USE OF COMPUTER SIMULATION IN PREDICTING THE EFFECT OF MILL STOPPAGES ON CANE TRANSPORT FLEET UTILISATION FOR A CANE HANDLING INSTALLATION USING A SPILLER

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Abstract

One of the main objections against the use of a spiller installation for off-loading cane from Hilos at a sugar mill is the fact that, when crushing operations cease as a result of mechanical difficulties, any vehicles containing loose cane at that time cannot be off-loaded until the mill is operational again, resulting in under-utilisation of the transport fleet. This paper describes how the severity of the problem was estimated by using a computerised Monte Carlo procedure to simulate the main operations which occur immediately prior to and during a mill stoppage, and immediately after the mill has been started up again. Among the random variables which are simulated, are the duration of mill stoppages, the number of vehicles loaded with loose cane at the time of the breakdown, the pattern of arrival times of such vehicles, the crushing times of the cane, and the number of loads of cane on the spiller table. The results show that the problem is not serious.

1. Reason for the investigation

Congestion of cane transport vehicles at the Darnall mill yard has become a problem during the past few years, and the cane transport company have complained that the long waiting times for off-loading at the mill yard were causing under-utilisation of their vehicles (called Hilos). Serious consideration is being given to supplementing the existing cane off-loading facilities at Darnall, consisting of 4 gantry cranes. Putting in a 5th crane, unless it were in a separate bay by itself, would increase the amount of crane interference and thus to some extent reduce the additional benefits gained in terms of handling capacity. A spiller installation, on the other hand, has a far higher handling capacity than a crane, does not interfere physically with the operation of the existing gantry cranes and reduces the problem of having to transport the bundle chains back to the loading zones. One of the biggest objections to the spiller is that, because the Hilos contain loose instead of bundled cane, their contents always have to be off-loaded directly onto the spiller table. Apart from the small capacity of the spiller table itself, there is no buffer capacity for the loose cane in the event of a mill stoppage, unless the Hilo is painstakingly off-loaded by means of a grab, the cane deposited on to the floor of the mill yard, and upon commencement of mill operations, picked up from the yard floor again by grab. Because this procedure usually is avoided whenever possible, it means that any vehicles which contain loose cane at the start of a mill stoppage cannot be used for subsequent hauls until the mill is running again. The mill will normally be in radio contact with the loading zones, and in the event of any breakdown which is expected to last longer than a couple of minutes, the personnel at the zones will be instructed to keep the chains on the bundles when loading any subsequent Hilos, so that these Hilos could, upon arrival at the mill yard, be off-loaded by gantry crane. This, however, does not solve the problem of the Hilos which already contain loose cane at the commencement of the mill stoppage period.

The object of this investigation was to determine how serious the effect of mill stoppages would be on a transport fleet having a proportion of its vehicles on loose cane for off-loading by spiller. Thought was given to using historical transport data for the Huletts mill at Amatikulu, which has a spiller installation, but the delays in the mill yard prior to off-loading which the vehicle drivers log, do not show whether the cause was a mill stoppage, congestion in the mill yard through too many vehicles arriving in rapid succession, or by some mishap which could affect the Hilos on bundled cane as well as on loose cane. For this reason it was decided rather to calculate the effects of mill breakdowns from first principles, by analysing the cycle of cane haulage, off-loading and crushing.

2. Description of transport cycle for loose cane

Figure 1 illustrates the zone-mill circuit for Hilos carrying loose cane. The empty Hilo leaves the mill yard and proceeds to one of several loading zones. At the zone, the Hilo might have to wait its turn if a previous Hilo is still being loaded, and will then be loaded with bundled cane, and the chains pulled out by means of the zone crane. Loaded, the Hilo proceeds on its return journey to the mill, where it first has to be weighed in, and might have to queue at the weighbridge. Subsequently it will be off-loaded by spiller onto the spiller table. The operation of the spiller itself is so rapid that it rarely is a bottle-neck. However, the spiller can only off-load a vehicle if there is sufficient space on the spiller table to accept the load, and if already full, can only be cleared at the rate at which the mill is crushing. If the vehicles temporarily bring cane in at a rate higher than the crushing rate, the mill will not be able to keep up, and the vehicles would then start queueing at the spiller.

It stands to reason that, in a properly operated

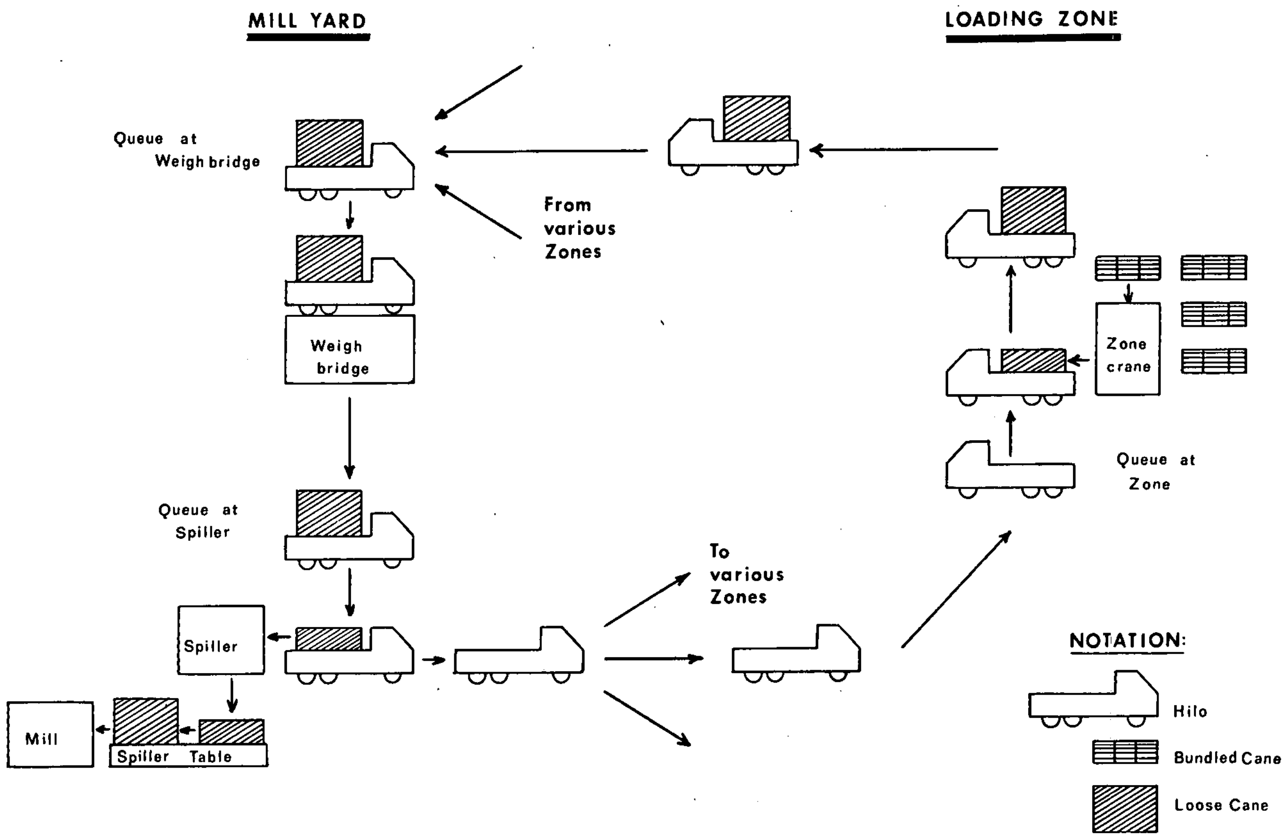

FIGURE 1 Schematic representation of Zone-Mill circuit for Hilos on loose cane.

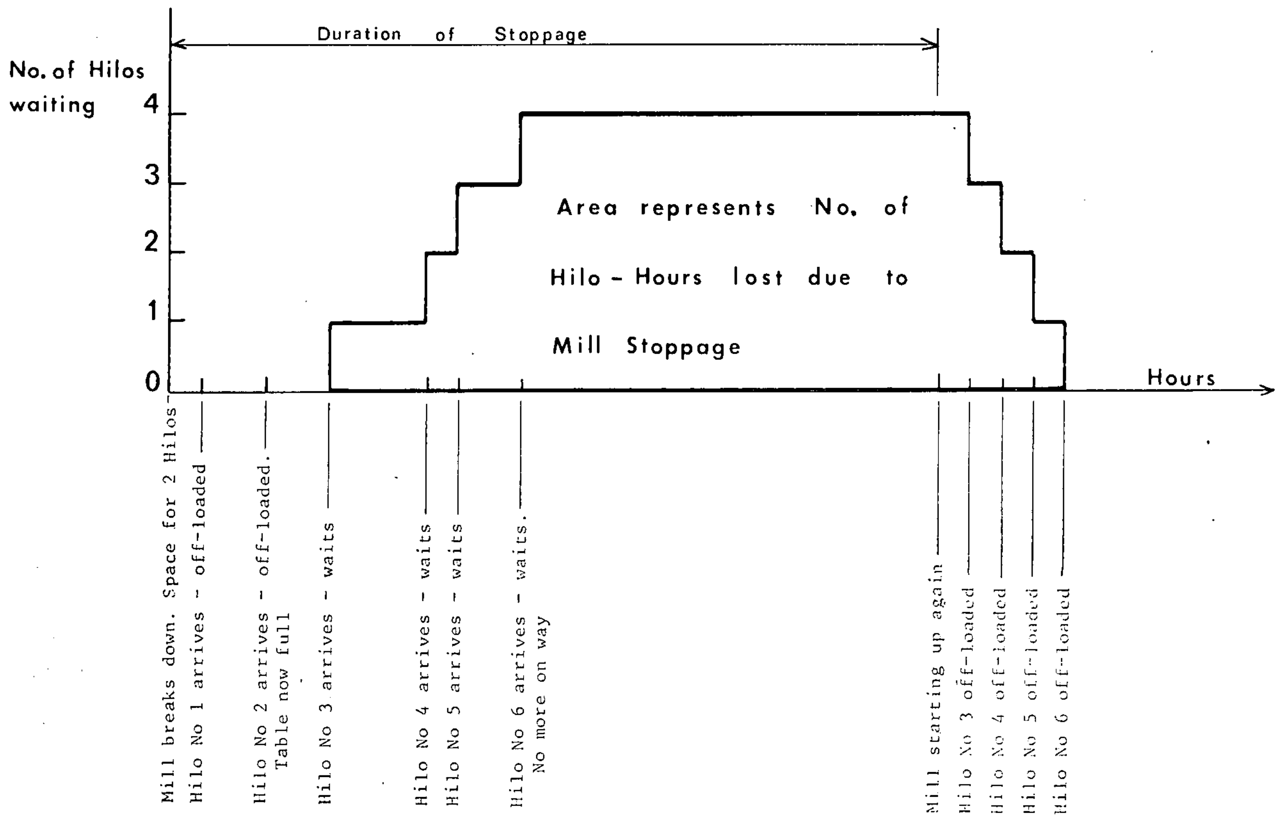

FIGURE 2 Graphical representation of consequences of a Mill stoppage

system, clearing the spiller table should be given priority over clearing the gantry table, firstly to leave sufficient space on the spiller table to cope with surges in arrivals of spiller Hilos, and secondly to leave as much effective buffer capacity as possible to minimise the consequences of a mill breakdown.

3. Description of events during a mill stoppage

Figure 2 shows graphically the effect of mill stoppages on Hilo off-loading. The horizontal axis represents the time elapsed since start of the stoppage, and vertical axis the number of Hilos with loose cane waiting to be off-loaded. In this example it was assumed that, at the start of the stoppage, there was sufficient space on the spiller table for two Hilo loads, and that six Hilos in the system contained loose cane. Such Hilos as were still empty would of course be loaded with bundled and not loose cane. The Hilos then start arriving at the mill at various times. The first two Hilos can still be off-loaded onto the spiller table, as there is still space. When the third and subsequent Hilos arrive, they have to stand idle, and on each arrival the graph shows an increase of one unit in the number waiting. After the sixth and last Hilo has arrived, the number of Hilos waiting remains at 4. When the mill starts up again, the Hilos cannot immediately be off-loaded, but must wait for the mill to crush sufficient cane to leave space for at least one Hilo load of cane, before that Hilo can be off-loaded. With each Hilo off-loaded, the number waiting is reduced by one unit, until all the back-log has been cleared. The total area under the curve represents the number of Hilo-hours lost as a result of that stoppage.

4. Problems in calculating effect of mill stoppages

It is very difficult, if not impossible, to calculate by algebraic means the effect of mill stoppages on Hilo idle times, because some of the most important variables in the calculations such as duration of the mill stoppage, number of Hilos with loose cane at the commencement of the stoppage, pattern of time intervals between Hilo arrivals, can vary unpredictably over a wide range, and so will the way in which they interact to determine the outcome of any particular case. Use was therefore made of a Monte Carlo simulation by computer. Appendix 1 describes the concept of Monte Carlo simulations. The simulation language used was CSL (Control and Simulation Language), and the computer was an ICL 1902 A.

5. Elements in the mill stoppage simulation

(*a*) *Mill stoppages:* The frequency distribution of the duration of mill stoppages for Darnall for the 1971 / 72 season was obtained from operating log sheets at the mill and is shown in Table 1. Stoppages caused by lack of cane were not included in the survey, because the mill would still have been capable of emptying the spiller table as and when a Hilo arrived. In cases where a false start was made after a stoppage commenced, two such stoppages would be added together and considered as one long stoppage, the reasoning being that the mill would not have had a chance to clear any of the back-log of Hilos. The computer was programmed to generate random stoppage times in accordance with the same probabilities as in Table 1.

TABLE 1

Frequency distribution of duration of mill stoppages during 1971 / 72 season at Darnall

Range of stoppage duration (minutes)	Midpoint (minutes)	No. of occurrences
0 to 10	5	134
10+to 20	15	126
20+to 30	25	92
30+to 40	35	51
40+to 50	45	23
50+to 60	55	19
60+to 80	70	42
80+to 100	90	14
100+to 120	110	11
120+to 150	135	13
150+to 180	165	5
180+to 210	195	8
210+to 240	225	6
240+to 270	255	3
270+to 300	285	2
	450	1
	510	2
	570	2

(*b*) *Number of Hilo loads on spiller table at commencement of mill stoppage:* No figures for this were available from practical operations at the time the simulation was done, but from another, as yet unpublished, simulation by the author of the detailed operations of a mill yard applicable to normal mill operation, a frequency distribution of the number of Hilo loads on the spiller table was estimated:

Loads on Table	*Relative frequency*
0	2 378
1	2 175
2	745
3	300
4	100

Spiller tables usually have a capacity of 3 Hilo loads of cane. The above-mentioned simulation assumed that priority would always be given to feeding the mill from the spiller table in preference to feeding from the gantry table, and because this state of affairs cannot always be realised in practice for various reasons, it was assumed that the effective maximum capacity of the spiller table would be only 2 Hilo loads. A random number of Hilo loads on the table was generated at the start of each stoppage, in accordance with the above probabilities.

(*c*) *Number of vehicles loaded with loose cane:* It was estimated that, should use be made of a spiller at Darnall, approximately 4 zones at any one time would be handling loose cane, with estimated average travelling times (one way) of 18, 27, 36 and 45 minutes, and served by 1, 2, 3 and 4 Hilos respectively.

To reduce the problems of returning chains to the zones, it was decided that the more distant zones should preferably be put on loose cane.

The average time in the yard was assumed to be 25 minutes, and in the zones 17 minutes. It follows

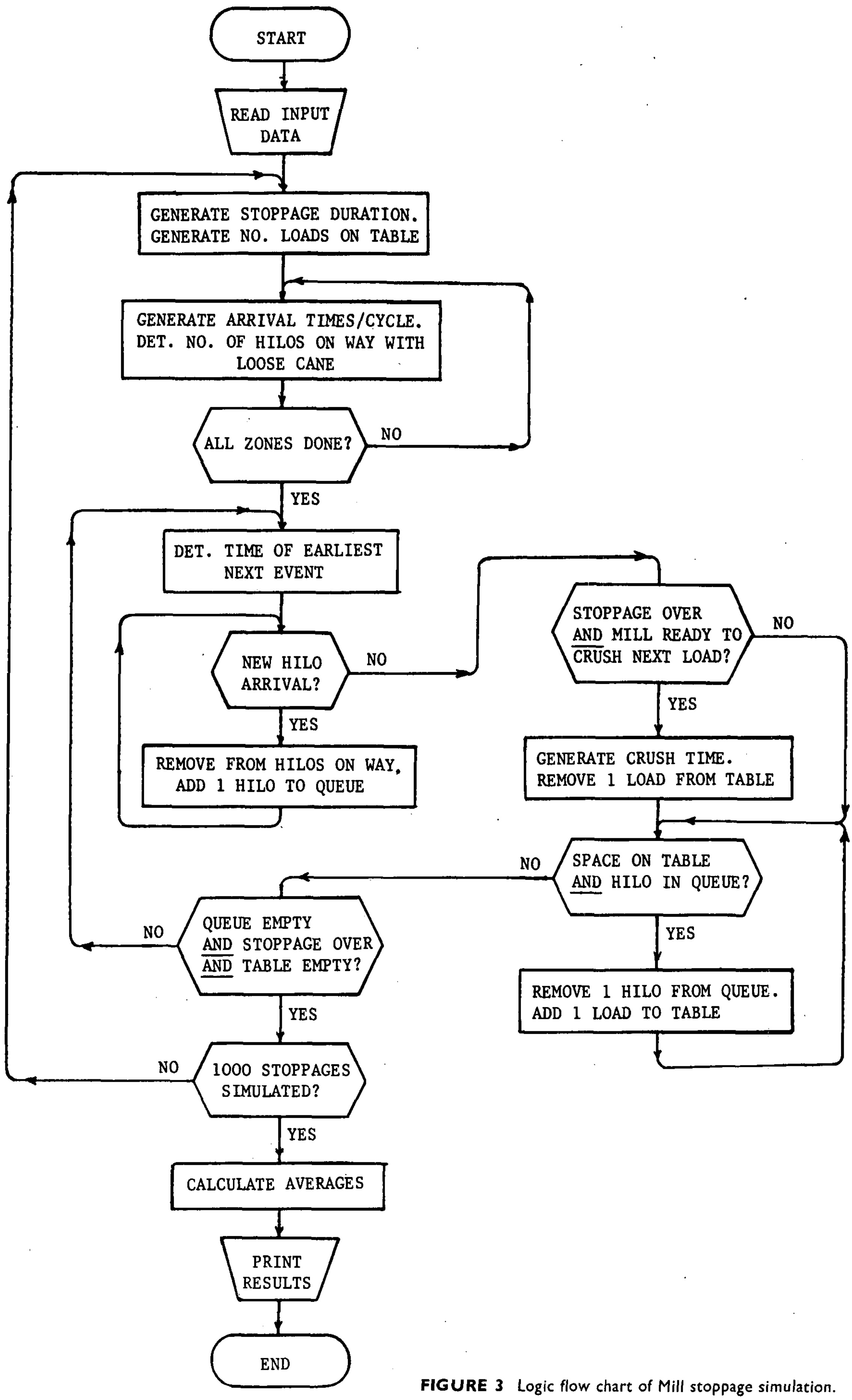

FIGURE 3 Logic flow chart of Mill stoppage simulation.

that the average cycle time for a Hilo operating on a given zone = Average time at zone + Average time in yard + 2 × (Travelling time). Within this cycle the position of any Hilo at a given instant will be a matter of chance. If one assumes the arrival times of successive Hilos in the mill yard to be completely independent of one another (which is not strictly true, but for this simulation is a reasonable assumption), it can be shown that[1] on a time scale, the Hilos will be distributed within the cycle for the zone in accordance with a rectangular probability distribution. (Figure 5 is an example of such a probability distribution). This kind of probability distribution can easily be generated by the computer, and will represent the arrival times at the spiller during normal operation.

Arrival time values obtained which are less than (Loading time in zone + Travelling time from mill to zone + Time in yard) will represent Hilos which, at the time of occurrence of the mill stoppage, were or had already been at the zone and therefore contained loose cane and would be affected by the stoppage.

For example: In the case of zone 4,

total cycle time $= 17 + 25 + 2 \times 45$
$= 132$ minutes.

Assume that the 4 values, representing the arrival times of the 4 Hilos, chosen out of a rectangular distribution of 0 to 132, are 19, 56, 67 and 124. Three of these values are less than $17 + 25 + 45 = 87$, meaning that for this random sample, 3 Hilos contained loose cane when stoppage occurred. As mentioned previously, the assumption is that the loading zone remains in radio contact with the mill, so that the remaining Hilo would, upon leaving the zone, contain bundled and not loose cane.

(*d*) *Arrival times of the Hilos:* These are given by the random times determined in (*c*) above. In our example, the arrival times of Hilos with loose cane, measured from the commencement of the mill stoppage, would be 19, 56 and 67 minutes.

(*e*) *Crushing rate of cane:* The Darnall mill crushes at a rate of approximately 210 tons per hour. The average Hilo carries 18 tons of cane, so that the mill requires approximately 5 minutes to crush one Hilo load of cane. The crushing rate, or more specifically, the rate of withdrawal of cane from the spiller table is not constant, but has a random element in it, and the crushing time per Hilo load of cane was assumed to follow a normal distribution with mean = 5 minutes and standard deviation = 1 minute. This the computer can also generate.

6. The complete simulation programme

Referring back to Figure 2, we have now defined all the necessary elements to construct the area representing the number of Hilo-hours lost due to the stoppage. From (*a*) we have the duration of the stoppage, from (*b*) how many Hilo loads of cane can still be off-loaded onto the spiller table, from (*c*) how many Hilos with loose cane in total could arrive at the mill if the stoppage were long enough, from (*d*) the arrival times of the Hilos at the mill and from (*e*) the crushing times for the successive Hilo loads of cane when the mill starts up again. It should be remembered, of course, that for a stoppage of short duration, the mill might be running again before all the Hilos with cane have arrived at the mill, in which event we would not get as far as the plateau on the graph, representing the maximum number of Hilos with loose cane standing idle.

The next step is to assemble these main elements into a complete program for the computer. Before writing out the instructions in the appropriate computer simulation language, it is useful to construct a logic flow chart, which is shown in Figure 3 and described in Appendix 2.

The entire procedure of Figure 2 is repeated for say 1 000 breakdowns, and the mean time in Hilo-hours lost per breakdown is calculated. This mean is then multiplied by the number of stoppages expected or recorded per season (450 for Darnall for 1971 / 72) and a total vehicle time in Hilo-hours lost per season is obtained.

7. Results and discussion

Figure 4 shows a sample of the computer print-out for the base case. Some of the results are given in Table 2.

(*a*) *Base case:* A total of 690 Hilo-hours per season would be lost due to Hilos not being off-loaded as a result of mill stoppages occurring during a season. Considering that a fleet of 20 operational Hilos hauling 6 days per week over 9 months represents

TABLE 2

Effect of No. and allocation of Hilos on loose cane on lost Hilo-hours / season

Average delay time at zone = 17 minutes
Average delay time in mill yard = 25 minutes

Zone ref. no.	1	2	3	4	Total no. of Hilos	Avr. Inter-arrival time (mins.)	Hilo-hours lost/ season
One-way travelling time (mins.)	18	27	36	45			
No. of Hilos / zone:							
Case 1 (Base case)	1	2	3	4	10	11.08	690
Case 2	0	1	3	4	8	14.92	558
Case 3	4	3	0	1	8	11.10	684

EFFECT OF MILL BREAK-DOWNS ON DELAYS OF TRUCKS CARRYING LOOSE CANE.

19/03/73 00003/73

INPUT DATA:

Frequency distribution of mill breakdowns.

Duration (Minutes):	5	15	25	35	45	55	70	90	110	135	165	195	225	255	285	450	510	570
No. of breakdowns:	134	126	92	51	23	19	42	14	11	13	5	8	6	3	2	1	2	2

Number of breakdowns per season: 450

TRAVELLING DATA:

Average delay of Hilo at zone (Mins.): 17
Average delay of Hilo in yard (Mins.): 25

Zone reference no.	1	2	3	4
No. of Hilos allocated to zone	1	2	3	4
Mean trav. time (one-way) (Mins.)	18	27	36	45
Mean inter-arrival times / zone (Mins)	78.00	48.00	38.00	33.00

Overall mean inter-arrival time during normal operation (Mins.): 11.08

CRUSHING DATA:

Crushing time per Hilo load of cane: Mean: = 5 mins. Std. Dev. = 1 min.
Effective table capacity: 2 Hilo loads of cane
Frequency distribution of no. of loads on spiller table.

No. of loads	0	1	2
Occurrence	2378	2175	745

Answer is based on 1000 simulation passes.

ANSWER:

Time lost per breakdown in Hilo-hours : 1.53
Average maximum no. of Hilos held up : 1.19
Time lost per season, in Hilo-hours : 689.72

FIGURE 4 Computer print-out for Case 1 (Base case).

110 000 Hilo-hours per season, the time lost is very small, particularly when comparing the advantages to be gained by the transport company through shorter off-loading times and queueing times in the mill yard during normal mill operation, and the fact that for a very long mill stoppage the transport fleet would in any event have to stop hauling cane even in a system operating entirely on bundled cane, simply because the yard would become too full to place any additional cane.

(*b*) *Effect of number of Hilos on spiller:* Table 2 shows, that if one reduces the number of Hilos on spiller from 10 to 8 in such a way that the more remote zones will continue to be served by spiller Hilos (Case 2), then the average inter-arrival time of Hilos will increase, as expected, and the number of Hilo-hours lost per season will be reduced from 690 to 558. On the other hand, if the number of Hilos is reduced to 8, but concentrated on the closer by zones (Case 3), so that the average inter-arrival time will again be of the same order as the base case, the time lost per season will go up again to 684 Hilo-hours. One can therefore conclude that the number of Hilo-hours lost per season will depend not so much upon the number of Hilos on spiller as on the average inter-arrival times of such Hilos at the mill yard.

(*c*) *Effect of capacity of the spiller table:* For cases 4 and 5 the effective capacity of the spiller table was increased to 3 and 4 Hilo loads respectively. The results were as follows:

	Effective capacity of Spiller table	*Hilo-hours lost / season*
Case 1:	2	690
Case 4:	3	455
Case 5:	4	263

It can be seen that, by increasing the capacity of the spiller table, the number of Hilo-hours lost per season can indeed be reduced. Deciding on the optimum size of table would be a matter of balancing with the additional capital required for increasing the size of the table against the possible savings to the transport company.

8. Conclusion

By means of computer simulation, it was possible to calculate the effect of a spiller on enforced Hilo idle time, and also how it would be influenced by different operating conditions, such as number of Hilos on loose cane, average travelling time to zones, and capacity of spiller table.

In our particular problem, the plans for installing a spiller were held in abeyance because the simulation on detailed mill yard operations, mentioned in Section 5 (*b*), showed that the delays which the vehicles experienced in waiting for off-loading could be reduced by improving operations with the existing equipment, and it was decided first to concentrate on those aspects. Should this not solve the problem of vehicle congestion, a spiller could be installed without reservations about it causing excessive enforced Hilo idle time.

APPENDIX 1

Brief explanation of the Monte Carlo method of simulation

First of all the concepts of random variable and stochastic process will be explained.

Random variables

A random variable is a variable which can unpredictably assume any one of a range of different values, and the probability of that value being assumed is given by its probability density function. If we throw a die, the value landing uppermost is a random variable, which could take on any one of the values of 1, 2, 3, 4, 5 and 6, each with a probability of $\frac{1}{6}$. (Figure 5).

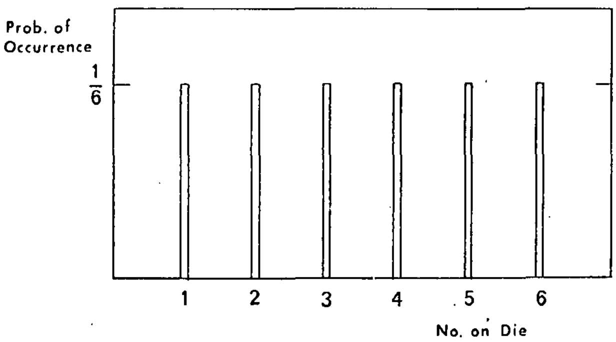

FIGURE 5 Probabilities of the outcome of Throwing a Die.

Or we could take a disc which can be spun around its axis, and mark off five sectors extending 36°, 72°, 144°, 72° and 36° of arc, and number them 1, 2, 3, 4 and 5 respectively. (Figure 6). On spinning the disc one could consider the value assigned to the sector which comes to rest opposite a fixed pointer as a random variable, and the probabilities of attaining the values 1, 2, 3, 4 and 5 will respectively be 10%, 20%, 40%, 20% and 10%. The duration of the mill stoppage, etc., mentioned in Section 5 are all random variables.

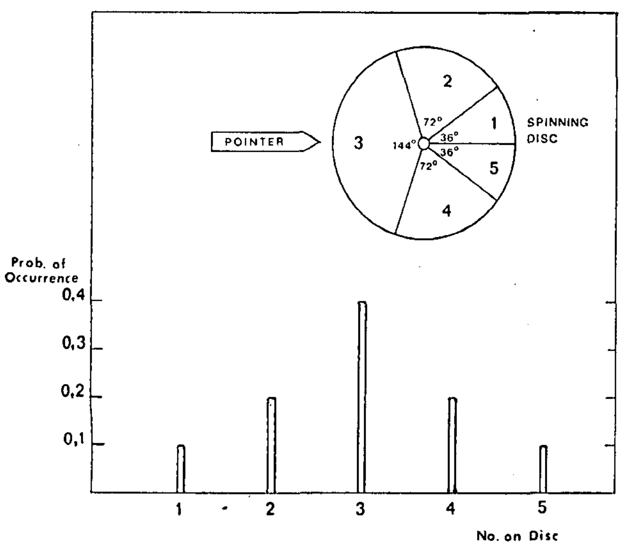

FIGURE 6 Probabilities of the outcome of spinning a Disc.

Stochastic process

A stochastic process can be regarded as any process in which some of the more important variables are random variables. A typical example is customers arriving at a check-out point in a supermarket, where the mean inter-arrival time between successive customers is say 5 minutes, and the mean service time of the server at the counter 4 minutes. If all inter-arrival times were exactly 5 minutes, and likewise if all service times were exactly 4 minutes, there would be no question of a queue forming. In practice, however, the customers arrive in a certain random pattern, with a probability distribution of inter-arrival times possibly as shown in Figure 7, and the service time required per customer will also vary randomly from customer to customer, possibly in accordance with the distribution shown in Figure 8, i.e. inter-arrival times and service times are random variables.* It is obvious that whenever the situation

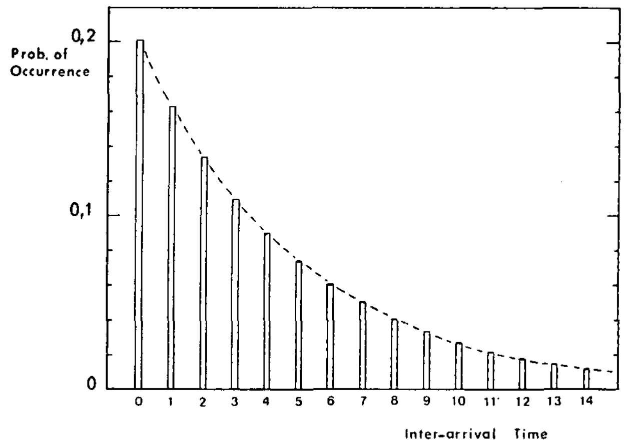

FIGURE 7 Probabilities of the occurrences of times between Customer arrivals.

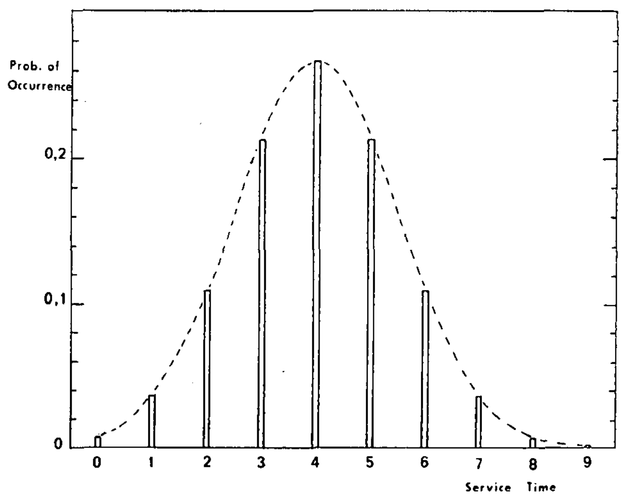

FIGURE 8 Probability distribution of service times required by customers.

*Figure 7 and Figure 8 show a negative exponential and a normal probability density function respectively. Although these are continuous functions, to simplify explanations they are shown as being defined only for discrete, integer values of the random variable. Besides, the computer simulation language used is such that only discrete values of time (say, in multiples of one minute), are sampled, both for discrete and continuous random variables.

occurs that a customer requires a longer than average service time and the arrival time of the next customer occurs relatively shortly after the arrival of the present customer, this next customer would have to wait his turn, i.e. a queue will start building up.

The task

The task in analyses of stochastic processes usually is to determine the average waiting time per customer or the average queue length under given conditions, and to calculate the effect of alternative policies such as bringing in an additional server, or having separate queues for people requiring long and short service times. Unfortunately, in all but the simplest cases, an analytical solution is prohibitively difficult if not impossible.

The Monte Carlo simulation

The only other way to obtain an answer is to simulate the operation of the process by randomly picking out inter-arrival times, service times, etc. in accordance with the appropriate probability distributions, and to let these times interact in a logical, realistic manner. The random samples of times could be obtained by spinning a roulette wheel, rather like the disc previously mentioned, shuffling and drawing from a pack of appropriately numbered cards, or reading off the values from tables of random numbers which occur in accordance with the appropriate distribution. Because this method suggests the use of gambling devices, it is generally called the Monte Carlo method.

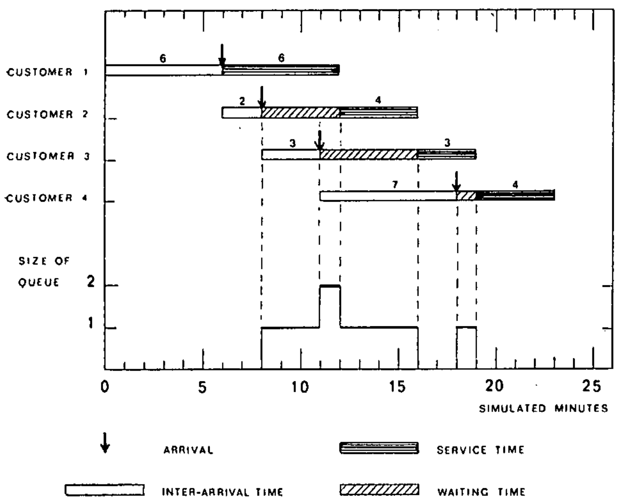

FIGURE 9 Simulation of customers arriving, waiting and being served.

In Figure 9 a bar-chart representation of such a simulation for the first 4 customers is given, in which the randomly sampled inter-arrival times are 6, 2, 3 and 7 minutes and their service times 6, 4, 3 and 4 minutes respectively. The occurrence of waiting times and the build-up of queues through the interaction of these random times are shown.

For the results of the Monte Carlo method to be reliable, the cycles of operation should be repeated many times, preferably several hundred times, and this would be very tedious to simulate by pencil and paper and using one of the above-mentioned methods of generating random variables. Fortunately, with the advent of the digital computer, this simulation can be programmed so that the computer will perform all the necessary logical operations, including the generation of random variables in accordance with the probabilities specified by the programmer. Computer languages are available, which are specially designed for performing simulation work of this kind.

APPENDIX 2

The logic flow chart

The logic flow chart shows the basic structure of the simulation program including the generation of the random elements previously discussed and is given in Figure 3. The blocks will be discussed in the sequence in which they occur.

START

This signifies the starting-point of the logic flow chart.

READ INPUT DATA

In Figure 4, is an example of the print-out of a computer run. The input data is shown, which includes information on number of zones, travelling times to the zones, mill residence time, frequency distribution of mill stoppages, etc. This is data which can easily be varied by merely changing one or more of the data cards, and does not require changing the program itself.

GENERATE STOPPAGE DURATION
GENERATE NUMBER OF LOADS ON TABLE

At the start of simulating a particular stoppage, it is necessary to know the duration of the stoppage and the number of loads of cane on the spiller table. Both these quantities are determined through the random number generation program in the computer, as previously described in 5 (*a*) and (*b*).

GENERATE ARRIVAL TIMES PER CIRCUIT
DETERMINE NUMBER OF HILOS ON WAY WITH LOOSE CANE

At the start of any one stoppage simulation, it is necessary to know at what times the Hilos on a given zone circuit will arrive at the spiller, and seeing that we are only interested in Hilos which contain loose cane, we want to know which of these Hilos will be carrying loose cane. The determination of these quantities were discussed in 5 (*c*) and (*d*).

ALL ZONES DONE?

Because each zone circuit will have its own number of Hilos and travelling distance, the process of generating random arrival times must be repeated for each zone. Therefore it is necessary to test when all the zones have been done, so that the program can move to the next step.

DETERMINE TIME OF EARLIEST NEXT EVENT

The program scans all the times of future events (Hilo arrival, completion time of crushing a load of cane, end of stoppage), and advances the imaginary clock to the earliest of these future events, which now becomes the present.

NEW HILO ARRIVAL?

A test is made whether, at this point of time, another Hilo has arrived.

REMOVE FROM HILOS ON WAY
ADD ONE HILO TO QUEUE

If a new Hilo arrived, it is removed from the group of Hilos on their way from the zones, and is added to the queue of Hilos at the spiller. Because of the possibility that more than one Hilo could arrive at the spiller at the same time, the test has to be repeated.

STOPPAGE OVER
AND MILL READY TO CRUSH NEXT LOAD?

The mill can only commence crushing a Hilo load if firstly, the stoppage is over, and secondly if it is no longer engaged in crushing a previous load. These conditions are tested for.

GENERATE CRUSH TIME
REMOVE ONE LOAD FROM TABLE

If the answer to both conditions of the test is "yes", the mill can commence crushing a new load of cane from the spiller table. Through the random number generation facility of the computer, a time for the duration of this particular crushing operation is generated, and this load is removed from the table, thereby leaving space for any Hilo which might be at the head of the queue at the spiller.

SPACE ON TABLE
AND HILO IN QUEUE?

A test is done to determine whether the spiller can place a Hilo load of cane onto the table. For this to be possible, it obviously must be necessary firstly, that there should be sufficient space on the table and secondly, that there should be at least one Hilo in the queue.

REMOVE ONE HILO FROM QUEUE
ADD ONE LOAD TO TABLE

If the answer to the test is positive, the spilling operation can commence (operating time assumed to be negligible), which involves removing one Hilo from the head of the queue, and adding its load to the table. Because, particularly at the start of a stoppage, there could be space for more than one Hilo on the table, this test is repeated.

QUEUE EMPTY
AND STOPPAGE OVER
AND TABLE EMPTY?

If the answer to the previous test is negative, it might be because the mill had been running sufficiently long after the stoppage ended for it to clear away the back-log so that there are no further Hilos in the queue. One can only make sure that the consequences of the stoppage have fully been accounted for by testing if there are no further Hilos in the queue, no loads on the table, and the stoppage is over. If this is not the case, the simulation for that particular stoppage is not yet over, and the program branches back to where it has to determine when the earliest next event will take place, and to advance the imaginary clock to that time.

1 000 STOPPAGES SIMULATED?

If the answer to all three conditions of the previous test was positive, it means that that particular stoppage simulation has come to an end. However, to obtain a mean result, it is necessary to perform a large number of such stoppage simulations, (say 1 000) and the program tests whether this number has been achieved. If not, the program branches back to where a new stoppage duration is generated.

CALCULATE AVERAGES

If the answer to the previous test is positive, simulation work is complete, and the averages have to be calculated.

PRINT RESULTS

The computer prints out the results. An example of these is shown in Figure 4.

END

This signifies the end of the logic flow chart.

REFERENCES

1. Ross, Sheldon M. Applied probability models with optimization applications (Holden-Day, 1970) p. 17.