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An Optimal Cane Delivery Scheduling using the Monte Carlo Method

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Abstract

Transporting sugarcane from farms to sugar mills plays a vital role in most raw sugar producing industries including those in Australia, Brazil, Thailand and Fiji. In Fiji, this issue needs to be urgently investigated and made cost effective due Fiji Sugar Corporation's (FSC's) plan to take over the responsibility of the delivery of sugar cane from farms to mills. The transportation of sugarcane is a complicated process and includes many variables and criteria that have to be fulfilled hence making it difficult for mill traffic planners/officers to produce optimal schedules manually. A non-optimal schedule of cane delivery leads to increased costs associated with either idle mill time or wait/queue time of the lorries or both. This issue is addressed in this paper and the Monte Carlo approach has been used to develop a scheduler for the cane delivery to the mills via cane lorries. The Monte Carlo approach relies on the use of random sampling to acquire a solution to a given problem. This approach is often used when traditional heuristics methods fail. Monte Carlo techniques are nowadays widely used for many applications including all types of optimization algorithms. This paper investigates the scheduling of cane delivery problem and presents a Monte Carlo scheduler that minimizes mill idle time as a first criterion and lorry queue time as the next, while incorporating different travel times to the mills from various locations, processing time of mills and time taken to cut cane and load lorries at the farms. Examples and scenarios are provided where the Monte Carlo scheduler is utilized and the generated optimal schedule is presented for real data related to Fiji Sugar Industry.

1. Introduction

Decreasing the cost of transporting sugar cane to mills is of paramount importance to all sugar producing industries and more so in Fiji, due to the Fiji Sugar Corporation's (FSC's); the corporation responsible for the manufacture and sale of raw sugar; plan to take over the responsibility of the delivery of sugar cane from farms to mills. FSC owns and operates the sugar mills in Fiji. The sugar industry is important to Fiji's economy because it contributes about 1.7 percent of GDP and generates about 8% of total exports. Due to global competition, there is pressure to reduce capital and operational costs, including cane transportation costs. In Fiji, a major portion of the total cost of sugar cane operations includes cane transportation.

Fiji has four sugar mills. Three of these are located at Lautoka, Ba and Rakiraki on the main island of Viti Levu while the fourth, Labasa mill, is located on the second largest island of Vanua Levu. The mills are located on the drier side of the two larger islands where conditions are better suited to cane growing. The mills operate from about June to November while cane is grown in the months of December to May. Harvesting of cane is mostly done by paid cane-cutters together with a small number of mechanical harvesters. The four mills collectively processed a total of 1.6 million tonnes of cane in 2014 (Fiji Sugar Corporation Ltd and Subsidiary Companies 2014)

Transportation of sugar cane from farms to mills is mostly done predominantly by road with rail also utilised. For road transportation mode, when sugar cane on the farm is harvested, it is transported to the designated mills by either farm owner acquired lorries or hired ones. Currently, there is no schedule for lorries to reach the mills and as such there is considerable amount of waiting time for the lorries at the mill. The other disadvantage of not having a schedule to reach the mill is that it leads to mill stoppage time as well. A non-optimal schedule or no schedule of cane delivery leads to increased costs associated with either idle mill time or wait/queue time of the lorries or both.

If the arrival time of the lorries were scheduled, taking into consideration different travel times to the mills from various locations, processing time of mills and time taken to cut cane and load lorries at the farms, the cost due to idle mill time and/or wait/queue time of the lorries could be reduced even totally eliminated.

Scheduling of sugarcane delivery has received attention beginning with Abel (1981) who was the first to develop a railway scheduling model. This model was later transformed by Pinkney and Everitt (1997) into a user friendly application. In relation to scheduling of road transportation of sugar cane, Hansen et al. (2001) attempted the scheduling process by simulation. Milan et al. (2003) developed linear programming model for pickup of canes from various farms and storage locations to minimise costs, accounting for more than one mode of transportation. Higgins (2006) developed a model to schedule road transport using meta-heuristics and tabu search to find solutions.

This paper focusses on using the Monte Carlo approach to road transportation scheduling of cane delivery and presents a Monte Carlo scheduler that minimizes mill idle time as a first criterion with lorry queue time as the next, while incorporating variables such as different travel times to the mills from various locations, processing time of mills and time taken to cut cane and load lorries at the farms.

2. Monte Carlo Simulation

Monte Carlo simulation is a computerized mathematical technique that approximates solutions to quantitative problems through statistical sampling. The technique is used by professionals in fields as finance, project management, energy, manufacturing, engineering, research and development, insurance, oil & gas, transportation, and the environment. This method is useful for obtaining numerical solutions to problems which are too complicated to solve analytically.

Monte Carlo simulation furnishes the decision-maker with a range of possible outcomes and the probabilities of the possible outcomes. The technique was first used by scientists working on the atom bomb Kochanski (2005).

Monte Carlo simulation involves building models of possible results by substituting a range of values with a probability distribution for any factor that has inherent uncertainty. It then calculates results repeatedly, each time using a different set of random values from the probability functions. The results of Monte Carlo simulation are not single values but distributions of possible outcome values Vose (2008).

Generally the following steps are involved in performing a Monte Carlo simulation:

- Step 1: Create one (or more) parametric Models, $y = f(x_1 x_2, \dots\dots, x_m)$.
- Step 2: Represent the inputs $(x_1 x_2, \dots\dots, x_m)$ using probability distributions
- Step 3: Generate a set of random inputs $(x_{k1} x_{k2}, \dots\dots, x_{km})$ from the distributions for each iteration $k,\ k = 1\ to\ t$
- Step 4: Evaluate the model using the random inputs, $(x_{k1} x_{k2}, \dots\dots, x_{km})$ for each iteration, k

- Step 5 Analyse the results of $y = f(x_{k1}x_{k2}, \ldots\ldots, x_{km})$, obtained for all the iterations, $k = 1\ to\ t$.

3. Model Formulation

The scheduling problem for sugarcane road transport in Fiji involves scheduling of vehicles (lorries) to arrive at the mill from various locations. These vehicles start their journey from the cane farms where they get laden with cane from a particular location and travel straight to the mill. This is unlike the scenario used in Higgins (2006) where the vehicles leave the mill to pick up several trailers before returning to the mill. For the road scheduling problem discussed in this paper, a good solution is characterised by minimal mill stoppage time and minimal waiting time for arriving vehicles at the mill. Since mill stoppage is costlier than the queueing time, priority is given to reducing mill stoppage after which queueing time is minimised.

To demonstrate Monte Carlo scheduling approach:

Suppose there are *n* locations $(L_1, L_2, \ldots\ldots, L_n)$ from which cane has to be delivered to a mill. These locations are of various distances away $(d_1, d_2, \ldots\ldots, d_n)$ from the mill and as such the time taken $(t_1, t_2, \ldots\ldots, t_n)$ for a cane lorry to reach the mill from each of these locations would vary. The quantity of cane available is $(Q_1, Q_2, \ldots\ldots, Q_n)$ tonnes of cane with as many lorries needed to transport cane to the mill as needed. Each lorry has a capacity to carry 10 tonnes of cane. Assume that the crushing rate of the mill is $Crushing\_Rate$ tonnes/hr.

If $x < Q$ tonnes of cane is needed to be crushed, what would be the best combination of deliveries from $(L_1, L_2, \ldots\ldots, L_n)$ such that mill idle time is minimised as a first criterion with minimisation of lorry queue time as the next?

To use the Monte Carlo approach, we treat this as a “Lorry Service queue” problem whereby cane lorries arrive at random times. If the mill is not processing another lorry, an arrival goes directly into processing and spends no time in queue. But if the mill is processing another, the arrival joins the end of a queue, from which lorries are processed on a first-come-first-served order. The system starts at time 0 and idle (no lorries present) and continues until $x < Q$ tonnes of cane have arrived. The input distribution used is a *discrete function* (see Figure 1 shown when *n=5*) such that the probability of choosing a cane laden lorry from any location $(L_1, L_2, \ldots\ldots, L_n)$ is the same.

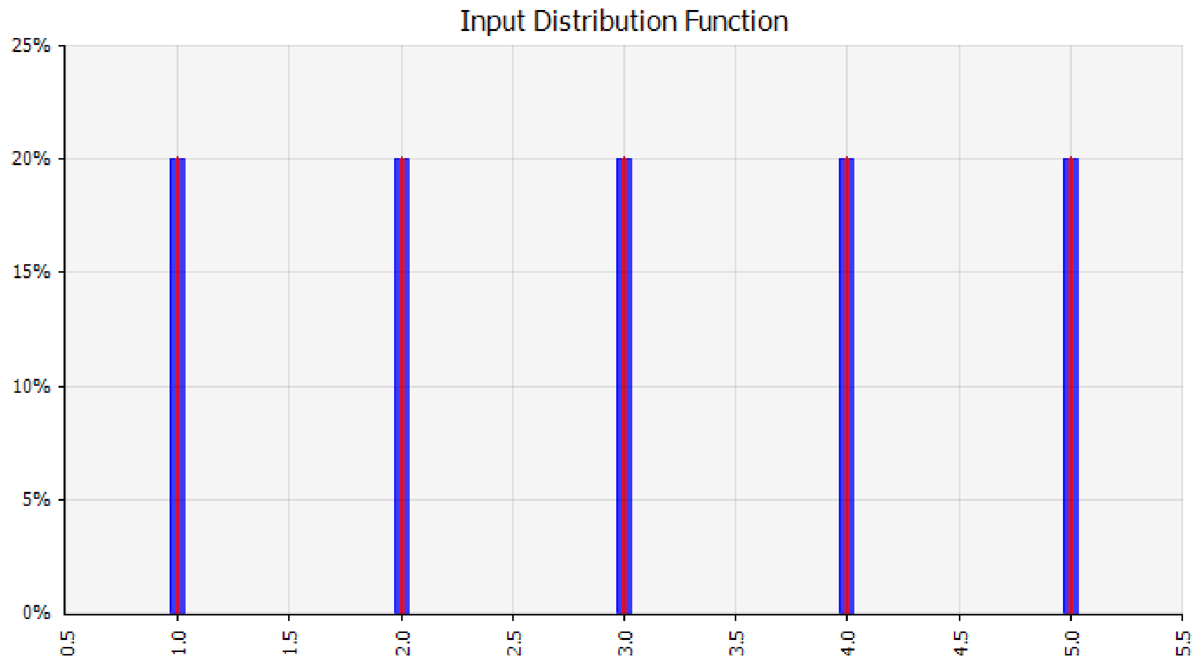
Let $(at_1, at_2, \ldots, at_i, \ldots\ldots, at_m)$ be the arrival times of lorries at the mill of the ith lorry and let $(pst_1, pst_2, \ldots, pst_i, \ldots\ldots, pst_m)$ be the possible start time for the ith lorry and let $(ast_1, ast_2, \ldots, ast_i, \ldots\ldots, ast_m)$ be the actual start time for the ith lorry and where m is the total number of lorries arriving at the mill.

Hence for kth Monte Carlo iteration, the models that are evaluated are:

- Total Queuing time, $QT_k = \sum_{i=1}^{m} ast_i - at_i$;
- Total Mill stoppage time, $MST_k = \sum_{i=1}^{m} ast_i - pst_i$

Each Monte Carlo iteration randomly selects 1 location from each of the locations as many times as required to satisfy the value of x and evaluates the mill wait time and the queue time of the lorries for each combination. The results generated are the probability distributions of mill wait time and the queue time of lorries.

Figure 1: Input Distribution Function



4. Model Solution

To demonstrate our Monte Carlo approach, two scenarios were chosen: one being a simplified version with made up data and the other with real data from FSC.

4.1. Simple scenario

Let's consider a simple approach with 5 locations (*n* = 5) with the following quantities:

Location	L_1	L_2	L_3	L_4	L_5
Distance (km)	30	60	100	150	200
Cane Quantity (tonnes)	2000	2000	2000	2000	2000
Time taken (hrs) to travel to mill*	0.5	1	1.67	2.5	3.33

*Assuming that all lorries travel at 60km/h

Table 1: Input variables to Monte Carlo simulation

Assume that $Crushing\_Rate$ is 42 tonnes/hr, the number of tonnes to be crushed, x is 1000 tonnes and the time taken to cut and load cane onto a lorry is 60 minutes. This implies that we need 100 lorries carrying 10 tonnes of cane from any of these locations.

Note that: The time taken to cut and load implies that if lorry A leaves location, L_1 at time t, the next lorry, B will leave L_1 after 60 minutes. Thus the difference in arrival at the mill, after $\frac{1}{2}$ hour of travel time each, of lorries A and B is 60 minutes. Note that we have assumed that the lorries travel at 60km/h as a deterministic quantity. It should be rightly have uncertainties associated with it. However, this will be dealt with in our future research.

Each Monte Carlo iteration randomly selects 1 location from each of these 5 locations 100 times and evaluates the mill wait time and the queue time of the lorries for each combination. The reason for the 100 is because that is the number of lorries needed to fulfil the requirement as per the value of x. All chosen locations start cutting and loading canes on lorries at the same time and stop when the required set quota is reached.

The results of a simulation with 50000 iterations are as below:

Figure 2: Distribution of Mill idle time

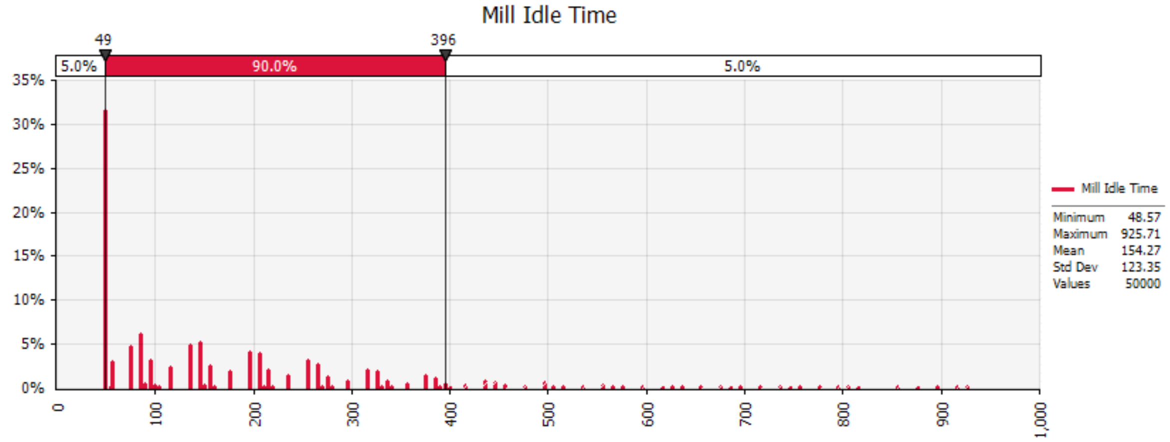
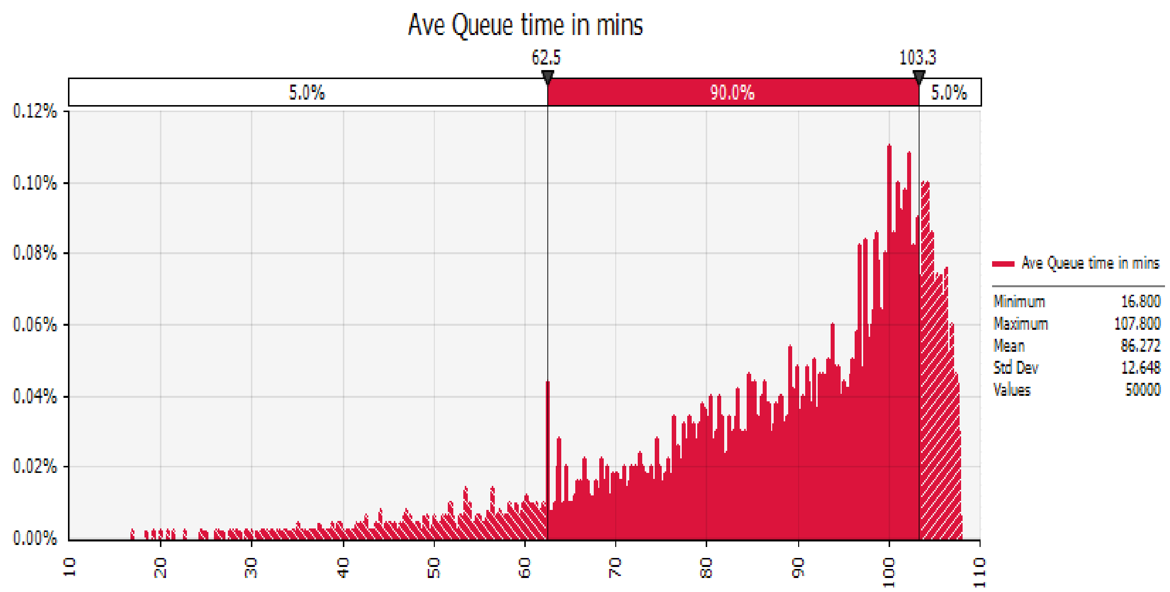


Figure 3: Distribution of Average queue time (in minutes)



The results show that both the mill idle times and the queue times vary according to the number of lorries arriving from each location. The mill idle time can vary from 925 minutes to 48 minutes while the average queue time per lorry can vary from 107 to 17 minutes.

A selection of results according to quantity of cane (quotas) from each location is presented below:

Location	L_1	L_2	L_3	L_4	L_5	Total mill idle time (mins)	Average queue time (mins)
Distance (km)	30	60	100	150	200		
Time taken (hrs) to travel to mill*	0.5	1	1.67	2.5	3.33		
Combination of quota 1 (# of lorries)	22	10	24	22	22	48.57	62.4
Combination of quota 2(# of lorries)	21	27	21	12	19	175.71	82.54
Combination of quota 3(# of lorries)	18	15	14	37	16	865.71	64.64

Table 2: Selection of result from Monte Carlo simulation

As shown in table 2, combination 1 is the best choice in terms of quantity of cane (quota) delivered from each location because of least mill idle time and minimal average queue time. Combination 2 on the other hand has increased mill idle time and increased average queue time. Combination 3 has the worst mill idle time but relatively lesser average queue time when compared to combination 2. Since mill idle time is costlier than queue time, combination 1 is the best choice and combination 3 the worst.

4.2. Scenario with real data

Consider the data below of the operations of Lautoka mill in Fiji. On a particular day, 3 August, it crushed 2519 tonnes of cane. The table shows the amount of cane received from each sector (location).

Sector	Av Distance to mill	Monday (3/8)
		Lorry(Tons)
Drasa	12	683
Lovu	11.5	356
Lautoka	10.5	69
Saweni	14	43
Natova	24	162
Drasa Est	13	72
Leqaleqa	27.6	237
Meigunyah	28.8	75
Qeleloa	30.2	25

Yako	55	29
Malolo	37.8	32
Nawaicoba	50	298
Lomawai	70	90
Cuvu	77	282
Olosara	100	66
Mill Total		**2519**

Table 3: Real data from Lautoka mill

The Monte Carlo approach is applied to this data to see which combination of quotas from each location would yield an optimal result and how different it is from the quota as provided in the table. Again assume that operations would begin at each location at the same time, i.e. the cutting and loading of cane will begin simultaneously till the required allocated quota is reached. The results are depicted in table below, which would yield an optimal mill idle time of 70.5 minutes and an average queue time of 315.37 minutes.

Sector	Av Distance to mill	Optimized Simulated quota - Monday (3/8)
		Lorry(Tons)
Drasa	12	80
Iovu	11.5	280
Lautoka	10.5	180
Saweni	14	130
Natova	24	220
Drasa Est	13	90
Leqaleqa	27.6	90
Meigunyah	28.8	190
Qeleloa	30.2	160
Yako	55	120
Malolo	37.8	100
Nawaicoba	50	260
Lomawai	70	240
Cuvu	77	250
Olosara	100	130
Mill Total		**2520**

Table 4: Monte Carlo simulated result

The difference in mill idle time and the average queue time of the real cane delivery and the Monte Carlo optimal quota is shown in the table below:

Quota	Mill idle time (mins)	Average queue time (mins)
Actual Allocation	2246.29	85.46
Monte Carlo optimised	0	315.37

Table 5: Difference in outcome of actual and optimised quota

Note that for the actual quota delivered to the mill on 3 Aug, the mill idle time would be comparatively much more than the quota as yielded by the Monte Carlo method. On the same note, the average queue time of Monte Carlo suggested quota is more. As pointed out earlier, mill operators would prefer to minimise mill idle time as opposed to queue time due to the cost factor. Nonetheless, using the Monte Carlo method provides one with the opportunity to choose the quota they believe is workable and know the effect of making that choice. Due to the nature of the Monte Carlo process, many combinations of various possible quotas are available to view together with their respective mill idle time and queue time. This feature can prove to be very handy to make contingency plans for events such as initially advised quota not achievable due to unforeseen events such as breakdowns and adverse weather conditions. Thus if the operator has to make immediate decisions as to what is the second best option, the results of Monte Carlo can be readily used. For instance, if the Monte Carlo optimised quota is not workable, then the second best quota can be chosen as an alternative from the simulated results together with the knowledge of respective expected mill idle time and queue time.

An extract of some of the results are provided below showing various quotas from each location and their respective mill idle time and queue time.

Sector	Av Distance to mill	Simulated quota - 1	Simulated quota - 2	Simulated quota - 3	Simulated quota - 4	Simulated quota - 5
		Lorry(Tons)	Lorry(Tons)	Lorry(Tons)	Lorry(Tons)	Lorry(Tons)
Drasa	12	80	300	280	230	160
Iovu	11.5	280	160	150	150	160
Lautoka	10.5	180	130	260	130	410
Saweni	14	130	180	90	140	150
Natova	24	220	220	170	200	90
Drasa Est	13	90	110	150	140	160
Leqaleqa	27.6	90	130	120	120	100
Meigunyah	28.8	190	110	160	160	120
Qeleloa	30.2	160	280	150	80	150

Sector	Av Distance to mill	Simulated quota - 1	Simulated quota - 2	Simulated quota - 3	Simulated quota - 4	Simulated quota - 5
		Lorry(Tons)	Lorry(Tons)	Lorry(Tons)	Lorry(Tons)	Lorry(Tons)
Yako	55	120	140	90	170	160
Malolo	37.8	100	170	190	150	160
Nawaicoba	50	260	80	70	330	170
Lomawai	70	240	120	310	160	220
Cuvu	77	250	130	150	190	150
Olosara	100	130	260	180	170	160
Mill Total		**2520**	**2520**	**2520**	**2520**	**2520**
Mill Idle Time (mins)		**0**	**0**	**13.8**	**113.8**	**554.3**
Ave. Queue time (mins)		**315.37**	**321.5**	**317**	**342.3**	**322.9**

5.Conclusion

Using real data related to transportation of sugar cane to mills in Fiji, an optimal cane delivery scheduling using the Monte Carlo Method was shown. The demonstrated model focused on minimizing mill idle time as a first criterion and lorry queue time as the next, while incorporating different travel times to the mills from various locations, processing time of mills and time taken to cut cane and load lorries at the farms. The generated output not only provides the optimal schedule or quota from each farm but also provides numerous other quotas with its respective mill idle time and average queue times.

This feature of having multiple scenarios, together with the optimal solution, provides versatility in that the other results could be used for planning and contingency purposes in the event that the optimal solution is not usable. For instance, if a decision has to made at the eleventh hour to revise the delivery schedule, one does not have to run the simulation again but instead use the generated scenarios to choose the one that best suits the situation and also have the knowledge of the consequence of choosing the particular scenario i.e. knowledge of mill idle time and queue time. The can also equip the operator of the mill to adjust the crushing rate of the mill appropriately so as to minimise the loss due to idle time.

Furthermore, Monte Carlo techniques are nowadays widely used for many applications including all types of optimization algorithms due to its easy to understand and use and implement unlike traditional heuristics or optimisation algorithms. This technique can be used in place of traditional heuristics methods either because heuristics methods fail or it is too difficult to implement. Monte Carlo technique can also incorporate the possibility of correlation within variables and also derive a more accurate scenario analysis by using probabilistic distributions of all the variables including the speed of the trucks/lorries and the distances of the farms from the mills.

6. Acknowledgements

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7. Reference

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