is a relatively lower cost operation, with variable and total costs estimated at \$358 and \$595 per hectare, respectively. However, for a typical farm in Louisiana which harvests sugarcane through a third stubble crop, harvest operations would be conducted on approximately 76.1 percent of the total farm area, accounting for 32.5 percent of total farm production costs. By accounting for such a large share of total farm costs, improvements in harvesting operations and efficiency would have a significant impact on reducing farm production costs.

Table 1. Estimated sugarcane production costs for Louisiana, 2007

Production phase	Percent of total farm area	Variable cost per hectare	Total cost per hectare	Percent of total cost
	(%)	(dollars/ha)	(dollars/ha)	(%)
Fallow / seed bed preparation	20.0	366	600	8.9
Cultured seed cane	0.1	1,334	1,361	0.6
Hand planting cultured seed cane	0.1	566	763	0.4
Harvesting whole stalk seed cane	0.4	165	294	0.8
Mechanical planting	19.4	501	650	9.0
Plant cane field operations	20.0	534	652	9.3
First stubble field operations	20.0	758	892	12.8
Second stubble field operations	20.0	776	909	13.0
Third stubble field operations	20.0	776	909	13.0
Harvest for sugar operations	76.1	358	595	32.5

Source: Salassi and Deliberto, 2007.

Estimates of harvests costs from various sugarcane producing regions have been published, either on an annual or periodic basis. Comparison of published estimates generally indicate that sugarcane harvest costs in Louisiana are significantly higher than harvest costs in major sugarcane producing regions of the world. Results from a study published in 2006 showed average sugarcane harvest costs in Louisiana, based on a survey of growers, at \$6.45 per metric ton (Salassi, 2006). An earlier South African study evaluating performance and utilization of sugarcane harvest machinery reported harvest costs ranging from \$3.23 to \$3.87 per ton of sugarcane harvested (Meyer, 1999). A study which evaluated a fully mechanized combine harvest system for several farms in South Africa reported harvest and infield transport costs ranging from \$2.14 to \$2.92 per ton (Meyer et al., 2000). Two more recent studies from Australia report harvest costs ranging between \$3.69 and \$5.01 per ton for the 2000 harvest season (Higgins and Muchow, 2002) and average harvest costs ranging from \$3.18 to \$5.39 per ton over the 1996 to 2002 period (Muscat and Agnew, 2004).

One factor which has a significant impact on sugarcane harvests costs is the number of hectares over which a machine is utilized. Fixed harvest costs are associated with the annual costs of owning the harvest machine. These costs are primarily comprised of depreciation and interest on investment charges, but can also include insurance and other fixed charge expenses. Fixed cost per unit, either on a per hectare or per tons harvested basis, are reduced as the harvester is used over more hectares. Operation of harvesters over the course of harvest season at less than full harvest capacity will cause fixed costs per unit to be higher.

Another significant factor which affects sugarcane per-hectare harvest costs is in-field waiting time incurred by harvest crews waiting for transport trucks to return. As the number of trucks arriving at a mill to unload harvested sugarcane within a given time period increases, the time required for a truck to be sampled at the core lab, unload in the mill yard, and return to the farm also increases. In some cases, the congestion and resulting increased turnaround time at the mill causes harvest operations at the farm to stop. This possible waiting time increases actual

harvest costs per hectare primarily due to the additional fuel and labor costs associated with the stoppage of harvest operations.

Considerable research has been conducted in other sugarcane-producing countries focusing primarily on optimizing harvest and transport operations. This work has included optimization of harvest group scheduling in Australia (Higgins, 2002), simulation of harvest to mill delivery systems in South Africa (Hansen et al., 2002), economic case study analysis of regional harvest operations in Australia (Higgins et al., 2004), as well as PC-based decision support tools to evaluate alternative harvest and transport situations in Thailand (Singh and Pathak, 1994). Little research has been conducted on the impact of waiting time at the farm on harvest costs as well as scheduling harvest and mill delivery operations to reduce waiting time impacts. The objective of the research study presented here was to estimate the impact of waiting time on harvest costs per hectare in Louisiana and to develop a modeling framework which had the capability to optimally schedule sugarcane harvest and transport operations with the goal of minimizing waiting time at the farm or mill.

MATERIALS AND METHODS

The impact of increased waiting time at the farm during harvest operations on sugarcane harvest costs was estimated by using published cost estimates and adjusting the performance rate factors for the harvester and wagons to reflect increased waiting time. Current estimated harvest costs for 2007 were taken from a report by Salassi and Deliberto (2007). Specific operations itemized in the budget included a combine harvester along with three support tractor and wagon sets. The performance rate specified for the harvester and wagons was 1.73 hours per hectare, representing the time required to harvest and load into wagons one hectare of sugarcane.

In order to evaluate the impact of increases in waiting time on harvest cost, an analysis was conducted to estimate changes in variable harvest cost resulting from increased waiting time by adjusting the performance rate of harvest operations. This analysis focused on the fuel and labor costs associated with the harvester and tractors and wagons since these are the cost items most directly impacted by waiting time. To simulate a range of possible waiting times, harvest time was arbitrarily increased from 12.3 to 49.4 minutes per hectare (five to twenty minutes per acre) to represent the stoppage of harvest operations to wait for a truck to arrive. This resulted in an adjustment of the harvest performance rate from 1.73 hours per hectare to values between a range of 1.93 and 2.55 hours per hectare. Fuel consumption of the harvester and tractors were adjusted using a factor of 40 percent to reflect idle speed. Labor for the combine harvester operator was charged at a rate of \$15.30 per hour and labor for tractor operators was charged at a rate of \$9.60 per hour.

Optimization of harvest and transport operations to minimize waiting time was accomplished through the development of a sugarcane harvest and transport scheduling model. A mathematical programming model was developed which was capable of determining an optimal harvest schedule for a group of farms delivering to a common mill with the objective of minimizing the waiting time of trucks delivering to the mill. The mathematical programming model simulates delivery of harvested sugarcane by truck and trailer over the course of one day during the grinding season. Alternative harvest starting times were included to represent

$$(4) \quad \begin{aligned} & A1UM_5 + B1UM_5 + A1UM_6 + B1UM_6 + A1UM_7 + B1UM_7 + A1UM_8 + A2UM_8 \\ & + B1UM_8 + B2UM_8 + C1UM_6 + C1UM_7 + C1UM_8 + D1UM_6 + D1UM_7 \\ & + D1UM_8 + E1UM_7 + E1UM_8 + F1UM_7 + F1UM_8 + DFUM_2 - EXUM_2 = 30 \end{aligned}$$

$$(5) \quad \begin{aligned} & A1UM_5 + A1UM_6 + B1UM_5 + B1UM_6 + C1UM_6 + C1UM_7 + C1UM_8 \\ & + D1UM_6 + D1UM_7 + D1UM_8 + E1UM_7 + E1UM_8 + E1UM_9 + E1UM_{10} \\ & + F1UM_7 + F1UM_8 + F1UM_9 + F1UM_{10} - TRUCKS \leq 0 \end{aligned}$$

The objective function minimizes the number of truckloads of harvested sugarcane unloading in a given hour (h) which exceed an hourly target of 30 trucks ($EXUM_h$) and are summed over a 14-hour delivery time period. Actual deliveries were over a 12.5 hour time frame, hence the 30 truck per hour target was determined by dividing 360 daily loads by an approximate 12 hour delivery time frame. This objective function is modeled to serve as a proxy for minimization of truck waiting time at the mill by spreading hourly deliveries more evenly over the daily mill delivery time window.

Constraint set 1 ensures that when one or more farms in any farm group (A-F) start harvesting the first truckload under a given harvest schedule, that those farms will continue with that harvest schedule through the remaining truckloads. Group A represents farms with six daily loads and are located 15 minutes from the mill. The variable $A1ST_a$ represents the number of group A farms starting to harvest their first daily load in time period a and $A2ST_{a+3}$ represents the same number of farms in group A starting to harvest their second daily load in time period $a+3$. Representative constraints for farm groups A and B are shown here. Similar constraints were also included in the model for the other farm groups, C through F. Constraint set 2 includes six constraints where the number of farms in each group to be simulated are specified by the right-hand-side value of each constraint.

For each possible harvest schedule, a set of constraints (constraint set 3) were included in the model to specify in what time period a particular truckload would be unloading at the mill given the time period when harvest of that load was started. For example, if $A1ST_a$ represents the time period in which the first load of Group A was harvested, $A1UM_{a+4}$ represents the time period when that truckload would be unloaded at the mill. The model assumes that a particular truckload would be unloaded at the mill in the immediate time period following its travel to the mill. Representative mill unloading constraints for farm groups A and B are shown here. Similar constraints were included for the other four farm groups.

Constraint set 4 sums the total number of trucks unloading at the mill in a given hour and determines the deficit or excess loads from a target of 30 truckloads per hour. The specific constraint shown here represents trucks unloaded at the mill during the second hour of delivery. Variables representing unloading at the mill in periods 5, 6, 7 and 8 from all six possible farm groups are included and set equal to the hourly delivery and unloading target of 30 trucks per hour. The variable $DFUM_2$ measures the number of trucks unloading in the second hour in deficit of the 30 per hour target. The variable $EXUM_2$ measures the number of trucks unloading

in the second hour in excess of the 30 per hour target. These constraints are continued through the fourteenth delivery hour.

The final set of constraints in the model (constraint set 5) counts the number of total trucks in use during each 15-minute time period. Variables included in each constraint represent trucks traveling to farms, trucks being loaded at farms, trucks traveling back to the mill, and trucks being unloaded at the mill. The variable *TRUCKS* included in each constraint will represent the minimum number of trucks required to achieve all deliveries for the specific harvest schedule determined by the optimal solution. The specific constraint shown here represents trucks in use during the first 15-minute period of the day. A total of 54 constraints in the model tabulated trucks required during each period. The full harvest schedule model included an objective function which was minimized subject to 176 constraints as defined above.

RESULTS AND DISCUSSION

Results of the harvest cost analysis of increased waiting time are shown in Table 2. Estimated harvest performance rates and variable harvest costs are presented for five cases. The first case represents harvest operations with no waiting time. It requires 1.73 hours of operation to harvest one hectare with an estimated variable fuel and labor cost of \$211.62 per hectare. Simulated increased harvest time due to waiting for trucks to arrive at the harvest location were evaluated for four cases. Waiting times of 12.3 to 49.4 minutes per hectare were used to adjust harvest performance rates and to estimate increased harvest costs. For example, an addition of 12.3 minutes per hectare of waiting time changes the harvest performance rate to 1.93 hours per hectare with a resulting variable harvest cost of \$227.06 per hectare. This increased waiting time results in an increase in harvest costs of \$15.44 per hectare. By contrast, a waiting time of 49.4 minutes per hectare increases harvest costs by \$63.65 per hectare. Over all situations evaluated, the impact of waiting on harvest costs resulted in an average increase in variable harvest costs of approximately \$1.30 per hectare for every minute of additional waiting time.

Table 2. Impact of increased waiting time on sugarcane harvest costs, 2007

Increased waiting time <i>(minutes per ha)</i>	Harvest performance rate <i>(hours/ha)</i>	Variable	Change in harvest cost	
		cost per hectare ¹ <i>(dollars/ha)</i>	<i>(dollars/ha)</i>	<i>(%)</i>
0	1.73	211.62	--	--
12.3	1.93	227.06	15.44	7.3
24.7	2.15	244.41	32.79	15.5
37.0	2.35	259.83	48.21	22.8
49.4	2.55	275.27	63.65	30.1

¹Fuel and labor costs of harvester and tractor/wagon units only.

The harvest scheduling mathematical programming model was used to design an optimal harvest schedule for a typical distribution of sugarcane being shipped to a common mill. The specific example situation evaluated is presented in Table 3. Approximately 80 percent of the harvested sugarcane is within close proximity (15 minutes) from the mill, farm groups A and B.

The remaining 20 percent of harvested sugarcane is located 30 and 45 minutes from the mill across farm groups C, D, E and F.

Table 3. Simulation of farm/tonnage distribution shipping to a common mill per day

	Sugarcane farm groups					
	A	B	C	D	E	F
Number of farms	24	12	3	2	3	1
Daily loads	6	12	6	12	6	12
Total daily loads	144	144	18	24	18	12
Total daily tonnage ¹	3,657	3,657	457	610	457	305

¹Simulation of 360 daily loads at 25.4 metric tons per load, 9,143 metric tons delivered per day. Farm group A = six loads per day, 15 minutes from the mill, farm group B = twelve loads per day, 15 minutes from the mill, farm group C = six loads per day, 30 minutes from the mill, farm group D = twelve loads per day, 30 minutes from the mill, farm group E = six loads per day, 45 minutes from the mill, farm group F = twelve loads per day, 45 minutes from the mill.

The optimal harvest and delivery schedule for the group of farms simulated and designed by the mathematical programming model is shown in Table 4. This harvest schedule was developed with the objective of distributing mill delivery of harvested sugarcane more evenly across the delivery time window per day. Results show exactly how many farms should start harvesting at specific times to achieve the objective of minimizing truck waiting time at the mill. More specifically, the mathematical programming results indicate that to achieve the objective stated, farms should start harvest operations at the specific times as follows: group A – 6:15 a.m. to 1:45 p.m., group B – 6:00 a.m. to 9:30 a.m., group C – 2:00 p.m., group D – 9:30 a.m., group E – 2:00 p.m., and group F – 9:30 a.m.

Table 4. Optimal harvest schedules to minimize waiting time by farm group¹

Harvest starting time	Number of farms					
	A	B	C	D	E	F
6:00 a.m.	--	4	--	--	--	--
6:15 a.m.	9	2	--	--	--	--
6:30 a.m.	--	4	--	--	--	--
8:00 a.m.	3	--	--	--	--	--
9:30 a.m.	--	2	--	2	--	1
11:15 a.m.	3	--	--	--	--	--
12:00 p.m.	1	--	--	--	--	--
1:30 p.m.	1	--	--	--	--	--
1:45 p.m.	7	--	--	--	--	--
2:00 p.m.	--	--	3	--	3	--

¹Farm group A = six loads per day, 15 minutes from the mill, farm group B = twelve loads per day, 15 minutes from the mill, farm group C = six loads per day, 30 minutes from the mill, farm group D = twelve loads per day, 30 minutes from the mill, farm group E = six loads per day, 45 minutes from the mill, farm group F = twelve loads per day, 45 minutes from the mill.

The estimated optimal delivery schedule from the mathematical programming results for each group of farms is shown in Table 5. Results show the estimated number of trucks unloading at the mill each hour from each farm group with a target of 30 trucks per hour across all farms over the delivery time window. Only nine individual hourly deliveries exceeded the 30 per hour goal and these deliveries occurred in the tenth hour. A total of 69 trucks was estimated to be required to cover all deliveries across all farms. For comparison purposes, a second mathematical programming run was simulated with the assumption that all farms would start harvest operations at 6:00 a.m. The estimated mill deliveries for this case are shown in the last column of Table 5. Deliveries for this case, which illustrates the problem faced by mills with no harvest scheduling, are concentrated in the earlier hours of the day. In addition, because the harvest operations are not coordinated in an optimal manner, it would take approximately 30 additional trucks per day to deliver the same quantity of harvested sugarcane.

Table 5. Estimated optimal mill delivery schedule by farm group¹

Delivery hour	Daily loads unloading at the mill by hour							Comparative Nonoptimal Total
	A	B	C	D	E	F	Total	
1	--	--	--	--	--	--	--	--
2	9	14	--	--	--	--	23	81
3	18	12	--	--	--	--	30	50
4	15	14	--	--	--	--	29	49
5	12	16	--	2	--	--	30	81
6	12	14	--	2	--	2	30	23
7	9	18	--	2	--	1	30	16
8	8	16	--	4	--	1	29	27
9	12	14	--	2	--	2	30	17
10	12	18	3	2	3	1	39	16
11	14	2	6	4	3	1	30	--
12	15	2	3	2	6	2	30	--
13	8	4	3	2	3	1	21	--
14	--	--	3	2	3	1	9	--
Total	144	144	18	24	18	12	360	360

¹Farm group A = six loads per day, 15 minutes from the mill, farm group B = twelve loads per day, 15 minutes from the mill, farm group C = six loads per day, 30 minutes from the mill, farm group D = twelve loads per day, 30 minutes from the mill, farm group E = six loads per day, 45 minutes from the mill, farm group F = twelve loads per day, 45 minutes from the mill.

CONCLUSIONS

The harvest of sugarcane in Louisiana represents a major cost item in the production of the crop in the state. Estimation of current sugarcane harvest costs as well as economic evaluation of the impact of various factors on the performance and cost of this production phase are important to growers in conducting these harvest operations as efficient and cost effective as possible. As unloading time at the mill is a primary factor influencing the efficiency of harvest

operations on the farm, developing harvest schedules for groups of farms to minimize waiting time at the mill is important for efficient and cost effective operations at both the farm and mill.

The general objective of this research project was to estimate the impact of increased waiting time at the farm for trucks to arrive from the mill on harvest costs and to develop a modeling framework, having the capability to optimally schedule harvest operations across farms delivering harvested sugarcane to a common mill, which could be applied to a specified mill operation situation. A couple of major conclusions can be drawn from the research conducted in this study. First, harvest costs were estimated to increase by up to \$1.30 per hectare for every minute spent delaying harvest to wait for trucks to arrive at the farm site. This cost can vary greatly depending upon the specific harvest situation, but results presented here illustrates that inefficiency in harvest transport operations can impose a real cost on sugarcane growers. Secondly, the mathematical programming model developed here provides a framework for scheduling sugarcane harvest at the farm and delivery to the mill with goal of distributing mill deliveries out more evenly over the delivery time window, thereby indirectly reducing truck waiting time.

Future areas of research related to this project would include the actual implementation of the type of mill-wide harvest schedules developed in this research. Data could be collected on current harvest and delivery operations to a specific mill and then evaluate the impact of implementing a coordinated harvest schedule for all farms delivering to that particular mill. Cost efficiencies and savings could be evaluated at both the farm and mill level.

REFERENCES CITED

- Hansen, A.C., A.J. Barnes, and P.W.L. Lyne. 2002. Simulation modeling of sugarcane harvest-to-mill delivery systems. *Trans. ASAE* 45(3): 531-538.
- Higgins, A. 2002. Australian sugar mills optimize harvester rosters to improve production. *Interfaces* 32(3):15-25.
- Higgins, A.J., G. Antony, G. Sandell, I. Davies, D. Prestwidge, and B. Andrew. 2004. A framework for integrating a complex harvesting and transport system for sugar production. *Agricultural Systems* 82: 99-115.
- Higgins, A.J., and R.C. Muchow. 2002. Assessing the potential benefits of alternative cane supply arrangements in the Australian sugar industry. *Agricultural Systems* 76: 623-638.
- Meyer, E. 1999. Improving performance and utilization to minimize machinery costs. *Int. Soc. Sugar Cane Tech., Proceedings of the XXIII ISSCT Congress* 11: 155-163.
- Meyer, E., K. Domleo, J. Bliss, and G.W. Maher. 2000. Assessing the viability of a fully mechanized harvesting operation for a large sugarcane estate. *Proc. S. Afr. Technol. Assoc.* 74: 188-191.

Salassi and Barker: Reducing harvest costs through coordinated sugarcane harvest and transport operations in Louisiana

Muscat, J., and J. Agnew. 2004. Oakenden harvesting company: Delivering harvesting best practice. Aust. Soc. Sugar Cane Tech., 26th Annual Conference.

Salassi, M.E. 2006. Survey Estimation of Sugarcane Chopper Harvester Costs in Louisiana. J. Ameri. Soc. Sugar Cane Techno. 26: 38-43.

Salassi, Michael E., and Michael Deliberto. 2007. Projected Commodity Costs and Returns, Sugarcane, Louisiana, Department of Agricultural Economics and Agribusiness, Louisiana State University Agricultural Center, A.E.A. Information Series No. 245.

Singh, G., and B.K. Pathak. 1994. Decision support system for mechanical harvesting and transportation of sugarcane in Thailand. Computers and Electronics in Agriculture 11:173-182.