HOW CANE DELAY TIMES ARE AFFECTED BY VARIOUS OPERATIONAL CONDITIONS

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Abstract

The various operational aspects in the system of harvesting-transport-crushing of cane are examined insofar as they affect delay times of cane in the fields, the trans-shipping zones and sidings and the mill yard, all of which will affect deterioration of sucrose.

A shift-by-shift simulation of the cane movements, changes in stock levels and delay times is done on an idealised steady-state week of operation for Amatikulu Mill, assuming perfect first in, first out within each yard handling category. This is taken as the standard of reference.

The technique of such simulations is described. The following variations on this are simulated to compare their respective effects on the distribution of delay times:

Crushing over exactly 6 days.
Sunday maintenance.
Putting more Hilos onto spiller.
Putting some Hilo cane onto self-delivery.
Shortening the weekly Hilo transport programme.
Deviating from first in, first out.
Irregular cane supplies to the mill.
Mill stoppages.
Carrying lower stocks of cut cane over the weekend.

The results of these simulations are then compared with actual values for the mill. The wider spread of delay times obtained in practice is largely caused by deviations from first in, first out.

Object

As part of the Harvest-to-Crush Time Elapse Survey conducted by the Sugar Industry Central Board, it was decided to combine the analysis of cane delays at the zones and in the mill yard, in view of the mill generally being responsible for the transport from the zones as well as for what happens in the mill yard. The main object in this paper is to examine how the overall structure and running of transport from zone to mill and crushing by the mill affect delays suffered by the cane. For completeness, however, the delay the cane experiences in the field after cutting is also included, as this will also contribute to the overall delay and hence sucrose deterioration. The report does not deal with delays experienced by the haulage vehicles.

Amatikulu mill was chosen for doing this analysis, because of the variety of transportation methods employed, namely:

(*a*) Self-delivery transport, by tractor or lorry direct from fields to mill, where the cane is offloaded onto the yard floor by gantry crane and subsequently picked up again for crushing.

(*b*) Hilo transport of bundled cane, where the cane is also handled by gantry crane.

(*c*) Hilo transport of loose cane, which is directly offloaded by spiller onto the spiller table.

(*d*) S.A.R. trucks, offloaded by grab onto the S.A.R. feeder table.

Approach

A. Theoretical Analysis

Simulate an idealised theoretical situation, and observe the effect of varying certain aspects of it.

B. Comparison with Practice

Examine how far in practice we deviate from the theoretical ideal, and put forward reasons for such deviations.

A. THEORETICAL ANALYSIS:

A. 1 Principles of the theoretical idealised model

This is an input-output model which shows, at successive time intervals, what has gone into the various stages of the system, what has left these stages, and what the build-up of stocks and the effect on residence times of the cane are.

Each case under investigation consists of 3 simulations which are used in conjunction with each other: cane movements in the fields; cane movements at the S.A.R. sidings and the zones; and cane movements in the mill yard.

Various simplifying assumptions have been made in the model, not only for the sake of easier calculations, but also because a more complex model would tend to obscure the very principles which it is the object of this report to illustrate.

The simplifications are the following:

(1) The model starts at 06h00 on Monday, and the situation is shown at 12 hour intervals. This enables one to conveniently talk about a day shift and a night shift. This model deals with 1 full ideal week, i.e. lasts up to 06h00 on Monday the following week. "Monday" shall mean the 24 hour period for Monday 06h00 until Tuesday 06h00, and likewise for the other weekdays.

(2) Cutting rates of cane by the growers, delivery rates of cane by the growers, transport rates by the Hilo transport contractor and crushing rates by the mill are consistent from day to day, i.e. random variations such as the effect of bad weather on cane supplies or mill breakdowns on crushing are not considered unless specified.

(3) Any cane which has arrived during a 12 hour shift and is still present by the end of the shift, is at that stage assumed to have incurred a delay time of half a day, i.e. 12 hours. If by the end of the following shift the cane has been removed, the additional delay time incurred is assumed to be zero.

(4) All cane passing through the zones is assumed to be dealt with on a first in, first out (FIFO) basis, unless otherwise stated. The cane arriving in the mill yard is assumed to be crushed on a FIFO basis within each of the categories: bundle cane, loose cane and S.A.R. cane.

(5) Loose cane is immediately crushed on receipt in the mill yard. No loose cane therefore ever goes into stock because it is not practical to double handle it, and the loose cane arrivals therefore constitute part of the feed to the mill.

(6) The time the cane spends in transit from the fields, the S.A.R. sidings or the zones is ignored in that it is, in effect, part of the time the cane spent in the field, siding or zone respectively. In practice, the calculation of the time spent at the zone is the difference between the time of arrival at the zone and the time of arrival at the weighbridge.

(7) Unless stated otherwise, all the cane on the zones and in the mill yard is worked away by the time the mill shuts down for maintenance.

(8) Unless stated otherwise, the cane which is cut on the one weekday is carried over in the fields until the next weekday, when it will be transported to the zones, sidings or directly to the mill yard.

A. 2. Case 1 Base Case

As a standard of reference, a situation for the model has been chosen which is as far as possible representative of typical operation at the mill, and will be referred to as the base case. Other cases for comparison will be assumed identical to the base case in all respects except where the differences are specifically mentioned.

Quantities and timing

The cane tonnage coming into the mill over the course of a typical week is distributed as follows over the various modes of transport:

	Day shift	Night shift	**Total**	%
Direct transport . . .	9 780	—	9 780	25
Hilos on bundled cane .	3 840	3 840	7 680	20
Hilos on loose cane . .	8 820	8 820	17 640	45
S.A.R. cane	—	3 900	3 900	10
Total	22 440	16 560	39 000	100

The cutting of cane takes place Mondays to Saturdays, day shift only, 1 working day ahead of deliveries to zones or direct to mill. One day's allocation of cut cane is therefore carried over the nights and over the week-end.

The deliveries of cane from the growers, either direct to the mill or to the zones, take place in equal daily quantities, Mondays to Saturdays, day shift only.

The mill crushing programme starts at 16h00 on Monday and carries on until 02h00 the following Monday, i.e. crushes for 154 hours, with a 14 hour Monday maintenance shut-down.

Hilo transport of cane starts at 16h00 on Monday and ends at 18h00 on Sunday, i.e. over 146 hours, and 70% of the Hilos are on spiller.

The S.A.R. trucks which the growers load during the day shifts come in during night shifts, Monday to Saturday, and are crushed out during the immediately following day shifts, i.e. Tuesday to Sunday inclusive.

Shift-by-shift simulation

In order to determine how the stocks position changes over the week in the various stages of the cane handling system, and how the distribution of delay times is affected, a shift-by-shift simulation of the cane movements is made in tabular form, namely Tables F.1, Z.1 and Y.1, dealing with the fields, zones and millyard respectively.

The amounts of cane brought into and removed from each stage of the system during each shift of the week follow directly from the specification of the base case times and quantities.

The changes in stock levels are simply the difference between the input to and removals from that stage during the shift.

The calculation of the distribution of the delay times is described in Appendix 1, using the base case for the mill yard as example.

TABLE F. 1

Simulation of cane movements and delay times in the fields

Case 1, Part F: Base Case: 1 day's allocation of cut cane carried over week-end.

Day and Shift	FIELDS																
	Cutting (Tons)				Delivered to (Tons)				*Closing Stocks (Tons)*				*Age distribution of stocks (in days)*				
	Self-Deliv.	Hilo	SAR	Total	Mill	Hilo Zone	SAR Siding	Total	*Self-Deliv.*	*Hilo*	*SAR*	**Total**	0	½	1	1½	2
Monday — D .	1 630	4 220	650	6 500	1 630	4 220	650	6 500	1 630	4 220	650	6 500	—	6 500	—	—	—
— N .	—	—	—	—	—	—	—	—	1 630	4 220	650	6 500	—	—	6 500	—	—
Tuesday — D .	1 630	4 220	650	6 500	1 630	4 220	650	6 500	1 630	4 220	650	6 500	—	6 500	—	—	—
— N .	—	—	—	—	—	—	—	—	1 630	4 220	650	6 500	—	—	6 500	—	—
Wednesday — D .	1 630	4 220	650	6 500	1 630	4 220	650	6 500	1 630	4 220	650	5 500	—	6 500	—	—	—
— N .	—	—	—	—	—	—	—	—	1 630	4 220	650	6 500	—	—	6 500	—	—
Thursday — D .	1 630	4 220	650	6 500	1 630	4 220	650	6 500	1 630	4 220	650	6 500	—	6 500	—	—	—
— N .	—	—	—	—	—	—	—	—	1 630	4 220	650	6 500	—	—	6 500	—	—
Friday — D .	1 630	4 220	650	6 500	1 630	4 220	650	6 500	1 630	4 220	650	6 500	—	6 500	—	—	—
— N .	—	—	—	—	—	—	—	—	1 630	4 220	650	6 500	—	—	6 500	—	—
Saturday — D .	1 630	4 220	650	6 500	1 630	4 220	650	6 500	1 630	4 220	650	6 500	—	6 500	—	—	—
— N .	—	—	—	—	—	—	—	—	1 630	4 220	650	6 500	—	—	6 500	—	—
Sunday — D .	—	—	—	—	—	—	—	—	1 630	4 220	650	6 500	—	—	—	6 500	—
— N .	—	—	—	—	—	—	—	—	1 630	4 220	650	6 500	—	—	—	—	6 500
Total/Average	9 780	25 320	3 900	39 000	9 780	25 320	3 900	39 000	1 630	4 220	650	6 500	0%	0%	83%	0%	17%

Field Delay Time: Mean = 28,00 h. Std. Deviation = 9,0 h.

TABLE Z. 1

Simulation of cane movements and delay times at the zones

Case 1, Part Z: Base Case: 146 hour Hilo Transport from Monday 16h00 to Sunday 19h00

Day and Shift	S.A.R. SIDING (TONS)						HILO ZONES (TONS)						Self-Delivery (Direct to Mill)
	Receipts from Fields	Despat. to Mill	*Closing Stocks*	*Age distribution of stocks (Days)*			Receipts from Fields	Despat. to Mill	*Closing Stocks*	*Age distribution of closing Stocks (In Days)*			
				0	½	1				0	½	1	
Monday — D	650	—	650	—	650	—	4 220	360	3 860	360	3 860	—	1 630
N	—	650	—	—	—	—	—	2 080	1 780	—	—	1 780	—
Tuesday — D	650	—	650	—	650	—	4 220	2 080	3 920	300	3 920	—	1 630
N	—	650	—	—	—	—	—	2 080	1 840	—	—	1 840	—
Wednesday — D	650	—	650	—	650	—	4 220	2 080	3 980	240	3 980	—	1 630
N	—	650	—	—	—	—	—	2 080	1 900	—	—	1 900	—
Thursday — D	650	—	650	—	650	—	4 220	2 080	4 040	180	4 040	—	1 630
N	—	650	—	—	—	—	—	2 080	1 960	—	—	1 960	—
Friday — D	650	—	650	—	650	—	4 220	2 080	4 100	120	4 100	—	1 630
N	—	650	—	—	—	—	—	2 080	2 020	—	—	2 020	—
Saturday — D	650	—	650	—	650	—	4 220	2 080	4 160	60	4 160	—	1 630
N	—	650	—	—	-	—	—	2 080	2 080	—	—	2 080	—
Sunday — D	—	—	—	—	—	—	—	2 080	—	—	—	—	—
N	—	—	—	—	—	—	—	—	—	—	—	—	—
Total/Average	3 900	3 900	325	0%	100%	0%	25 320	25 320	2 970	5%	49%	46%	9 780

Siding Delay Times: Mean = 12 h. Std. Dev. = 0. Zone Delay Time: Mean = 16,9 h. Std. Dev. = 7,1 h.

TABLE Y. 1

Simulation of cane movements and delay times in mill yard

Case 1, Part Y: Base Case: 154 hour crushing from Monday 16h00 to Monday 02h00; 70% Hilos on Spiller

Day and Shift	MILL YARD												
	Receipts (Tons)					Crush (Tons)			*Stocks (Tons)*				
	Total receipts	S.A.R.	Self-delivery	Bundle Hilos	Spiller Hilos	S.A.R.	From bundles	**Total crush**	*Closing stocks*	*Age distribution of stocks (in days)*			
										0	½	1	1½
Monday — D	1 990	—	1 630	120	240	—	260	500	1 490	500	1 490	—	—
N	2 730	650	—	630	1 450	—	1 590	3 040	1 180	1 550	1 180	—	—
Tuesday — D	3 710	—	1 630	630	1 450	650	940	3 040	1 850	1 860	1 850	—	—
N	2 730	650	—	630	1 450	—	1 590	3 040	1 540	1 450	1 280	260	—
Wednesday — D	3 710	—	1 630	630	1 450	650	940	3 040	2 210	1 500	2 210	—	—
N	2 730	650	—	630	1 450	—	1 590	3 040	1 900	1 450	1 280	620	—
Thursday — D	3 710	—	1 630	630	1 450	650	940	3 040	2 570	1 450	2 260	310	—
N	2 730	650	—	630	1 450	—	1 590	3 040	2 260	1 450	1 280	980	—
Friday — D	3 710	—	1 630	630	1 450	650	940	3 040	2 930	1 450	2 260	630	40
N	2 730	650	—	630	1 450	—	1 590	3 040	2 620	1 450	1 280	1 340	—
Saturday — D	3 710	—	1 630	630	1 450	650	940	3 040	3 290	1 450	2 260	630	400
N	2 730	650	—	630	1 450	—	1 590	3 040	2 980	1 450	1 280	1 700	—
Sunday — D	2 080	—	—	630	1 450	650	940	3 040	2 020	1 450	630	630	760
N	—	—	—	—	—	—	2 020	2 020	—	—	—	—	—
Total/Average	39 000	3 900	9 780	7 680	17 640	3 900	17 460	39 000	2 219	47%	35%	15%	3%

Yard Residence Times: Mean = 8,9h. Std. Deviation = 9,9h.

Graphical representation

Table 2 shows the cumulative end-of-shift tonnages and closing stocks for the base case at the various stages of the cane handling system.

This information is used in Figure 1 to provide a pictorial representation of the operation of the system.

Four cumulative curves are shown i.e.

(*a*) Total cane cut by growers.

(*b*) Total cane deliveries by growers.

(*c*) Total cane receipts at the mill. (The deliveries of cane by direct transport are included in this curve as well as in the curve in (*b*) above).

(*d*) Total crush of cane.

TABLE 2

Cumulative End-of-shift tonnages and closing stocks at various stages of the cane handling system for the base case

Day and Shift	Field cutting		*Field stocks*	Field despatches	*Zone and siding stocks*	Mill yard receipts	*Mill yard stocks*	Crush
	Carry-over from previous week	Present week						
Sunday — N		**6 500**	—	—	—	—	—	—
Monday — D		**13 000**	6 500	6 500	4 510	1 990	1 490	500
— N		**13 000**	6 500	6 500	1 780	4 720	1 180	3 540
Tuesday — D		**19 500**	6 500	13 000	4 570	8 430	1 850	6 580
— N		**19 500**	6 500	13 000	1 840	11 160	1 540	9 620
Wednesday — D		**26 000**	6 500	19 500	4 630	14 870	2 210	12 660
— N		**26 000**	6 500	19 500	1 900	17 600	1 900	15 700
Thursday — D		**32 500**	6 500	26 000	4 690	21 310	2 570	18 740
— N		**32 500**	6 500	26 000	1 960	24 040	2 260	21 780
Friday — D		**39 000**	6 500	32 500	4 750	27 750	2 930	24 820
— N		**39 000**	6 500	32 500	2 020	30 480	2 260	27 860
Saturday — D	**6 500**	45 500	6 500	39 000	4 810	34 190	3 290	30 900
— N	**6 500**	45 500	6 500	39 000	2 080	36 920	2 980	33 940
Sunday — D	**6 500**	45 500	6 500	39 000	—	39 000	2 020	36 980
— N	**6 500**	45 500	6 500	39 000	—	39 000	—	39 000

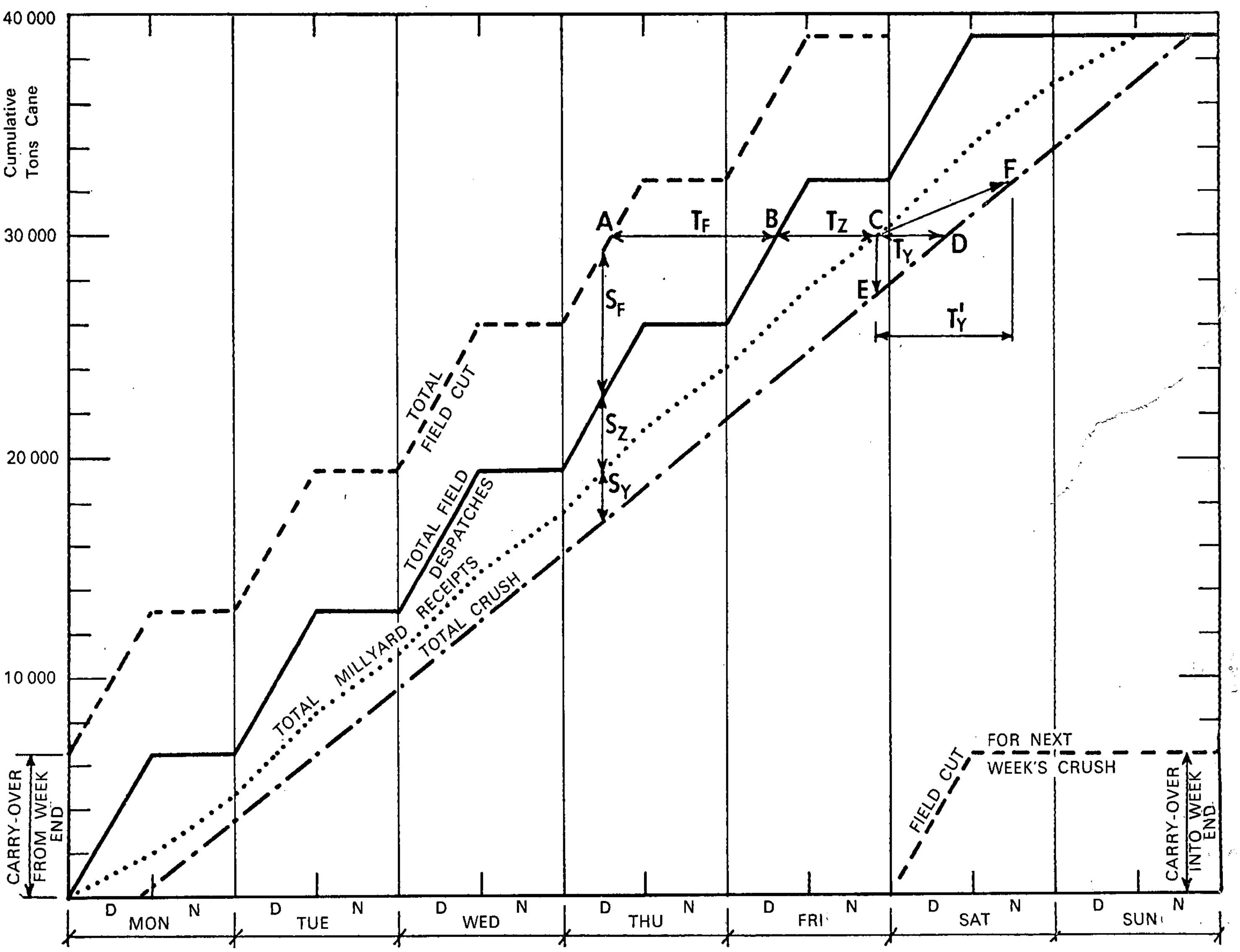

FIGURE 1 Representation of stock levels and delay times in cane handling system.

At any point in time, the vertical distance between 2 adjacent cumulative curves gives the cane stocks at that point e.g. S_F = Field stocks; S_Z = Zone and siding stocks; S_Y = Yard stocks. The graph shows that delivery of cane by the growers and crushing by the mill are out of step. Because the mill, due to having maintenance on Monday, only starts crushing late on Monday afternoon, there already is a sizable amount of cane in the system. This situation becomes more pronounced during the course of the week, because the growers supply cane for exactly 6 days of the week, whereas crushing takes place for 6,42 days, with the result that the cane stocks in the system become higher and higher, to be worked down again to a theoretical zero during the weekend. This is shown by the divergence of the lines representing Total Mill Yard Receipts and Total Crush. Cutting and despatching from the fields are very much out of step, as indicated by the high field stocks.

If the system could work on the basis of perfect FIFO for all cane, regardless of method of transport, it would be correct to say that the 30 000th ton of cane cut (point A on Figure 1) would be the 30 000th ton of cane to reach the zones (point B), the 30 000th ton of cane to enter the mill yard (point C) and the 30 000th ton of cane crushed (point D). These points would lie on the same horizontal line ABCD on Figure 1, and the delay times of that ton of cane in the fields, at the zones and in the mill yard will respectively be given by the horizontal distances AB = T_F between the Field Cutting and the Field Despatches curves, BC = T_Z between the Field Despatches and the Millyard Receipts curves and CD = T_Y between the Millyard Receipts and Crush curves.

If however, we deviate from perfect FIFO for all cane, in that the consignment of cane entering the mill yard at point C is on a spiller Hilo, such cane will be crushed almost immediately (neglecting the relatively short time it might spend waiting to be offloaded), and the point at which it is offloaded is represented by E on the Total Crush line, which is vertically underneath point C because entry into the mill yard and crushing of that consignment are therefore assumed to take place at the same point in time. It can be seen that, although such a consignment is the 30 000th ton to enter the mill yard, it is about the 27 500th ton to be crushed, indicating that the consignment had "jumped the queue" of cane waiting to be crushed to the extent of CE = 2 500 tons.

On the other hand, if the consignment arriving at point C in the mill yard is bundle cane and suffers a relatively long delay before being crushed, the point at which it is crushed might be represented by point F on the Total Crush line, i.e. it would then only be somewhere between the 32 000th and 33 000th ton of cane to be crushed. The delay which this consignment of cane then has to experience is represented by the horizontal distance between C and F i.e. by line T_Y^1.

Depending on whether the line connecting successive stages in the processing of a consignment falls or rises, indicates whether that consignment has "jumped the queue" or "lost its place in the queue" of cane waiting to be crushed.

A. 3. Summaries of important data from various cases under review:

Cane stock levels

These are important because they directly affect the average delay times of the cane, as well as causing problems such as the mill and/or the transport organisation possibly coming to a standstill through the stocks being too low, or cane handling and storage at the zones and/or the mill yard becoming awkward through the stocks being too high.

Tables F. 3, Z. 3 and Y. 3 show the daily cane stock levels at 06h00 in the fields, on the zones and in the mill yard respectively for each of the cases to be examined. The tables also show by how much the 18h00 stocks are higher than the 06h00 stocks.

TABLE F. 3
Field cut cane stock levels at 06h00 (tons)

Case No.	Brief description of case	Mon	Tues	Wed	Thu	Fri	Sat	Sun	Mean	18h00 stocks higher by
1	Base Case: 154 h crush; 70% spiller Hilos									
2	144 h crush, Monday to Sunday									
3	Sunday Maintenance									
4	90% of Hilos on spiller	6 500	6 500	6 500	6 500	6 500	6 500	6 500	6 500	—
5	Some Hilo cane put onto self-delivery									
6	140 h Hilo transport instead of 146 h									
7	50% of cane FIFO; 50% LIFO									
8	Irregular cane supplies	6 500	6 500	6 500	4 880	3 250	6 500	6 500	5 804	—
9	12 h Mill stoppage on Wednesday	6 500	6 500	6 500	6 500	6 500	6 500	6 500	6 500	—
10	Reduced week-end field stocks	4 500	6 500	6 500	6 500	6 500	6 500	6 500	6 221	—

TABLE Z. 3
Loading zone stock levels at 06h00 (tons)

Case No.	Brief description of case	Mon	Tues	Wed	Thu	Fri	Sat	Sun	Mean	18h00 stocks higher by
1	Base Case: 154 h crush; 70% spiller Hilos	—	1 780	1 840	1 900	1 960	2 020	2 080	1 654	2 140
2	144 h crush, Monday to Sunday	—	1 750	1 750	1 750	1 750	1 750	1 750	1 500	2 110
3	Sunday Maintenance	300	360	420	480	540	600	2 380	726	2 140
4	90% of Hilos on spiller	—	1 780	1 840	1 900	1 960	2 020	2 080	1 654	2 140
5	Some Hilo cane put onto self-delivery	—	1 570	1 630	1 690	1 750	1 810	1 870	1 474	1 930
6	140 h Hilo transport instead of 146 h	—	1 690	1 590	1 450	1 330	1 210	1 090	1 194	2 050
7	50% of cane FIFO; 50% LIFO	—	1 780	1 840	1 900	1 960	2 020	2 080	1 654	2 140
8	Irregular cane supplies	—	1 780	1 840	1 900	3 010	4 130	2 080	2 106	2 140
9	12 h Mill stoppage on Wednesday	—	1 780	1 840	2 880	1 960	2 020	2 080	1 794	2 140
10	Reduced week-end field stocks	—	700	700	700	700	700	700	600	2 110

TABLE Y. 3
Mill yard stock levels at 06h00 (tons)

Case No.	Brief description of case	Mon	Tues	Wed	Thu	Fri	Sat	Sun	Mean	18h00 stocks higher by
1	Base Case: 154 h crush; 70% spiller Hilos . .	—	1 180	1 540	1 900	2 260	2 620	2 980	1 783	670
2	144 h crush, Monday to Sunday	—	1 150	1 500	1 500	1 500	1 500	1 500	1 286	490
3	Sunday Maintenance	700	1 060	1 420	1 780	2 140	2 500	1 660	1 609	670
4	90% of Hilos on spiller	—	1 180	1 540	1 900	2 260	2 620	2 980	1 783	670
5	Some Hilo cane put onto self-delivery. . . .	—	1 390	1 750	2 110	2 470	2 830	3 190	1 963	880
6	140 h Hilo transport instead of 146 h	—	1 270	1 810	2 350	2 890	3 430	3 970	2 246	760
7	50% of cane FIFO; 50% LIFO	—	1 180	1 540	1 900	2 260	2 620	2 980	1 783	670
8	Irregular cane supplies	—	1 180	1 540	1 900	2 830	3 760	2 980	2 027	670
9	12 h Mill stoppage on Wednesday	—	1 180	1 540	3 960	2 260	2 620	2 980	2 077	670
10	Reduced week-end field stocks.	—	810	1 230	1 650	2 070	2 490	2 910	1 594	700

Distribution of cane delays

For the purposes of this investigation, we are not only interested in the average delay time, but also how the delay times are distributed. An average delay time of 13 hours might sound quite acceptable, but if the average is made up of 90% of the cane with a delay time of 10 hours and 10% of the cane with a delay time of 40 hours, this is obviously not a satisfactory situation.

The technique of calculating the distribution of cane delay times, in 12 hour (or ½ day) intervals, is described in Appendix 1.

Tables F. 4, Z. 4 and Y. 4 show the frequency distribution of cane delay times in the fields, on the zones and in the mill yard respectively over the course of a week, for each of the cases to be examined.

A more compact characterisation of the distribution is useful, and the mean and the standard deviations have been included in the tables. The mean is simply the weighted average delay time, and the standard deviation is a measure of the dispersion about the mean. Appendix 2 describes how they are calculated.

Summary of mean cane delay times

To facilitate comparison, Table 5 shows case by case, the mean cane delay time for each stage of the cane handling system, as well as the mean overall delay from cutting to crushing, which determines the extent of deterioration which the cane suffers.

TABLE F. 4
Distribution of cane delays in the fields

Case No.	Brief description of case	% Distribution per half-day interval						Mean Delay Time (h.)	Std. Dev. Delay Time (h).
		0	½	1	1½	2	2½		
1 2 3 4 5 6 7	Base Case: 154 h crush; 70% spiller Hilos . . 144 h crush, Monday to Sunday . . . . . Sunday Maintenance . . . . 90% of Hilos on spiller . . . . Some Hilo cane put onto self-delivery. . . . 140 h Hilo transport instead of 146 h . . . . 50% of cane FIFO; 50% LIFO	0%	0%	83%	0%	17%	—	28,0	9,0
8	Irregular cane supplies	12%	0%	71%	0%	17%	—	25,0	13,0
9	12 h Mill stoppage on Wednesday	0%	0%	73%	0%	27%	—	30,4	10,7
10	Reduced week-end field stocks.	0%	0%	88%	0%	12%	—	26,8	7,7

TABLE Z. 4
Distribution of cane delay times in the Hilo zones

Case No.	Brief description of case	% Distribution per half-day interval						Mean Delay Time (h.)	Std. Dev. Delay Time (h.)
		0	½	1	1½	2	2½		
1	Base Case: 154 h crush; 70% spiller Hilos . .	5	49	46	—	—	—	16,9	7,1
2	144 h crush, Monday to Sunday	9	50	41	—	—	—	15,8	7,6
3	Sunday Maintenance	39	43	9	8	1	—	10,9	11,5
4	90% of Hilos on spiller	5	49	46	—	—	—	16,9	7,1
5	Some Hilo cane put onto self-delivery. . . .	6	49	45	—	—	—	16,7	7,2
6	140 h Hilo transport instead of 146 h	16	51	33	—	—	—	14,0	8,2
7	50% of cane FIFO; 50% LIFO	22	32	29	17	—	—	16,9	12,2
8	Irregular cane supplies	4	38	46	12	—	—	19,9	8,9
9	12 h Mill stoppage on Wednesday	5	41	46	8	—	—	18,8	8,5
10	Reduced week-end field stocks.	33	50	17	—	—	—	10,3	8,3

TABLE Y. 4
Distribution of cane delay times in mill yard

Case No.	Brief description of case	% Distribution per half-day interval						Mean Delay Time (h.)	Std. Dev. Delay Time (h.)
		0	½	1	1½	2	2½		
1	Base Case: 154 h crush; 70% spiller Hilos	47	35	15	3	—	—	8,9	9,9
2	144 h crush, Monday to Sunday	50	47	3	—	—	—	6,4	6,7
3	Sunday Maintenance	51	34	10	5	—	—	8,2	10,1
4	90% of Hilos on spiller	59	20	9	12	—	—	8,9	12,6
5	Some Hilo cane put onto self-delivery	46	30	17	7	—	—	10,2	11,4
6	140 h Hilo transport instead of 146 h	46	27	18	9	—	—	10,8	12,0
7	50% of cane FIFO; 50% LIFO	63	17	5	13	2	—	8,9	13,8
8	Irregular cane supplies	47	32	12	9	—	—	10,0	11,6
9	12 h Mill stoppage on Wednesday	43	28	19	10	—	—	11,5	12,2
10	Reduced week-end field stocks	49	36	12	3	—	—	8,2	9,5

TABLE 5
Summary of mean cane delay times per stage and for the system
(in hours)

Case No.	Brief description of case	Fields	S.A.R.* Sidings	Hilo* Zones	Mill Yard	Overall System
1	Base Case: 154 h crush; 70% spiller Hilos	28,0	12,0	16,9	8,9	49,1
2	144 h crush, Monday to Sunday	28,0	12,0	15,8	6,4	45,9
3	Sunday Maintenance	28,0	12,0	10,9	8,2	44,5
4	90% of Hilos on spiller	28,0	12,0	16,9	8,9	49,1
5	Some Hilo cane put onto self-delivery	28,0	12,0	16,7	10,2	49,2
6	140 h Hilo transport instead of 146 h	28,0	12,0	14,0	10,8	49,1
7	50% of cane FIFO; 50% LIFO	28,0	12,0	16,9	8,9	49,1
8	Irregular cane supplies	25,0	12,0	19,9	10,0	49,1
9	12 h Mill stoppage on Wednesday	30,4	12,0	18,8	11,5	55,3
10	Reduced week-end field stocks	26,8	12,0	10,3	8,2	42,9

* Weighted by the amount of cane passing through when calculating overall system delay.

A. 4. Variations on base case through changes in mill operating policy

Changing the timing of the Hilo haulage and/or the mill crushing programmes or changing the mode of transport are management decisions of policy, and the effect of some of these changes will be examined:

Case 2: *144-hour crushing*

As mentioned previously, although the cane is delivered from the zones over 6 days, the mill crushes for 6,42 days, and gradually moves further out of step with the cane supply during the course of the week. This simulation shows what would happen if the mill were to crush over a period of exactly 6 days, from Monday 18h00 to Sunday 18h00 but still assuming Monday maintenance.

In view of the small modification required to the Hilo transportation programme, to be from Monday 16h00 to Sunday 16h00, the pattern of delay times at the zones is not significantly different from the base case, but there is a considerable improvement in both the mean and spread of delay times in the mill yard, and also the overall delay time. The stock level situation also is far lower and more steady.

In practice, the main drawback of such a scheme is the additional crushing capacity required to process the same amount of cane in 144 instead of 154 hours.

Case 3: *Sunday maintenance*

Besides not taking place over the same number of hours per week, crushing and harvesting are also out of step with each other as a result of the maintenance shut-down being on Monday, during which harvesting already takes place for the new week. This case examines the effect of having the maintenance shut-down on Sunday instead of Monday, with crushing from Sunday 18h00 to Sunday 04h00. The Hilo transportation programme was shifted accordingly to be from Sunday 18h00 to Saturday 20h00.

A feature of this particular case is that, unlike the cases with Monday maintenance shut-downs, cane stocks have to be carried on the zones and in the millyard during the shut-down, so that the mill has something to crush when it starts up again on Sunday evening and to keep it going until the following week's cane starts arriving. This will of course mean that any cane carried over the maintenance period would suffer a disproportionately long delay time. Furthermore, management have to make a decision on how much cane to carry over, because if too little is carried over, the mill could run out of cane before the new lot starts arriving. This case was based on a minimum cane stock of 1 000 tons on Monday 06h00, consisting of 250 tons on S.A.R. trucks and 450 tons in bundles in the mill yard, plus 300 tons on the zones.

As to be expected, the average delay times of cane in the mill yard and on the zones are lower than in the base case, but the spread of delay times is wider.

The main drawback of this scheme is that the engineering staff are reluctant to work on Sundays.

Case 4: *90% of Hilos on spiller*

Whenever vehicles are on direct offloading, such as when loose cane is offloaded by spiller, there is a deviation from the principle of FIFO, in that such cane in effect jumps the queue of other cane in bundles waiting to be crushed, as already illustrated in Figure 1. Here the percentage of Hilos on spiller has been increased from the 70% in the base case to 90%.

Contrary to popular belief, putting more cane onto spiller does not reduce the average delay time of cane in the yard. It does of course reduce the delay time of the additional cane which went onto spiller, but at the expense of the other cane which remains on bundles. This shows up in that the spread of delay times in the mill yard is significantly wider than in the base case.

Case 5: *Some Hilo cane put onto self-delivery*

Here 420 tons per day of bundle cane are taken off Hilo transport and put onto self-delivery. The average overall delay time for the system is the same as in the base case, which is understandable, because the timing of cane deliveries from the fields and the timing of crushing are identical to those of the base case. However, a smaller amount of cane now passes through the zones, and because the zones are no longer able to act as a kind of delayed storage for these 420 tons of cane per day, such cane will proceed directly into the mill yard as soon as it leaves the fields. The result is that the average stock level and the spread in delay times in the mill yard will increase compared with the base case.

Case 6: 140 *hours Hilo transport instead of* 146 *hours*

The effect is examined of starting Hilo transport operations at the same time as in the base case, i.e. at 16h00 on Monday, but transporting the cane from the zones to the mill yard at a higher rate, so that the week's haulage is completed on Sunday 12h00 instead of 18h00.

The average zone stock levels and hence delay times become lower and the average mill yard stock levels and hence delay times will be higher. The average overall residence time for the system is exactly the same as for the base case because the timing of cane deliveries from the fields and of crushing the cane are unchanged.

A. 5. Variations on base case through deviations from the idealised situation

The simulations thus far were all based on the assumption of ideal operating conditions, especially regarding adherence to the principle of FIFO and steady rates of delivery and of crushing. The effects of deviating from these perfect conditions are simulated and examined.

Case 7: 50% *of cane FIFO*, 50% *LIFO*

In practice, it often is difficult to adhere to a strict FIFO policy, even within each transport category, because the later arrivals block access to the earlier arrivals and, in the case of the zones, practical transport considerations could hamper clearing the cane in strict rotation.

This case assumes that 50% of cane removed from a zone or 50% of the bundle cane stocks crushed out from the mill yard is treated on the basis of last in — first out (LIFO).

The summary in Table 5 shows that the average delay times of cane at the zones and in the mill yard, and also for the overall system, are no different from the base case of FIFO, which is understandable, considering that the stock levels in both cases are identical. However, the spread in delay times, as summarised by the respective standard deviations, is considerably higher than for the base case.

Case 8: *Irregular cane supplies*

Here deliveries were assumed to be: Thursday 25% over-delivery, Friday 25% over-delivery, Saturday 50% under-delivery of daily allocation, i.e. the deliveries were premature.

The growers were assumed to be cutting cane at a steady rate, but were erratic in their deliveries to the zones, sidings and direct to the mill.

The average delay times of cane increase at the zones and in the mill yard, but decrease in the fields, so that the average overall delay remains the same as for the base case, because the cutting and crushing programmes are unchanged. The standard deviation however is wider at all 3 stages.

Conversely, if the irregularity in deliveries had consisted of delayed deliveries, the average delay times for the zones and the mill yard would have been lower than in the base case, and there would have been a risk of running out of cane.

Case 9: *Mill stoppage on Wednesday*

Here the other side of the picture is examined, where milling takes place irregularly. A stoppage lasting the full 12 hours of Wednesday day shift is assumed. To cope with the reduced throughput of the mill for the week, deliveries from growers to the S.A.R. sidings, zones and the mill yard for Thursday were proportionately cut, and Hilo haulage during Wednesday night and Thursday day shifts was reduced. To avoid paying demurrage on S.A.R. trucks already in the mill yard, those which should have been crushed on Wednesday day shift were crushed on Wednesday night.

As expected, the average and spread of delay times of cane for the fields, the zones and the mill yard will all be higher as compared with the base case.

A.6. Variations on base case through changes in grower operating policy

As already stated, examining delays in the fields is not the main object of this investigation. There is however an aspect of grower operating policy that will have a marked effect on delays in the mill yard and on the zones as well as on the overall delays and will for this reason be discussed.

Case 10: *Reduced week-end field stocks*

The one day's allocation of cut cane is still carried over from one harvest day to the next, but over the week-end only $\frac{2}{3}$ day's allocation is carried over, because $\frac{1}{3}$ day's allocation of the carry-over cane is despatched on Sunday to the zones or direct to the mill yard, but not to the S.A.R. sidings. During the course of Sunday, this newly-arrived cane on the zones will be taken to the mill by Hilo. On Sundays the S.A.R. would not be likely to clear the sidings anyway, so there would be no point in taking cane to the sidings on Sundays.

Because the field carry-over cane from Sunday to Monday was $\frac{2}{3}$ day's allocation and the carry-over cane from Monday to Tuesday will be one full day's allocation, it follows that only $\frac{2}{3}$ day's allocation will be delivered to the zones or direct to the mill yard on Monday. The result is that, unlike the base case which already starts off the week on a high level of cane stocks on the zones and in the mill yard, the stock levels remain considerably lower during the course of the week, with the additional cane required to keep the mill going until the early hours of Monday morning being delivered from the fields on Sundays. The crushing programme is moved back slightly to be from Monday 18h00 to Monday 04h00, and the Hilo transport programme is over 144 hours from Monday 18h00 to Sunday 18h00.

The lower average zone and mill yard stocks as well as the lower week-end carry-over of cut cane result in an overall delay value which is even superior to that for Sunday maintenance (Case 3).

B. COMPARISON WITH PRACTICE

In the comparison of actual performance with the foregoing theoretical analyses, operating results for the weeks ending 16th, 23rd and 30th November 1974, representing a period of fairly normal, steady operations, were used.

The simulation and the actual average weekly performances were as follows:

Description	Theoretical simulation		Actual (average)	
	Tons	%	Tons	%
Direct transport . . .	9 780	25	9 815	26,5
Hilos on bundled cane .	7 680	20	6 310	17,0
Hilos on loose cane . .	17 640	45	17 461	47,1
S.A.R. cane . . .	3 900	10	3 955	9,4
Total	39 000	100	37 081	100,0

The data collected in the Sugar Industry Central Board Harvest-to-Crush Time Elapse Survey was used to compare actual delay performance with the theoretical model. Some of the information is summarised in Table 6, which will now be discussed.

When making comparisons, it must be remembered that the simulated delay distribution for the theoretical model is rather inexact in view of the 12-hour time intervals and the simplifying assumptions mentioned in A. 1.

TABLE 6

Comparison of cane delay distributions for theoretical cases and in practice (in hours)

	Fields		Zones		Mill yard	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Base Case — Theoretical .	28	9	16,9	7,1	8,9	9,9
Case 7 — Theoretical: 50% FIFO, 50% LIFO.	—	—	16,9	12,2	8,9	13,8
Actual Performance . .	40	35	24	26	9,7	19,2
Actual, if on 100% FIFO within each transport category	—	—	23	8	9,2	11,3
Actual, if on 100% FIFO, regardless of transport category	—	—	—	—	9,2	5,1

B. 1. Base Case — Theoretical:

This is simply a repetition from Tables F. 4, Z. 4 and Y. 4 of the means and standard deviations of the delay time distributions for the fields, the loading zones and the millyard. S.A.R. sidings were not considered, firstly because of the relatively small amount of cane passing through, and secondly because of the erratic deliveries from sidings to millyard over which neither grower nor miller have any control.

B. 2. Case 7 — Theoretical, 50% FIFO, 50% LIFO:

These values were again taken from the previously mentioned tables. Field stocks had not been simulated on this basis.

B. 3. Actual performances:

Fields

Only data applicable to trashed cane which had been tagged could be used for this analysis. Being only 18% of the total tonnage crushed, it is not very representative.

The mean delay time of cut cane in the field at 40 hours is higher than for the theoretical base case, indicating that more than one full day's cane allocation is carried over from one day to the next in the fields. The standard deviation of 35 hours also is higher than for the theoretical base case. These differences could partly be due to mill stoppages and the time lags in the growers receiving notification and being able to implement cut-backs in allocations.

It is interesting to look at the relative daily deliveries from the fields for the months August to November, 1974, of tagged, trashed cane and what percentage of that cane had been cut on days prior to the day of delivery.

Day of delivery	Mon	Tue	Wed	Thu	Fri	Sat	Sun
% cut prior to day of delivery	69	62	68	70	69	67	—
Relative daily tonnages delivered (Total = 100) .	19	14	18	12	15	18	4

It will be seen that the deliveries on Mondays, and the amount of cut cane carried over into Mondays are about as high as on other days, thus indicating that week-end carry-over stocks are not reduced, such as described in Case 10.

These conclusions are subject to the above reservation on representativeness of the data analysed.

Zones

Again, the data obtained is not fully representative because only 48% of the cane was tagged.

The mean delay time of 23 hours is significantly higher than for the theoretical base case, which may be due to deliveries to the zones being too high near the beginning of the week and because, when there is trouble on the mill, deliveries of cane to the zones can only be reduced the following day. For the weeks ending 12th October, 19th October and 2nd November, 1974, when the mill experienced troublesome operation, the zone delay times were indeed higher, at 28 hours average.

The standard deviation of delay times of 26 hours is considerably higher than for the base case or even for 50% FIFO, 50% LIFO. This will be due to the abovementioned irregularities, deviation from FIFO, and the strong effect that a small number of "stray" outlying points has on the calculation.

Millyard

The delay data is fully representative, as all cane has the times of entering the mill yard and of crushing recorded. The mean millyard delay time of 9,7 hours is slightly higher than for the theoretical base case, the values for the 3 individual weeks being 11,0, 11,4 and 5,8 hours respectively. The latter week was low because the mill had succeeded is crushing ahead of allocation.

The standard deviation of 19,2 hours is higher than for the base case or even for Case 7, again due to irregularities in crushing and delivery rates, deviation from FIFO and the effect of outliers.

B. 4. Actual performance, but assuming 100% FIFO within each transport category:

The extent to which deviation from FIFO affects the spread in delay times can be gaged by comparing the actual standard deviation of delay times with what it would have been if the same hourly tonnages were to be moved as in the actual situation, but on the basis of FIFO.

The principle of FIFO is confined within each transport category because, for practical reasons, each type of cane has its own handling requirements and priorities, e.g. loose cane from spiller Hilos is not suitable for storage on the yard floor, and S.A.R. trucks may not incur demurrage charges. Similar considerations of cane handling were in fact also taken into account in the theoretical simulations in Part A.

Zones

Using a computer, the actual data of tonnages and times of receipts at and despatches from the zones was first grouped per transport method (bundle or spiller Hilo) and then re-arranged in such a way that the *n*th ton of bundle cane to enter the zone stage would also be the *n*th ton of bundle cane to leave the zone stage, and likewise for spiller cane.

Within the limits of approximation errors resulting from grouping into class intervals, the mean delay time of the FIFO cane is the same as for the actual situation, as it also should, but the spread is significantly smaller with a standard deviation of 8 hours.

To implement such a degree of FIFO would be impossible in practice, as it would not only require FIFO at each zone, which might still be possible, but also FIFO on all zones collectively, which the Hilo transport could never achieve.

Millyard

The same was done for tonnages and times of arrivals in the mill yard and crushing of cane. The mean delay time for all cane is approximately the same as in part B. 3, but the standard deviation is significantly smaller at 11,3 hours, and comes near the base case value of 9,9 hours. This indicates that it is deviation from FIFO, probably mainly within the bundle cane stocks, rather than erratic supplies and crushing that are the cause of the wide spread of delay times obtained in practice.

B. 5. Actual performance, but assuming 100% FIFO regardless of transport category

Millyard

The actual data of tonnages and times of receipts at the mill yard and crushing of the cane was re-arranged on the basis of 100% FIFO for all cane, regardless whether it was loose, in bundles or on S.A.R. trucks, i.e. the *n*th ton overall to enter the mill yard would also be the *n*th ton overall to be crushed. This of course is a fictitious situation which assumes that loose cane can be stockpiled to await its turn, and is akin to operating on horizontal line CD on Figure 1, connecting the Total Millyard Receipts and the Total Crush curves.

Referring to Table 6, the mean delay time was again the same as previously, but the standard deviation dropped to 5,1 hours, less than half the value for 100% FIFO within each transport mode obtained in B. 4, and also is lower than for the theoretical base case model which takes into account constraints such as inability to store loose cane.

This exercise merely underlines again how transport and handling considerations unavoidably cause a spread in the distribution of delay times.

B. 6. Irregularity in deliveries and in crushing

In view of the effect which irregular deliveries and irregular crushing have on the distribution of delay times, the daily tonnages of crushing and total millyard receipts for Tuesdays to Saturdays inclusive for the months August to November, 1974, were examined for consistency. These are the days over which normal deliveries of cane to the millyard and a full crushing day should take place.

The results were as follows (Units: Tons cane per 24 hours):

	Mean	*Standard deviation*
Deliveries	5 538	1 008
Crush	5 618	1 068

The conclusion is that daily deliveries and daily crush both exhibit approximately the same degree of variability.

B. 7. Effect of irregular crushing on deliveries

It is logical that the deliveries to the mill over say a 24 hour period should be affected by its performance over the present 24 hours and the past 24 hours, because of reductions in allocations which have to follow any significant mill stoppages.

The extent to which the delivery rate is affected was examined by correlating daily total deliveries for Wednesdays to Saturdays with respective daily crushing for Wednesdays to Saturdays as one independent variable, and Tuesdays to Fridays as the other, for the months August to November, 1974.

Both independent variables were significant, and the multiple correlation coefficient was 0,83, meaning that $(0{,}83)^2 = 69\%$ of the variance in daily deliveries was attributable to the crushing performance of the present and the previous days. The remaining 31% would be due to other reasons.

Conclusions

Although the shift-by-shift simulation technique of cane movements and distribution of delay times deals with an idealised situation of perfect first-in, first-out and steady delivery and crushing rates, it is useful for comparing the merits of alternative operational policies, e.g. what the effect on delay time distribution in the mill yard would be if a mill, presently only on bundle cane, were to instal a spiller.

In the simulations which had been done, the following basic truths were illustrated:

(1) The average delay time of all cane between cutting and crushing is only dependent on the respective timings of the cutting and the crushing programmes.

(2) The average delay time for all cane between cutting and crushing will not be affected by the timing of the Hilo transport programme, although it could affect the respective average delay times for cane coming to the mill by different transport modes.

(3) The average delay of cane in the mill yard is not dependent on the percentage of Hilos which are on spiller, but increasing it will increase the spread of delay times.

(4) Crushing over exactly 6 days reduces the average and the spread of delay times.

(5) Sunday instead of Monday maintenance or alternatively the growers reducing their carry-over stocks of cut cane over the week-end will reduce the average delay between cutting and crushing.

The main reason for the spread of delay times obtained in practice for the zones and the mill yard being so much higher than in the steady-state simulation model is non-adherence to the principle of first-in, first-out, rather than irregular crushing or deliveries.

Acknowledgement

The provision of the detailed data on cane deliveries on computer tape by the Sugar Industry Central Board Data Processing Department is acknowledged. My thanks also go to Trevor Ireland and Marc Masson for their work in the computerized analysis of the data.

APPENDIX 1

Method of calculating the delay distribution of cane stocks

Table Y. 1 — Simulation of cane movements and delay times in the mill yard — Base case: will be used as an example of the method.

Monday day shift

The week started off with zero yard stocks (refer to Sunday night shift closing stocks), and the closing stocks at shift end are 1 490 tons. In agreement with our convention, they will at this stage have an age of ½ day, and this tonnage will be written in under the corresponding column. The mill has however crushed 500 tons during that shift, all of which entered the yard during the same shift, i.e. there will be 500 tons with a delay of zero for that shift, consisting of 240 tons of spiller cane, and 260 tons of bundle cane.

Monday night shift

3 040 tons of cane are crushed, of which 1 450 comes from spiller hilos, and the balance of 3 040−1 450=1 590 therefore all from bundles, because S.A.R. cane is only crushed during day shift. Because we assume first-in, first-out for bundle cane, all of the 1 490 carry-over stocks from the previous shift will be crushed, as well as 100 tons of the bundle cane which had entered the yard during the present shift. Adding last-mentioned to the 1 450 tons of spiller cane, a total of 1 550 tons of cane was crushed during the same shift that it entered the yard, i.e. this must appear under the column headed zero age. The entire yard closing stock of 1 180 tons will consist of 650 tons S.A.R. + 630 tons bundle Hilo received during the present shift, less 100 tons of it crushed, and all have an age of ½ day, because no cane from the previous shift remains.

Tuesday day shift

3 040 tons of cane are crushed, consisting of the 1 450 tons of spiller cane which entered the mill yard during that shift and must of necessity be crushed, 650 tons of S.A.R. cane which entered during the previous night shift and must also be crushed to avoid incurring demurrage penalties, and the balance of 940 tons from bundle cane. The carry-over stock of 1 180 tons from the previous shift consists of 650 tons S.A.R. cane and 530 tons bundle cane, all of which is crushed during the present shift, meaning that an additional 940 − 530 = 410 tons of bundle cane must come from the consignments received during the present shift. Adding this to the 1 450 tons of spiller cane, we obtain 1 860 tons which was crushed during the same shift that it entered, with an age of zero. Because all the cane from the previous shift was crushed, the mill yard closing stock of 1 850 tons will consist only of 1 630 tons self-delivery + 630 tons bundle Hilo cane which had entered during the present shift, less the 410 tons crushed, and will have an age of ½ day.

Tuesday night shift

3 040 tons of cane are crushed, of which 1 450 is from spiller Hilos and the remaining 1 590 must come from bundles. Again in accordance with the requirement of FIFO for bundle cane one must first draw from the 1 850 tons stock brought over from the previous shift which, at that stage, had an age of ½ day. After crushing there will however remain 1 850−1590 = 260 tons of that stock, which will have an age of one day by the end of this shift. The remainder of the yard stock consists of the 650 tons S.A.R. + 630 tons bundle Hilos = 1 280 tons which had arrived during the shift, none of which was crushed. The only cane crushed during the same shift that it entered the yard is the 1 450 tons of spiller cane, and incurred a delay of zero days.

So we continue from shift to shift, always allocating cane for supplying the crushing requirements in the order of spiller Hilo cane, S.A.R. cane (if on day shift) and bundle cane. The oldest bundle cane will always be crushed first, and any cane remaining will be ½ day older at the end of the shift than at the end of the previous shift.

The part of Table Y. 1 dealing with age distribution of stocks is repeated as Table 7.

TABLE 7

Portion of Table Y. 1 dealing with stocks, to illustrate method of of calculating delay distributions

Day and Shift	Age distribution of stocks (In days)					
	X = :	0	½	1	1½	2
Monday — D		500	1 490			
N		1 550	1 180			
Tuesday — D		1 860	1 850			
N		1 450	1 280	260		
Wednesday— D		1 500	2 210			
N		1 450	1 280	620		
Thursday — D		1 450	2 260	310		
N		1 450	1 280	980		
Friday — D		1 450	2 260	630	40	
N		1 450	1 280	1 340		
Saturday — D		1 450	2 260	630	400	
N		1 450	1 280	1 700		
Sunday — D		1 450	630	630	760	
N		—	—	—	—	
Tonnage in for X days *or more*			20 540	7 100	1 200	—
Tonnage in for X days		18 460	13 440	5 900	1 200	—
% of weekly crush in for X days		47%	35%	15%	3%	—

Representing the heading of each column by age "X" days, the tonnages are totalled up. It is important to remember that all the cane which appears say in the X = 1½ day column must also earlier on have appeared in the 1-day and the ½-day columns.

The totals should therefore be considered to be of a cumulative nature, e.g. under X = ½ we have that 20 540 tons have been in the yard for ½ day *or more*; under X = 1 7 100 tons have been in the yard for 1 day *or more*; under X = 1½ 1 200 tons have been in the yard for 1½ days *or more*; under X = 2 zero tons have been in the yard for 2 days *or more*; etc.

The amount of cane which incurred a total delay of 1½ days will be the difference between the totals for "1½ days or more" and "2 days or more", that is, 1 200 − 0 = 1 200 tons. Likewise, the tonnage which incurred a total delay of one day will be the difference between the totals for "one day or more" and "1½ days or more", that is, 7 100 — 1 200 tons = 5 900 tons, and for ½ day delay will be 20 540 — 7 100 = 13 400 tons.

The column under X = 0 is treated differently, in that the quantities are not really stocks, but represent tonnages which had left the mill yard within the same shift that they arrived, i.e. by our convention they incurred a total delay of zero hours in the mill yard. The quantities are therefore already in the correct format. As a check, totalling the values for "Tonage in for X days", gives 18 460 + 13 440 + 5 900 + 1 200 = 39 000 tons, which is the total tonnage that passed through the mill yard during the week. These tonnages can then easily be converted to percentages by multiplying them by 100/39 000.

APPENDIX 2

Calculation of means and standard deviations

Mean

If $X_1, X_2, ---, X_n$ are the values for which the mean is to be obtained, and the value X_1 appears W_1 times,

X_2 appears W_2 times,

....,

X_n appears W_n times,

the mean is defined as

$$\bar{X} = \frac{X_1W_1 + X_2W_2 + \ldots + X_nW_n}{W_1 + W_2 + \ldots + W_n}$$

Using the delay distribution in Appendix 1 as example:

$$\text{Mean delay time} = \frac{0 \times 18\,460 + 0{,}5 \times 13\,440 + 1 \times 5\,900 + 1{,}5 \times 1\,200}{18\,460 + 13\,440 + 5\,900 + 1\,200}$$

= 0,371 days

= 8,9 hours.

Standard deviation

This could be described as a measure of the dispersion of the distribution about the mean.

Using the same notation, the standard deviation is defined as:

$$S = \sqrt{\frac{W_1(X_1-\bar{X})^2 + W_2(X_2-\bar{X})^2 + \ldots + W_n(X_n-\bar{X})^2}{W_1 + W_2 + \ldots + W_n - 1}}$$

Again using the delay distribution in Appendix 1 as example: Standard deviation of delay time

$$= \sqrt{\frac{18\,460(0-0{,}371)^2 + 13\,440(0{,}5-0{,}371)^2 + 5\,900(1-0{,}371)^2 + 1\,200(1{,}5-0{,}371)^2}{18\,460 + 13\,440 + 5\,900 + 1\,200 - 1}}$$

= 0,413 days

= 9,9 hours.