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A management assistance package for optimising harvester/infield transport productivity

by
D R Ridge and J Powell*
Queensland Caneharvesters Association

SD98005

Principal Investigator:

Mr D R Ridge
Principal Research Officer
BSES
PO Box 651
BUNDABERG QLD 4670
Phone: (07) 41593228
Fax: (07) 41593383

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1. SUMMARY

The two year project to develop a management assistance package for optimising harvester/infield transport productivity was completed during 1997.

The project involved several phases:- initial data collection from contractors; development of a model to utilise this data in predicting harvest-transport costs and throughput; utilisation of the model in sensitivity analysis of throughput and costs for different scenarios; and, conversion of the model to a user-friendly format for use by various sectors of the industry.

Data collection from contractors included economic data for 57 groups from Tully, Ingham, Burdekin, Proserpine and Mackay and logbook data on group operating conditions and throughput from a separate panel of contractors. In addition observations were carried out to obtain data on harvester pour rates, turn times, haulout travel speed and unloading times. Capital costs and fuel usage figures were also obtained from harvester and tractor manufacturers to supplement survey data.

In developing the final harvest-transport model the first step was an Excel spreadsheet based model utilising throughput and cost sub-models to develop a cost and throughput summary for particular scenarios. A simple model was also developed in the program 'I Think' to visually demonstrate the dynamics of harvesting and transport. While this feature was attractive the model was less suitable for obtaining hard data on costs and throughput and it was decided to proceed with a menu driven model in Visual Basic and Excel. The final model allows field, harvester, transport, wages and maintenance components to be entered for a given scenario from separate menus, with background economic and throughput data being called up automatically by the program. This model is now available and will be modified where appropriate to improve accuracy and ease of use.

Output of the model has been checked against average economic data from the contractor survey and the fuel usage sub-routine was modified to improve prediction of fuel costs. There is now good agreement with average survey figures for wages, fuel and maintenance. A similar comparison of throughput predictions with logbook data shows relatively good agreement, with the model on average indicating a 10% higher throughput. It is felt that some of the disagreement is due to difficulty in estimating average operating parameters for harvester groups.

The model has been used for assessing factors affecting optimising of harvester/haulout configurations; for assessing the impact of changes to harvest organisation; and for evaluating the impact of field presentation and crop condition on harvest/transport costs and throughput.

Haulout capacity and operating speed between the field and drop-off points was shown to be important in reducing costs and increasing throughput for long hauls.

The model was also used to predict group sizes for optimum use of particular haulout sizes and numbers and this exercise highlighted the benefit from larger capacity haulouts.

It also showed that costs are significantly higher where haulout capacity (and harvester capacity) is under-utilised because of mismatching of haulouts to the operating conditions.

Changes in harvest organisation such as shift harvesting and continuous crushing were shown to increase throughput and reduce costs significantly where group sizes were changed to take advantage of the additional cutting time. This would not be the case if group sizes remained constant. The potential reduction in costs with 'continuous cutting' and double or three shift harvesting are more significant than those achievable through better matching of harvester and transport capacity.

Changes in row length, crop size, headland width and from burnt to green cane were shown to have less impact on costs and throughput than haul distance, harvest organisation and inadequate transport. The exceptions were the extremes of very short rows coupled with narrow headlands and small crop size; and large, lodged green cane as in the Burdekin and northern New South Wales.

The model has been demonstrated to a range of contractors and used to provide guidance in purchasing equipment and costing the impact of long haul distances, short rows and small crop sizes. It has provided a useful tool for such exercises.

2. BACKGROUND

Cane harvesting and infield transport represent an annual industry cost of approximately $200 million. The annual capital component of this is estimated to be approximately $70 million. The capital investment of an individual harvesting group for modern harvesting and infield transport equipment is between $500 000 and $750 000. It is therefore essential that equipment be used efficiently to give an adequate return on capital investment and ensure long-term viability of the harvesting sector of the industry.

Previous research by Ridge and Dick (1985) and Powell (1992) indicates that there is considerable scope for improving harvesting efficiency. This may involve an increase in group size in order to sustain capital investment and improving the output of harvesting groups for their particular operating conditions. Areas for improvement include better matching of harvesting and infield transport equipment to operating conditions, minimising travel distance to delivery points, longer cane rows, better headlands and access roads, and adequate crop tonnages per hectare. To date there has been no readily available method of assessing the reduction in costs and the improved throughput if these problems are addressed.

Important changes have been implemented or proposed for the harvesting sector in recent years. These include continuous crushing, shift harvesting, larger mill bin sizes, and changes in the number and distribution of mill delivery points. A model which allows estimation of throughput and costs for different scenarios is essential for efficient planning of such changes, and minimising any negative effects on the harvesting sector.

There have been significant improvements in output per unit capital investment in New South Wales where harvest/transport operations have been rationalised. It is envisaged that similar benefits can be achieved throughout the Australian industry resulting in improved industry profitability.

3. OBJECTIVES

- Develop a computer-based management system to predict operating requirements, throughput and costs over a wide range of harvester and haulout operating conditions.
- Optimise harvester/haulout configurations, using the model.
- Evaluate the impact of continuous crushing, shift harvesting and changes to mill bin sizes and siding distribution on costs and throughput.
- Quantify and demonstrate the benefits from improved field layout and crop presentation.

4. METHODOLOGY

The project involved several phases:- initial data collection from contractors; development of a model to utilise this data in predicting group tonnage output and costs for particular conditions; utilisation of the model in sensitivity analysis of throughput and costs with varying field conditions; conversion of the model to a user-friendly format for use by various sectors of the industry.

4.1 Contractor survey

4.1.1 Economic data

A survey of contractor costs and returns was carried out in the 1993 and 1994 seasons in the Mackay-Proserpine, Burdekin, Ingham and Tully districts. Initially ten contractors were targeted in each district but additional figures were obtained in the Ingham, Mackay and Burdekin areas. Detailed survey forms were given to each contractor and where possible these were filled out in consultation with the contractor. Survey form details are given in Appendix 1. Full details were obtained on equipment used; hours spent in different operations such as harvesting, servicing, burning and waiting for bins; equipment age, value, repair costs and fuel use; overhead costs such as registration, insurance, electricity, telephone, interest on loans, bank charges and accounting fees; and, harvest throughput parameters including tonnes per hour, haulout distance and bin weights.

The survey data and supplementary data on capital costs of machinery and fuel usage of harvesters and haulouts was used to formulate a cost model for harvesting and transport of cane.

4.2 Model development

4.2.1 Excel spreadsheet model

Initially a throughput model developed by BSES and an economic model developed by Queensland Canegrowers were combined in a series of Excel spreadsheets to allow prediction of cutting rates and costs for particular field conditions and equipment combinations. A number of refinements were made to improve flexibility and generality of the model so that it could handle most equipment and manpower combinations encountered in the field. This included a simplified approach for different sized haulouts where haulout size was averaged.

Output of the throughput component of the model was checked against logbook data and cost outputs against industry survey data.

4.2.2 'I Think' model

In addition to the Excel model a simple model was developed using an interactive program called 'I Think'. This program allows visual illustration of harvesting and haulout dynamics in the field. Some simple economic calculations were also incorporated in this model.

4.2.3 User-friendly visual basic model

A requirement for contractor use of the harvest-transport model is that it be user-friendly and protected from accidental alteration. A user-friendly version of the model based on the Excel spreadsheet framework was therefore developed using Visual Basic. This includes simple menu driven options, which can be selected by the model user to suit particular operating conditions.

4.3 Use of the model

4.3.1 Optimising harvester/haulout configurations

The model was used to determine optimum group sizes for particular harvest/haulout combinations assuming average operating conditions (crop sizes, haul distances, field conditions and haulout travel speeds). A maximum single shift length of 10 hours was assumed, allowing for normal lost time each day.

These calculations also allowed assessment of the impact of haulout size and number on costs and throughput; assessment of benefits from increased haulout speed; and assessment of the importance of faster haulout unloading speed.

4.3.2 Assessing of impact of changes to harvest organisation

4.3.2.1 Mill bin sizes

The impact of changes to mill bin sizes was assessed from the standpoint of faster unloading at the mill sidings, assuming that larger bins did not leave the siding.

4.3.2.2 Siding distribution

The effect of changes to siding distribution was assessed by looking at the impact of haul distance on harvester/haulout throughput and/or costs of operation.

4.3.2.3 Shift harvesting

The impact of double or three shift harvesting on throughput and costs was assessed by comparing several scenarios:

- a single daily shift of 10 hours
- two shifts of 8 hours
- two shifts of 10 hours
- three shifts of 8 hours

4.3.2.4 Continuous crushing

The impact of continuous crushing on potential throughput and costs was assessed by comparing several scenarios. These included:

- conventional operation of 5 days in 7
- operation for 12, 13 and 14 days in 14

4.3.3 Field layout and crop presentation

4.3.3.1 Row length

Row length effects were assessed by determining throughput and costs for a range of row lengths typical of those encountered in the field. For this assessment the model was modified to include dead travel time within the field entering and leaving cane rows.

4.3.3.2 Crop size

The model includes estimates of crop size on harvester pour rates and this allowed the assessment of crop size effects on throughput and costs.

4.3.3.3 Green v burnt cane

The model also includes estimates of pour rates in green and burnt cane for different crop sizes and an allowance for increased maintenance costs for the harvester in green cane. Changes in haulout capacity in green cane due to higher EM levels can also be allowed for. These factors were used to compare throughput and costs in green and burnt cane.

4.3.3.4 Turning at end of rows

The impact of headland width and severe crop lodging on the haulout turn time and therefore on throughput and costs was assessed by adjusting turn time for several scenarios:

- normal turns by the harvester and haulout
- cutting in by the harvester because of narrow headlands
- rapid turn round involving a full track harvester and an articulated haulout capable of backing down rows
- one way cutting in lodged cane

5. RESULTS AND DISCUSSION

5.1 Contractor survey

5.1.1 Economic data

Survey data was obtained from a total of 57 contractors with the following break up between districts: Tully (6), Ingham (14), Burdekin (15), Proserpine (2), and Mackay (20). Groups size ranged from 20 000 t to 102 000 t (mean 46 290) with a price range estimate for green cane harvesting and hauling of $5.80 to $7.20 per tonne (mean $6.11). For the Burdekin price estimates for harvesting averaged $3.12 per tonne and hauling $2.05 per tonne.

Variable cost data from the survey was summarised as three group size categories (Table 1).

TABLE 1
Variable cost comparisons for three group size categories in $ per tonne

Category	Wages	Maintenance	Fuel
>35 000 t	0.94 (0.48-1.79)	0.94 (0.55-1.56)	0.45 (0.26-0.93)
35 000 – 55 000 t	0.93 (0.73-1.25)	0.95 (0.73-1.25)	0.66 (0.35-0.99)
>55 000 t	1.14 (0.55-1.66)	0.95 (0.55-1.66)	0.58 (0.30-0.91)

A selected panel of contractors from Ingham (green cane) and Mackay, Proserpine, Ayr (burnt cane) was used to compare maintenance figures for green and burnt cane. This showed an increase in maintenance costs of approximately 50% in green cane and this differential was used for harvesters in the harvest-transport cost model.

Several average maintenance categories in burnt cane were derived for different harvester ages and group sizes. These are summarised in Table 2.

TABLE 2
Maintenance categories for harvesters

Age of harvester (years)	Maintenance $/tonne	
	full track	wheeled
1-5	0.50	0.30
6-10	0.90	0.50
11-15	1.00	0.75

Maintenance for haulout equipment was usually not separated by contractors and estimates were derived from manufacturers comments (Table 3).

TABLE 3
Maintenance categories for haulouts

Self-propelled		Tractor		Trailer	
age	$/tonne	age	$/tonne	type	$/tonne
1-5	0.10	1-5	0.05	RO-RO	0.15
6-10	0.125	6-10	0.075	Tipper	0.030
11-15	0.15	11-15	0.10	Elevator	0.10

Labour for maintenance is computed separately in the model and is a combination of pre-season labour and within season maintenance. Some of the latter is absorbed in the normal working day. The annual labour in man-days is entered specifically for each particular situation. Some approximate guidelines are given in Table 4.

TABLE 4
Estimated annual labour for maintenance in man days
For different group sizes

Group size (tonnes)	Maintenance labour (man days)
≤30 000	40
31 000 – 60 000	70
61 000 – 90 000	90
>90 000	100

Initial capital costs were derived for harvesters of different ages from survey data and published resale values of second-hand harvesters. These were incorporated in the model by appropriate discounting of the new prices over 15 years to a final value of $10 000. For older model harvesters present value was considered as the new value and discounting was over 5 years to 25% of the current value. Similarly haulout capital values were calculated by discounting new values to a nominal salvage value of $5 000 - $10 000 over a period of 15 years.

Depreciation of harvesters is estimated as 75% of current value over a period of 5 years. Haulouts are depreciated to 10% of their initial value over 15 years.

To allow calculation of the impact of harvester and haulout type and haulout distances on fuel usage the figures in Table 5 were obtained. These include an estimate of full working fuel usage and fuel usage while waiting with the engine running. For the harvester fuel waiting is taken as the mean of fast idle with the feed train running and slow idle with the feed train turned off. For haulouts fuel usage of different sized motors at full revolutions was available from manufacturers and an estimate was made of average operating revolutions. From comparisons with a limited number of contractor figures for haulout fuel usage and more extensive figures on total harvesting fuel use a figure of 40% of full revolutions was adopted for average haulout travel.

TABLE 5
Estimated fuel usage for different types of harvesters and haulouts

Harvester/Prime mover type	Capacity (t)	Fuel L/h	
		operating	waiting
Truck	6	8*	4
	8-12	10*	5
Tractor	6	8*	4
	8-10	10*	5
	12-14	12*	6
Self-propelled	8-10	10*	5
	12-14	12*	6
Austoft, Cameco		58.5	15**
Toft 4000-6000		50	12**
MF205, 305		40	10**
MF102, 105, 201		28	7**

* Based on average operating conditions of 40% of full motor power use
** Mean of fast idle with feed train running and slow idle with feed train turned off (supplied by manufacturer)

Typical model figures for wages, maintenance and fuel usage with different sized groups are given in Table 6. These compare well with survey figures in Table 1 where wages are likely to have been underestimated for smaller groups.

TABLE 6
Model figures for wages, maintenance and fuel usage
For a range of group sizes

Group size (t)	Wages ($/tonne)	Maintenance ($/tonne)	Fuel ($/tonne)
30 000	1.43	1.00	0.67
45 000	1.32	1.02	0.55
60 000	1.13	1.00	0.53

* flat wage rate, 30 000 t with harvester and 2x8 tonne tipper elevators; 45 000 t with new harvester and 3x8 tonne tipper elevators: 60 000 t with 3* 12 t tipper elevators; 85 t/ha crop size, 300 m rows, 50% green cane.

In addition survey data was used to obtain average figures for incidental costs such as insurance, electricity, accounting costs, registration and these are summarised in Table 7. There is some variation in these figures but the variations do not have a large impact on overall group costs.

TABLE 7
Harvesting group incidental costs

Item	Total annual cost ($)
Insurance	3 000
Accounting	600
Telephone	500
Bank charges	200
Legal expenses	400
Registrations	1 500
Electricity	250
Membership fees	250
Other	200
Sundries	120
Total	**7 020**

5.1.2 Throughput data

In development of the harvest-transport throughput model field observations of pour rate, turning times, haulout travel speed and haulout unloading time were used to develop suitable model input options.

5.1.2.1 Pour rate

Pour rates in different sized crops were combined to give a best estimate for particular crop conditions. The model recognises reduced throughput in small crops due to harvester speed restrictions (maximum of 13.5 kph adopted for wheeled machines and 9.5 kph for full track machines). It also recognises reduced throughput in large, lodged crops, particularly in green cane. Pour rates used in the model are shown in Table 8. Fitted equations for calculating pour rates are as follows:

BURNT/WHEELED (BTWH) = $0.34 + 2.381\ \text{YIELD} - 0.00942\ (\text{YIELD})^2$
BURNT/FULL TRACK (BTFT) = $-51.73 + 3.037\ \text{YIELD} - 0.01143\ (\text{YIELD})^2$
GREEN/WHEELED (GRWH) = $16.25 + 1.5796\ \text{YIELD} - 0.0071\ (\text{YIELD})^2$
GREEN/FULL TRACK (GRFT) = $3.74 + 1.77\ \text{YIELD} - 0.00776\ (\text{YIELD})^2$

These may be combined to calculate average pour rate according to the percentage of the crop cut green.

POUR RATE = 0.01 {(BTWH*% BURNT) + (GRWH*%GREEN)}
Or = 0.01 {(BTFT*%BURNT) + (GRFT*%GREEN)}

TABLE 8
Comparison of pour rates in green and burnt cane
For a range of crop sizes

Yield t/ha	Pour rate* G%B	Pour rate t/hour			
		Green		Burnt	
		wheeled	full track	wheeled	full track
180	55	70.5	70.5	124.2	124.2
160	60	87.1	87.1	139.4	139.4
140	64	97.6	97.6	149.1	149.1
120	67	102.6	102.6	151.2	151.2
100	72	103.8	103.8	144.3	142.5
80	76	98.8	98.8	130.2	114.0
60	80	86.4	85.5	108.9	85.5
40	82	66.0	57.0**	80.8***	57.0**

* Approximate only
** 9.5 kph
*** 13.5 kph

5.1.2.2 Turning times

Differences in turning times depend on the width of headlands, type of haulout equipment and harvester and severity of crop lodging. A range of conditions were recognised as options in the model as indicated in Table 9.

TABLE 9
Turn times for a range of field conditions

Condition	Turn time (minutes)
Normal-wide headland	0.75
Cutting in-narrow headland	1.00
Haulout reversing	0.5
One way cutting	*

* computed value depending on row length and harvester non-cutting travel speed

5.1.2.3 Haulout travel speed

A range of haulout speeds was recorded depending on haulout type and load. The default values used in the model are 30 kph empty and 15 kph loaded but these can be adjusted as required for different situations.

5.1.2.4 Haulout unloading time

The haulout unloading time varies significantly depending on the unloading system, operator skill and mill bin size. The model uses some typical figures derived by timing unloading of different types of haulouts in the field (Table 10).

TABLE 10
Typical unloading times for different haulout sizes and systems

Haulout type	Unloading time (minutes)
Single tipper	0.75
Double tipper	1.5
Tipper-elevator/9 tonne	1.75
Tipper-elevator/12 tonne	2.5
Austoft tipper-elevator/9 tonne	2.5
Roll on-roll off/single	2.0
Roll on-roll off/double	3.0
Roll on-roll off/triple	4.0

For mixed haulout combinations the model computes average unloading time and average bin size and uses these in throughput calculations.

5.1.2.5 Logbook data

A typical sample of group throughput data provided from logbooks completed by contractors is given in Table 11, together with model throughput estimates for the same parameters.

The agreement between the two is only moderate but this should be considered in the context of possible inaccuracies in some logbook data (eg average row length, haul distance) and uncertainty about field conditions such as headland widths, degree of lodging, suitability of varieties for green cane harvesting and haulout travel speeds. In general the model appears to overestimate tonnes per engine hour by approximately 10%.

TABLE 11
Comparison of logbook data with model predictions of harvester engine hours for the 1994 season

District	% green	Av crop size t/ha	1994 tonnes	Haul distance km	Row length m	Haulout type	Tonnes per engine hour	
							Log	Predicted
Burdekin	0	110	52 000	2.8	400	2*12 t trucks	61.2	59.5
Burdekin	0	110	62 300	2.5	250	3*12 t trucks	60.2	82.1
Tully	30	100	74 000	1	200	3*12 t E/B	74.0	73.3
Tully	14.5	90	51 500	2.5	300	3*8 t E/B	60.0	53.1
Tully	90	80	63 800	1.9	300	3*12 t E/B	51.9	62.9
Tully	60	94	48 000	1	250	2*10 t E/B	59.0	64.1
Tully	70	96	62 059	1.4	350	3*12 t E/B	56.4	65.0
Ingham	100	100	55 200	3.5	300	3*4 t*2 RO-RO	47.5	43.0
Ingham	100	100	48 947	1	300	2*10 t E/B	50.5	58.0
Ingham	100	81	41 240	1.1	300	3*8 t E/B	49.8	59.4
Ingham	100	92	43 305	1.2	300	2*10 t E/B	51.9	53.8
Ingham	100	95	55 100	1	300	3*4 t tip	48.8	47.8
Ingham	100	100	45 600	3	360	3*4 t*2 RO-RO	46.0	47.0
Ingham	100	103.8	32 550	1.8	262	3*8 t tip	50.1	60.9
Mackay	0	110	39 300	2.15	300	3*6 t*2 RO-RO	57.5	69.9
Mackay	82	100	52 500	1	280	3*5 t*2 RO-RO	55.9	73.7
Proserpine	60	100	72 000	3.5	250	3*10 t tip 1*12 t E/B	50.3	62.0
Sth Johnstone	100	87	31 000	0.8	360	3*4 t tip	51.7	53.6
Sth Johnstone	85	91	71 091	1	300	2*8 t E/B 1*4 t tip	70.9	72.4
Mourilyan	97	85	41 701	1.8	200	3*6 t tip	50.0	51.7
Babinda	98	75	40 636	1.5	200	3*8 t E/B	47.3	53.3
Mean							**54.8**	**60.3**

5.2 Model development

5.2.1 Excel spreadsheet model

The Excel spreadsheet combined throughput and costing model has been crosschecked against logbook data on throughput (Table 11) and against costs from the contractor survey data and other sources. In general, agreement has been relatively close and sufficient to allow use of the model for evaluating the impact of alternative strategies on costs and throughput. It was found that fuel usage for haulouts appeared to be overestimated by the model and this was thought to be due to uncertainty about operating load on haulout engines. Adjustments were made to allow for reduced load when filling bins, unloading and travelling empty. There is also some uncertainty about maintenance costs as these vary considerably from year to year with major costs in particular years when items such as hydraulics, motors, elevators are overhauled or replaced. However, average costs derived from survey data are considered to be a reasonable estimate of maintenance and the 50% allowance for green cane harvesting is supported by district comparisons.

While the Excel spreadsheet is easy for an experienced operator to use it is more difficult for new users and is not protected from accidental alterations. For contractor and grower use it has been replaced by a more user-friendly Visual Basic model.

5.2.2 'I Think' model

A simple model developed in the interactive program called 'I Think' was evaluated as a possible tool for contractor education. The model allowed visual illustration of harvesting and haulout dynamics in the field. While this feature was attractive it was difficult to obtain hard economic data and specific case information. A decision was therefore made to proceed with incorporation of the Excel spreadsheet into a Visual Basic framework allowing easy entry of data for particular case studies.

5.2.3 Visual Basic model

The Visual Basic model includes a number of menu driven options (Appendix 2) allowing data on field factors, harvester details, cane transport, wages and maintenance to be selected for particular harvester contracts.

In the field factors sheet (Appendix 2.1) season length, operating days per week, crop yield, time spent in burning, row length, haulout distance, travel speed of haulouts, group size, % green cane harvesting and turn time at the end of rows can be selected. Previous tonnes per engine hour for the harvester can also be entered as a reference.

Harvester details (appendix 2.2) include selection of wheeled/full track systems, harvester type, age of harvester, fuel usage (standard or own) and pour rate (low, average, and high). The pour rate options represent approximately older model harvesters (Massey

Ferguson and Toft), older Austoft and Cameco harvesters and recent high capacity models. Alternatively, they may refer to the cutting philosophies of aiming for quality of the end product or quantity of throughput. The model estimates harvester capital value according to model and age or own values can be entered.

In the cane transport section (Appendix 2.3) prime mover type, bin type, bin capacity, age, number of haulouts of each type can be entered. The program estimates the value of the selections or users can enter their own values.

The wages sheet (Appendix 2.4) allows selection of flat wage rates (15% loading), overtime payments, or piece rates. Individual piece rates can be entered as an option.

In the maintenance section (Appendix 2.5) labour time for off-season maintenance can be entered and this is included separately in the final report. If necessary additional within season maintenance labour costs could be included here. This sheet also allows growers own fuel usage (total) to be entered as an alternative to a calculated value. Total maintenance cost can also be entered to replace the computed maintenance (wages are still kept separate).

Program defaults (Appendix 2.6) for capital values, salvage values, maintenance, wages and incidental costs are given as a separate sheet to allow updating.

The final Harvest Transport Report (Appendix 2.7) shows group specification, throughput and cost sections. This can be printed out for each scenario.

5.3 Use of the model

A number of scenarios were investigated using the model as outlined in the project objectives. In most cases it was assumed that new equipment was being used and the corresponding high harvester throughput was used in calculations. Using a lower throughput would be more appropriate for older harvesters or where improved cane quality was desired. This would be likely to increase capital related costs.

5.3.1 Optimising harvester/haulout configurations

5.3.1.1 Group size

Potential group sizes estimated with the model for particular harvester-haulout combinations assuming specified operating conditions are given in Table 12.

TABLE 12
Effect of haulout capacity on potential group size and harvest-transport costs

Haulout capacity	Cost/h	Group size tonnes 30 000	40 000	45 000	50 000	55 000	60 000	70 000
2x8 tonne	$/tonne	7.10	5.88	5.48	5.14			
	h/day	5.43	7.27	8.19	9.11			
2x12 tonne	$/tonne		5.91	5.48	51.3	4.84		
	h/day		5.94	6.69	7.44	8.19		
3x8 tonne	$/tonne		6.69	6.20	5.81	5.48	5.12	
	h/day		5.41	6.09	6.77	7.44	8.12	
3x12 tonne	$/tonne				6.06	5.71	5.42	4.95
	h/day				6.23	6.86	7.48	8.73

* For 250 m row length, 85 t/ha crop, 50% green, 15 kph loaded, 30 kph unloaded, self-propelled, 2.5 min unloading time, 0.75 min turn time, 1 km haul distance, high pour rate of 117 t/hour. Underlined figures represent approximately 10 hour working day allowing 2 hours non-cutting time, flat wage rate, maintenance 40 man-days.

These figures indicate that for expensive tipper elevator bins in combination with a new harvester it is critical to match group size to capacity to ensure minimum cost and a practical working day. There are also some economies in using 12 tonne capacity haulouts compared to 8 tonne units, particularly where group size is matched to haulout capacity. It is also noteworthy that the pour rates used in this exercise of around 135 t/h for burnt cane and 99 t/h for green cane are within the cleaning capacity of current harvesters and should result in moderate extraneous matter levels. A lower pour rate would increase harvesting costs while improving cane quality and should probably attract an incentive payment.

5.3.1.2 Haul distance

The impact of haul distance on cutting rates and harvest-transport costs is shown in Table 13. For two 8 tonne haulouts, a change in haul distance from 0.5 to 3 km resulted in a 50% reduction in cutting rates and a 17% increase in harvest-transport costs for this case study. The loss in throughput was significantly reduced by increasing the number of transporters to three, but this did not reduce harvest-transport costs for the long hauls. Haul distance is therefore a critical cost component in harvest-transport planning. This will be discussed later in the evaluation of high speed haulouts and larger capacity transporters.

TABLE 13
Effect of haul distance on harvester cutting rates, cutting hours per day and harvest-transport costs

Haulout number	Haulout distance (km)	Cutting rate (t/h)	Cutting time (h/day)	$/tonne
2	0.5	67.6	5.91	5.44
	1.0	56.2	7.12	5.62
	2.0	42.0	9.51	5.99
	3.0	33.6	11.91	6.35
3	0.5	84.6	4.73	6.35
	1.0	76.7	5.21	6.45
	2.0	59.0	6.78	6.76
	3.0	47.9	8.35	7.08

* For haulout speeds of 15 kph loaded, 30 kph unloaded, 50% green cane, crop size 85 t/ha, 8 tonne self-propelled elevator bins, new harvester, 40 000 t group, maintenance 40 man-days, flat wage rate, standard turn time, 300 m row.

5.3.1.3 Haulout capacity

One approach for reducing the impact of haul distance on cutting rates is to increase the size of the transporter. Changes in cutting rates and costs with different sized transporters are shown in Table 14. For a haul distance of 3 km a change in size from 6 tonnes to 12 tonnes increased throughput by 63%. This means that the 400 tonnes daily throughput for a 40 000 tonne contract can be achieved in a practical working day. If allowance is made for the increased capital cost of the 12 tonne transporters harvest-transport costs are reduced by 4% for the particular circumstances. The impact of transporter capacity on throughput was shown to be less for shorter distances (25% gain with 12 tonne capacity at 0.5 km). For the 0.5 km haul distance the more expensive 9 and 12 tonne transporters increased harvest transport costs.

TABLE 14
Effect of haulout capacity on harvester cutting rate, cutting hours per day and harvest transport costs

Haul distance km	Haulout capacity t	Cutting rate t/h	Cutting time h/day	$/tonne
0.5	6	67.4	5.94	4.92
	9	76.3	5.24	5.15
	12	84.6	4.73	5.22
3.0	6	28.5	14.02	6.08
	9	37.9	10.55	5.93
	12	46.4	8.62	5.81

* for haulout speeds of 15 kph loaded, 30 kph unloaded, 50% green cane, crop size 85 t/ha, tractor drawn tippers, new harvester, 40 000 t group, maintenance 40 man-days, flat wage rate, standard turn time, 300 m row, two haulouts.

5.3.1.4 Haulout speed

A second approach to reducing the impact of haul distance is to move to higher speed transporters. This has prompted the move to truck transport for long hauls in some districts. However, there is still scope for improvement in the performance of conventional equipment by using more stable suspensions and high speed prime movers. The impact of haulout speed on throughput and costs is illustrated in Table 15. An extra capital allowance has been made for the higher speed haulouts to cover improved suspension. This was $5 000 for the 20/40 kph haulouts and $10 000 for the 30/60 kph haulouts.

TABLE 15
Effect of haulout speed on harvester cutting rates

Haulout distance km	Haulout speed kph		Cutting rate t/h	Cutting time h/day	Cost $/tonne
	loaded	unloaded			
0.5	15	30	76.3	5.24	5.15
	20	40	82.7	4.84	5.13
	30	60	84.6	4.73	5.16
3	15	30	37.9	10.55	5.93
	20	40	45.4	8.82	5.72
	30	60	56.5	7.09	5.50
3 (3 haulouts)	15	30	53.7	7.45	6.60

* for 2*9 tonne tractor drawn tippers, 300 m rows, crop size 85 t/ha, 50% green cane, new harvester, maintenance 40 man-days, flat wage rate, standard turn time.

For a 3 km haul distance, two high speed haulouts give a similar output to three conventional haulouts with a significant potential saving in costs. Similarly, despite the additional capital allowed for the high speed haulout it is less expensive than two conventional haulouts because of the shorter working hours per day.

5.3.2 Assessing the impact of changes to harvest organisation

5.3.2.1 Mill bin sizes

The impact of a change in mill bin size on harvest-transport costs and throughput will be mainly due to more rapid unloading of haulouts with larger bin sizes. The change in unloading times was estimated for 12 tonne elevator bins with 4 and 10 tonne capacity bins. The larger bins required only one shift to fully unload a 12 tonne haulout whereas, the smaller bins required two shifts. total unloading times were estimated as 2 min 18 sec and 2 min 27 sec, respectively. This was found to have minimal impact on costs in a large harvesting group (70 000 tonnes). The impact would be more significant if haulouts were matched to mill bin size or a change to tipper bins was practical.

Changes in mill bin sizes have other obvious benefits in increasing storage capacity of mill sidings and tipping rate at the mill and in reducing spillage in unloading haulouts.

5.3.2.2 Siding distribution

Rationalisation of mill sidings to give greater bin capacity for large groups and reduce mill maintenance costs impacts on harvest-transport capacity and costs mainly through increased haul distances. The actual increase in haul distance depends on the extent of rationalisation and the spacing of the current sidings. Table 13 gives an indication of the impact of haul distance on costs and throughput, eg an increase in haul distance from 1 to 2 km with two haulouts reduced cutting rates by 25% and increased costs by approximately 7% for the case study in Table 13. It also increased the actual cutting time from 7.1 to 9.5 hours per day. The impact of siding rationalisation on harvest-transport costs and throughput should therefore be carefully considered before such changes are put into practice.

5.3.2.3 Shift harvesting

The impact of two and three shift harvesting on harvest-transport costs and throughput is illustrated in Table 16. The original Excel spreadsheet model was used for these calculations to allow adjustment of wages and downtime for different scenarios. In this exercise it was assumed that there were two hours non-cutting time in each shift and an additional hour of non-cutting time for maintenance in the three shift operation. It was also assumed that the group size would be matched to available time for the particular scenario and that a backup harvester was not required for new equipment. Maintenance times were adjusted for group size approximately in accordance with Table 4. Two crews were used for two shift harvesting, and three for three shift harvesting with appropriate allowances for overhead costs.

TABLE 16
Effect of shift harvesting on harvesting costs and potential group sizes

Shifts		Potential group size (tonnes)*	Effective cutting time per day (hours)	$/tonne
1 x 10 hour	5/7 days	48 000	8	5.12
	13/14 days	63 000	8	4.40
2 x 8 hour	5/7 days	72 500	12	4.23
	13/14 days	95 000	12	3.71
2 x 10 hour	5/7 days	96 000	16	3.64
	13/14 days	125 000	16	3.25
3 x 8 hour	5/7 days	102 000	17	3.72
	13/14 days	132 000	17	3.35

* Using a crop size of 85 t/ha, 50% green, row length 300 m, 2.5 min unload time, 1.5 km haul distance, flat wages rate, on costs added for additional crews, new harvester, 2x12 tonne self-propelled elevator bins.

With the above assumptions and group details as footnoted in Table 16 there is a significant increase in output with multi-shift harvesting and a consequent decrease in harvesting costs. It is interesting to note that 2 x 10 hour shift harvesting is cheaper than 3 x 8 hour shifts despite the drop in potential group size.

These results are similar to those found by Page *et al.* (1985) who also showed a benefit from fresher cane with multiple shift harvesting.

This may also be a more practical operation in terms of flexibility for maintenance, crew management and crew satisfaction. When compared to Table 12 which deals with single shift operation with additional transport support multi-shift operation has an obvious advantage in reducing harvesting costs and increasing throughput per harvester. It also offers the opportunity for operating at lower pour rates to reduce extraneous matter levels without a major impact on harvesting costs.

5.3.2.4 Continuous crushing

The data given in Table 16 also highlights the impact of one continuous crushing scenario on throughput and costs. There is a significant improvement in seasonal harvester throughput and a corresponding decrease in harvest-transport costs with a change from 5 days in 7 cutting to 13 days in 14. This is one option that has already been taken to increase mill throughput for at least part of the season in most districts, and it can increase harvester efficiency where group sizes are expanded to take advantage of longer available cutting time. The change to ‘continuous cutting’ has affected the lifestyle of both growers and contractors, but the additional monetary incentive where group size is expanded will encourage contractors to accept such a change.

5.3.3 Field layout and crop presentation

5.3.3.1 Row length

The model takes the impact of row length into account by allowing for the turn time at the end of each row, and haulout travel time between the harvester and the end of each field after filling or unloading. The effect of row length on cutting rate, cutting time per day and costs is shown in Table 17.

The model indicates that short rows have a significant impact on cutting rates and costs, particularly in small crops. At row lengths longer than 500-600 m, throughput decreases and costs increase due to extra travel time leaving blocks, but this effect is not large.

TABLE 17
Effect of row length on cutting rate, cutting hours per day and harvest-transport costs cor a standard group configuration and three crop sizes

Crop size t/ha	Row length m	Cutting rate t/h	Cutting time h/day	$/tonne
120	100	49.8	8.03	5.82
	200	58.4	6.85	5.57
	400	60.9	6.57	5.50
	600	59.2	6.76	5.52
	800	56.6	7.07	5.56
	1000	53.9	7.42	5.61
90	100	44.2	9.05	6.03
	200	54.0	7.41	5.69
	400	57.9	6.90	5.57
	600	57.0	7.02	5.57
	800	53.1	7.53	5.60
	1000	52.6	7.61	5.65
60	100	35.4	11.30	6.49
	200	45.8	8.73	5.97
	400	51.5	7.76	5.76
	600	51.8	7.72	5.73
	800	50.6	7.91	5.75
	1000	48.8	8.19	5.78

* for haulout speeds 15 kph loaded, 30 kph unloaded, 2*8 tonne self-propelled elevator bins, new harvester, 2.5 min unloading time, turn time 0.75 min, flat wage rate, maintenance 40 man-days, 1 km haul distance, 50% green, 40 000 t group.

5.3.3.2 Crop size

The impact of crop size on throughput and costs can also be seen in Table 17. This effect is most marked for short rows but is significant for all row lengths with higher crop tonnages increasing throughput and decreasing costs. This is a reflection of pour rates and the time lost in turns to cut a given tonnage each day. In heavily lodged, large crops there will obviously be a negative impact of crop size on throughput, particularly in green cane.

5.3.3.3 Green v burnt cane

The model allows for some differential costing of green and burnt cane through changes in pour rate and maintenance costs in green cane. The impact of this on cutting rates and estimated costs for a standard group situation is illustrated in Table 18.

The increase in costs estimated by the model for green cane is of the order 17-35 4 per tonne which compares to figures quoted by McWhinney *et al.* (1988) of 22 4 per tonne for fuel and repairs and additional charges of 50 4-$1.00 per tonne for green cane in some districts.

TABLE 18
Comparison of cutting rates and costs between green and burnt cane for a range of crop sizes

Yield t/ha	Cutting rate t/ha		$/tonne		
	green	burnt	green	burnt	difference
180	52.5	63.0	5.80	5.45	0.35
160	56.0	64.1	5.68	5.42	0.26
140	57.2	63.8	5.64	5.42	0.22
120	56.8	62.3	5.64	5.45	0.19
100	55.0	59.7	5.69	5.51	0.18
80	51.7	55.7	5.79	5.61	0.18
60	46.6	49.7	5.97	5.80	0.17

* For 250 row length, 15 kph loaded, 30 kph unloaded, 2*8 tonne self-propelled elevator bins, new harvester, 2.5 min unloading time, standard turn time, flat wage rate, maintenance 40 man-days, 1 km haul distance, 40 000 t group.

5.3.3.4 Turning at the end of rows

Turn time varies significantly depending on field conditions with narrow headlands, reversible haulouts and one-way cutting recognised as variations on the standard turn at the end of rows. Turn time is likely to have most impact in short rows and low yielding crops where there is more turning involved in delivering the daily tonnage allocation. Typical model predictions for different turn times are given in Table 19. These turn times represent reversing haulouts down the row, conventional turns with a wide headland, and cutting-in next to a narrow headland.

TABLE 19
Effect of turn time at the end of rows on cutting rate, cutting hours and costs for two row lengths under standard conditions

Row length m	Turn time min	Cutting rate t/h	Cutting time h/day	$/tonne
200	0.5	55.6	7.19	5.65
	0.75	50.4	7.93	5.80
	1.00	46.1	8.67	5.95
500	0.5	57.7	6.93	5.57
	0.75	55.3	7.23	5.63
	1.00	53.2	7.53	5.69

* For haulout speeds of 15 kph loaded, 30 kph unloaded, 2*8 tonne self-propelled elevator bins, new harvester, 2.5 min unloading time, flat wage rate, maintenance 40 man-days, 1 km haul distance, 40 000 t group, 50% green cane, crop size 75 t/ha.

As expected the model indicates a significant increase in costs with slower turning in short rows and a smaller effect in long rows. Haulouts which can reverse up the row to speed turning are therefore a significant advantage in small crops and short rows.

6. DIFFICULTIES ENCOUNTERED DURING THE PROJECT

Changes in staff between submission and commencement of the project caused some delays in development of the computer model and necessitated considerably more time input, by the project supervisor than anticipated. The decision to develop the Visual Basic model in-house in the BSES also caused some delays as expertise was developed, but this allowed more interaction in drawing up the program framework. It also gives the potential for future modification of the model as required. Fine tuning of the accuracy of the throughput model has also been difficult due to lack of accurate information on haul distances, haulout travel speeds and pour rates. However, this does not detract from the use of the model in sensitivity testing.

7. RECOMMENDATIONS FOR FURTHER RESEARCH

Logging of haulouts and harvesters during operation would be a valuable aid to fine tuning of the throughput model and as background for more sophisticated models. The type of information required is actual cutting time, fuel usage of the harvester and haulouts and haulout distance and travel speed. Suitable instrumentation is now available for such measurements.

8. APPLICATION OF RESULTS TO THE INDUSTRY

Application of the model to the industry has significant potential benefits through guidance in applying the optimum equipment combinations for particular situations; encouraging improved field and crop conditions for harvesting; supporting higher haulout travel speeds and larger capacity haulouts for long haul distances; providing a basis for assessing the impact of multiple shift harvesting; continuous crushing and reorganisation of mill sidings on costs and throughput.

9. PUBLICATIONS ARISING

Brennan, L E, Ridge, D R and Milford, B J (1996). Raising profitability and productivity by improving harvesting procedures. Proc. Intensive sugarcane production – meeting the challenge beyond 2000, Brisbane, Australia, August 1996.

Ridge, D R, Brennan, L E and Powell, J G (1996). Factors influencing industry harvest-transport performance. Proc Aust. Soc. Sugar Cane Technol. 18: 6-13.

10. REFERENCES

McWhinney, W, Crawford, D M, Ridge, D R, Cameron, J M and Absolom, J E (1988). The economics of cane from field to factory. Proc. Aust. Soc. Sugar Cane Technol. 10: 7-18.

Page, W, Couchman, J and Bathgate, R (1985). A method for determining the effect on industry economies of a change to present harvesting systems. Proc. Aust. Soc. Sugar Cane Technol. 7: 1-11.

Powell, J (1992). The effect of row length, crop density and haul distance on harvesting delivery rate in the Mackay district for 1991. Proc. Aust. Soc. Sugar Cane Technol. 14: 163-168.

Ridge, D R and Dick, R G (1985). Factors affecting cane harvesting and transport costs. Proc. Aust. Soc. Sugar Cane Technol. 7: 139-145.

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12. APPENDIX 1 – DATA COLLECTION SHEETS

13. APPENDIX 2 – HARVEST TRANSPORT SIMULATOR

13.1 Appendix 2.1 – Field factors menu

13.2 Appendix 2.2 – Harvester details menu

13.3 Appendix 2.3 – Cane transport menu

13.4 Appendix 2.4 – Wages menu

13.5 Appendix 2.5 – Maintenance menu

13.6 Appendix 2.6 – Program defaults

13.7 Appendix 2.7 – Harvest transport report