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TOWARDS FUNCTIONAL SPECIFICATIONS OF A SAMPLING SCHEME FOR COMMERCIAL SAMPLING OF PREPARED CANE.

by

Geoff Robinson

CSIRO Division of Mathematics and Statistics
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Towards functional specifications of a sampling scheme for commercial sampling of prepared cane.

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Summary

Some options for an automated system for sampling prepared cane are described. They are based on a system currently in use in South Africa.

Some modifications of the South African system are proposed, largely because that system has a different goal.

Introduction

Payment by Australian sugar mills to sugar cane growers has for many years been based on samples of "first expressed juice" — the juice squeezed from prepared cane at the number one mill. This basis for payment is perceived by some sugar industry bodies as being less than completely satisfactory. The weaknesses being focussed on in this report is that it is an inferential method. The amount of pol in first expressed juice is used to estimate the total amount of pol in the cane. This is unsatisfactory because the relationship between pol in first expressed juice and total pol was derived many years ago when there was less pressure exerted at the number one mill. The relationship has not been altered to allow more accurate estimation of total pol.

In reference 5, page 3, the Sugar Research Council suggested that future study and research in the area of miller-grower equity assessment should include

"a technology survey and research on effective equipment and techniques for sampling shredded cane by time division of the full flow of cane."

The Sugar Research Council has provided funds for travel to South Africa, allowing Jeff Loughran of the Sugar Research Institute and me to review the methods of sampling prepared cane used there.

It has also funded projects in which I am to give functional specifications for a prepared cane sampling system and Jeff Loughran is to provide detailed engineering specifications and estimated costings for a prototype system. This prototype is to be designed to achieve satisfactory accuracy for grower-miller equity. i.e. for deciding total division of monies between millers and growers.

The South African System

The South African system for sampling of prepared cane and the associated testing is referred to as DAC, which stands for Direct Analysis of Cane. It has achievement of grower-grower equity as its goal. i.e. to ensure that the total payment to growers is fairly divided between them. The basis for achieving grower-miller equity is the weighing of mixed juice by juice scales, the sampling of that mixed juice and the sampling of final mill bagasse. See reference 1 for details.

Because sampling and testing of prepared cane is only used for grower-grower equity, precision is important but a systematic bias would not be important. If all results were high by a consistent factor then this would not affect payments to farmers: the total payment to farmers is based on the juice scales and the division of this payment amongst farmers is based on the testing of prepared cane.

In contrast, because we are interested in prepared cane sampling for grower-miller equity, we must be concerned about all forms of bias. We need not be very concerned about precision because many samples can be taken over a milling season.

In fact, the use of juice scales is far from being all of the story about grower-miller equity in the South African system. There are effectively two markets for raw sugar — the home market which is referred to as "Pool A", and the international market which is referred to as "Pool B". The Pool A sugar price has been substantially higher than the Pool B sugar price for the last few years. Most growers have a "Pool A quota". This means that for that amount of sugar in cane they will be paid according to the Pool A price. For Pool B sugar, they are paid relative to the international sugar price.

For Pool A sugar, grower-miller equity in average over all sugar mills is controlled as outlined in "Distribution of proceeds and determination of sucrose price" in Schedule B of the Sugar Industry Agreement, 1979. The current expenses and investments of growers and millers are assessed and proceeds from sale of sugar are divided according to agreed rules. Because of this method of dividing the proceeds between millers and growers, it would not matter much if the juice scales method had a bias which was uniform over all mills. The division of proceeds between growers and millers would not be affected.

Physically, the South African system of sampling prepared cane consists of the following. Reference 1 gives more details.

1. A tracking system follows the consignments of cane and triggers the primary sampling device so that it operates six times per consignment (for consignments which are at least 20 tonnes).
2. The primary sampling device is either a sliding gate which is used to take a sample of prepared cane from a slat conveyor or a swing gate which diverts a sample of prepared cane as it falls from the head pulley of a belt conveyor.
3. One or more screw conveyors transport the prepared cane to a primary flap subsampler which reduces the sample mass by about half. Reference 1 specifies reduction by a factor of 2, but greater reduction was observed at Mt. Edgcombe Mill.
4. Another screw conveyor transports the cane to a second flap subsampler which further reduces the sample. Note that the first screw rotates at 16 or 18rpm and the second screw rotates at about 50rpm.
5. The sample is reduced to about 2kg by hand subsampling.
6. This 2kg is shredded in a Waddell hammer mill.
7. Material for testing is manually extracted from this 2kg of shredded cane.

It should be noted that reference 1, section 4.3.2 says "The primary stage flap should be operated at the highest possible frequency". This means that the sample reduction of the first flap is about a factor of two (with the flap directing the stream of cane to sample or to be returned each about half of the time) and so the sample reduction of the second flap is larger than that of the first — A major function of the first flap and the screw conveyors is to spread out the primary samples so that the second flap can operate effectively.

Discrepancies between the DAC and juice scales systems are monitored. The ratio of the total pol as estimated by juice scales to the total pol as estimated by DAC is called the "pol factor". The ratio of the total brix as estimated by juice scales to the total brix as estimated by DAC is called the "brix factor". For each week for each tandem the pol factor and the brix factor are calculated.

Some evidence about the possible bias and usefulness of the South African system for sampling prepared cane lies in the fact that for the 88/89 season the average pol factors for the 20 tandems ranged from 99.25% to 100.71%. This means that the pol discrepancies between using DAC and using juice scales for grower-miller equity were a maximum of 0.75%.

These discrepancies arise because different tests are involved in the DAC and juice scales systems. A particular problem with DAC is that it is based on the weight of cane at the weigh-bridge but uses the amount of pol or brix per unit weight measured at a different place much later in time. — Rain on cane in the yard and evaporation can change the total weight of the cane and this change of weight is not considered

by DAC. This problem with the South African system should not be important to an Australian system because there is very little delay between weighing and milling at Australian mills.

The two methods have been operating in parallel since 1971 so most of the problems in the systems have been eliminated. (e.g. There have been many changes to blades of cold digesters). On a weekly basis, pol factors outside the range 98.5% to 101.5% are considered to be a cause for concern.

For the 20 tandems the average brix factors for the 1988/89 season ranged from 99.72% to 102.17%. The average pol factor was 99.76% and the average brix factor was 100.75%. The fact that the average brix factor is so far from 100% is currently a minor worry.

Gy (1982) argues that flap samplers are always biased and should be avoided. The bias arises from the fact that one side of the stream of material is sampled for longer than the other side of the stream. Some evidence as to the lack of bias in the flap subsampling system used in South Africa is provided by the results included as Appendix 1. In 1970 a single flap was tested for bias using 3 seconds between movements. The results gave a sucrose bias for the subsamples of 0.02% with a standard error of 0.06%. Thus "no bias" was concluded. Note however, that a Rietz prebreaker was in use and may have tended to homogenize the incoming prepared cane. Also, bias would be expected to be greater when smaller samples are taken for fixed speed of motion of the flap, so the results for three-second samples should not be regarded as indicative of bias likely to occur in practice.

An extract from Weekly Report No. 31 dated 14th October, 1970: CB.18.31.7 said:

"A further 3 tests were conducted with the sampler set at 3 seconds on reject and $2\frac{1}{2}$ seconds on sample. The sucrose % cane results for both sample and reject were identical.

The ratio of the cuts were then set at 4 seconds reject and 1 second sample and on two tests, the sucrose % cane varied by 0.1 unit."

I remain concerned about bias with flap samplers.

Possibilities for an Australian system

The various options for an Australian system for sampling prepared cane will be discussed in six stages.

1. Primary sampling

The best way of getting primary samples would be to have prepared cane drop from one conveyor belt to another and for a large rectangular sampling bucket to be passed at uniform speed through the stream of falling prepared cane. This might be expensive for existing milling tandems if there is not enough height available. I believe it has been tried in South Africa, but I have not seen it.

South African work has shown that samples were biased when less than the full width of the stream was sampled. Mining industry experience also supports the principle that the full width of a stream of material must be sampled.

For a slat conveyor, it would be adequate to use a sliding gate to take all of the cane between a pair of adjacent slats. This should give an unbiased sample since the probability of being in the slat-load sampled is the same for all particles of prepared cane. A partial slat-load might undersample cane which is held in place by nearby cane and does not fall through the sampling hatch despite being above the opening.

Note that it is desirable that the particular physical slats delimiting the sample not be the same from one opening of the sliding gate to the next.

For a belt conveyor, a reasonably large primary sample may need to be taken in order to reduce the bias. In order to investigate the bias of primary samples as a function of sample size, experimental data should be collected on the differences in composition between the cane nearest the belt and the cane furthest from the belt (the top and the bottom of the prepared cane stream). The extent to which these layers might be unequally represented in primary samples can be crudely estimated by considering the time for which only part of the stream of cane is diverted. The bias of the samples can be estimated by simple calculations.

For instance, suppose the layers of prepared cane were found to differ by 0.2% pol and the layer of higher pol was sampled for 0.2 seconds longer than the other layer. Then if the average pol was 13.0% and the sampling time was 1 second, the average pol of primary samples would be

$$\frac{1.1 \times 13.1 + 0.9 \times 12.9}{1.1 + 0.9} = 13.01.$$

The difference between the layers (here 0.2% pol) must always be greater than the bias of the samples (here 0.01% pol) and therefore easier to detect.

It will be desirable that the swing gate move quickly so that the top and bottom layers of prepared cane are not sampled very unequally. (The swing gate for the samples for the milling train at Maidstone Mill in South Africa took about 1 second to move and did not pause before returning to its non-sampling position.)

A possible bias of the sliding gate for use with slat elevators is that some prepared cane is carried around the head pulley by the slats — Such material is more likely to be sampled — it gets two chances at least because it is part of the material between one pair of slats and if not sampled there it becomes part of the material between another pair of slats. The potential bias from this source is most unlikely to be important, but it should be estimated for individual installations if more than 1% of cane gets two chances of being sampled.

I am worried that it will be difficult to use a sliding gate to achieve a slat-load-sized sample. As the gate starts to open material is unlikely to fall immediately. The end of the sample is easy to control — particularly if the gate is closed at the same speed as the conveyor moves. At least the hard-to-control end of the sample is the one involving less material.

Note that taking a large primary sample (say, more than 3 seconds) could interfere with the flow of prepared cane through the sugar mill substantially enough to be a serious problem. Good mill control should be able to overcome problems caused by small primary samples.

2. Spreading the primary sample

The primary sample must now be spread out so that a subsampling device can be used to reduce its volume. This should be done with minimal segregation and in such a way that the sample is conveyed to the subsampler.

A few possibilities are worth considering.

- (a) Use two screw conveyors with a spreading slide in between them so that material dropping in a batch from the first screw tends to be spread over several threads of the second screw. The second screw should operate at, say, 6 times the speed of the first screw. The precise ratio of speeds needs to be considered further. In South Africa, the ratio is about 3. In Australia we would like to achieve more spreading out of the sample in order to achieve greater sample reduction.
- (b) Use three screw conveyors with speeds in the ratio $1:2\frac{1}{2}:6$. Watching cane drop from the first subsampling flap to the second screw in the sampler for the diffuser at Maidstone Mill gave on the impression that batches of cane tended to be distributed over 2 or 3 threads of the second screw conveyor.
- (c) A feed roller might be devised to control the flow of prepared cane onto a single screw conveyor.
- (d) Screw the cane to the top of a long vertical chute. Use feed rollers at the bottom of the chute to control flow to a subsampling device immediately underneath.
- (e) Adopt essentially the South African system except that the timing of the first flap not be adjustable.

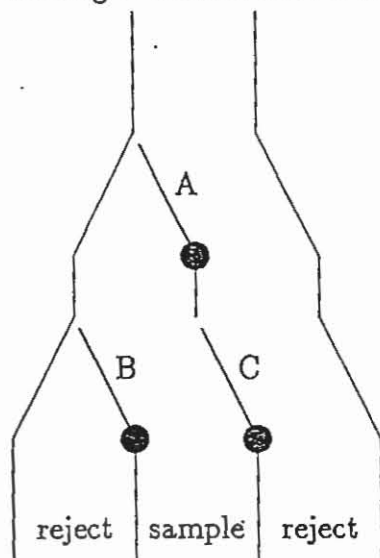
3. Automatic Subsampling

Three forms of subsampling device seem to be worth considering.

- (a) Simple flaps as used in the South African system. These flaps are relatively cheap. Their bias may vary with orientation since the cane may be slightly segregated either by the screw conveyors or in that material falling far from the screw is on average different from material falling near the screw.
The bias could be estimated by simple experiments in which a screw feeds cane into two rectangular buckets. This would enable the segregation of the cane coming from the screw to be estimated. The bias of the flap sampler can

then be approximately calculated using the speed at which the flap moves. The segregation will be larger than the sampling bias so its estimation will be less constrained by sample preparation and testing errors.

- (b) An unbiased flap sampler can be constructed using 3 flap samplers. Starting with all the flaps to the left, as illustrated, flap A is moved to the right and the sample commences. When flap C has no cane passing it, it is moved. Then flap A is moved back to its original position on the left. This motion of flap A does not terminate the sample, it only changes the route that cane takes through the subsampling device. When flap B has no cane passing it, it is moved. Then flap A is moved to the right again — this terminates the sample. Moving C then A then B returns to the original position.



The reason why a subsampler designed this way is unbiased is that the motion which starts the sample is the same as that which ends the sample: flap A moving to the right.

Disadvantages of this subsampler are

- It is more expensive.
 - It uses a lot of height.
 - It is slow to operate. The minimum sample size is the time for four flap motions plus two time delays while waiting long enough for flaps B and C to be clear of cane.
- (c) A moving rectangular bucket could be used. The bucket would in practice be a chute so that emptying it was easier. The chute would have to be wide enough for cane not to be able to bridge across the opening — say 400mm. It must be moved a constant speed across the region where cane is passing.

4. Manual Subsampling

The sample delivered by the automatic system must now be subsampled by hand to give the 2kg for the Waddell mill. (Australian analysis requires about 3kg.)

Buchanan and Brokensha (1974) found that hand subsampling of prepared cane introduced variation with a standard derivation of about 0.21% pol and 0.49%

fibre. Comparing the variation between duplicate tests where duplicate samples were taken from Waddell-milled cane with the variation between duplicate tests where the duplicate samples were taken from ordinary prepared cane indicates that essentially all of the variation comes from the subsampling of prepared cane.

Ivin and Edwards (1987) found that the standard deviation between repeat sampling and testing results was 0.062% pol, 0.17% fibre by the bag method and 0.30% fibre by disintegrator. I have used the more variable results in my calculations in order to be conservative. We need to allow for varieties of cane which are difficult to subsample and to allow for technicians with little skill at manual subsampling.

It may be desirable to study hand subsampling to train people in the art of hand subsampling or to put more material into a Waddell shredder in order to reduce the errors and possible bias from this source. Alternatively, avoid hand subsampling completely. Test methods could handle somewhat variable quantities of material without much loss of precision.

5. Size reduction

It is not clear whether or not there should be a size reduction step. Selwyn King said that they were currently considering the removal of this stage in their sampling scheme. They are concerned that evaporation might cause a bias. The loss of precision should not be a problem if a large number of samples are tested.

6. Take subsamples for testing

Again we must be careful about the possible errors in subsampling by hand.

Notes on the proposed system

1. It should be able to handle foreign objects. A billet of cane should cause no damage and no interruption. A shredder hammer should not cause a catastrophe.
2. Viewing hatches should be generously provided, especially on the prototype.
3. Screw feeders must not choke. The South African screw conveyors have pitch equal to diameter. It seems advisable for screws to turn in the direction such that cane arriving is first lifted by the turning of the screw.
4. Cover sample collection areas and other parts of the sampling system so that only the intended material is collected.
5. Need to think carefully about where variable speeds and variable timings will be allowed.
6. Collection bins to be large enough to collect largest possible samples.
7. Motors to be overpowered and metal parts to be of generous gauge in order to make the sampler reliable.

8. Routine monitoring of differences between prepared cane samples and first expressed juice samples in order to detect problems.
9. There should be no spots where cane tends to collect.
 - Flaps to have rest positions under ledges
 - Flaps to always be near enough to vertical for cane to slide off them
 - No rough edges
10. No synchronization between parts of sampling system. In particular, add a random time to the scheduled time for subsampling to ensure that subsamples do not tend to occur at consistent times relative to the threads of a screw conveyor.
11. To return the material rejected by the subsampler to before the primary sampler is completely all right if the system is only being used for grower-miller equity. If the system were to be used for grower-grower equity there is in theory a tiny bias — it should be estimated for the smallest possible rakes at individual installations, but would probably be negligible.

Measurements to be made before using swing gate sampler for a belt conveyor

Stop belt conveyor and remove a fixed length, say a metre, of cane from the belt, endeavouring to put the top and bottom material into separate containers. Test for differences in, say,

- moisture
- pol or brix
- fibre
- sand

between top and bottom of the blanket of cane. Repeat for a few varieties, green and burnt. Repeat experimentation if shredder settings are changed. Use dirty cane if possible so that there is most chance of detecting segregation.

Measurements of this type have been made by Charles Ivin and Jeff Loughran of the Sugar Research Institute using samples from Racecourse Mill. The details are given in Appendix 2. The conclusion was that segregation between top and bottom of the blanket of cane could not be detected for the type of cane being processed at the time (fairly clean and well-shredded). Estimated differences between top and bottom were $0.006 \pm 0.065\%$ brix, $0.087 \pm 0.162\%$ moisture, and $0.004 \pm 0.049\%$ ash.

Experiments to be conducted using prototype or experimental screw conveyor with single flap

1. Experiment to find conditions which cause choking so that they may be avoided.
2. Experiment with ways of spreading cane.
3. Estimate segregation following a screw conveyor (or whatever other type of conveyor might be proposed). Mount two large rectangular bins under the output from a screw such that the line between the bins is either parallel to or square to the screw axis as required. Move the bins until at least 25% of the cane ends up in each bin.

Test for segregation by measuring

- moisture
- pol or brix
- fibre
- sand or dirt.

If there is no detectable segregation then the South African subsampling system could safely be adopted. If there is segregation for one orientation of the bins but not the other, then the South African system could be adapted provided that the flaps were always given an appropriate orientation. — Currently, the South African system orients the flaps so as to minimize the width of the stream of cane to be collected and returned to the mill. Commonly, this results in the first flap being square to its feed screw and the second flap being parallel to its feed screw.

Checks to be conducted using prototype

1. Check for bias of primary sampler, possibly by comparing samples obtained automatically with samples obtained by stopping the belt or slat conveyor as soon as possible afterwards and removing all the material in a fixed length of the belt or between two slats. This need not be done if the primary sampler is less likely to be biased than is the reference sampling method based on stopping the conveyor.
2. Check for bias of subsampler by collecting all reject material. I see more potential for bias in the % sand than for any other quality characteristic (pol, brix, fibre, ...), so I would suggest that Australian bias tests of subsampling equipment use sandy prepared cane and test for ash.
3. Weigh some primary samples and some secondary samples to check that the average size of sample agrees with predictions based on total flow rate and expected sampling fraction.

Installation checks

1. No collection of prepared cane anywhere other than the sample bucket.
2. Moving parts work as intended.
3. Does not choke on extremely large primary sample of prepared cane.
4. Handles a few billets of cane in with some prepared cane.
5. No unintended synchronization so that primary samples are taken from only a few intervals between pairs of slats or that the subsampler has a cycle relative to its screw feeder.
6. For slat conveyors, check that not much material falls back as the slat passes around the head pulley.

Routine maintenance/checks

1. Regular steam cleaning. (Once per shift in South Africa)
2. Flap to move quickly and smoothly. If using unbiased flap sampler then check that flaps B and C move only when no cane is passing them.
3. Bucket samplers to move at constant speed.
4. Sliding gates on belt conveyors to move crisply.
5. Sliding gates on slat conveyors to take a slat load.
6. Monitor differences from comparable tests — in particular first expressed juice results. Look for changes over time in the relationship between comparable tests.

Time and Speeds

An estimate of the (time) size of subsample taken by the unbiased flap subsampler can be derived by the times for the motions required. These are approximately

- 4 flap movements. $4 \times 0.6\text{sec} = 2.4\text{sec}$
- 2 times of waiting after flap A has moved for the prepared cane to have passed one of the lower flaps. $2 \times 0.3\text{sec} = 0.6\text{sec}$

Hence minimum sample size is 3sec. (One-directional transit times of flaps at Maidstone Mill in South Africa were measured to be about 1.3sec for a large flap (about 1m wide and 1.3m high) and 0.6sec for a small flap.) Flaps could no doubt be moved more quickly.

How much prepared cane is needed after automated sample reduction? In South Africa they use 1000g for disintegration analysis plus 300g for determination of fibre and the Waddell mill handles about 2000g. In Australia we expect to use 2000g for disintegration analysis plus 500g for fibre determination.

The extra sampling error which would be incurred with ideal subsampling procedures by taking a 2000g sample without first using the Waddell mill can be estimated using experiments conducted by Charles Ivin at SRI. Using cane of Q63R variety from No. 1 mill at Racecourse Mill on 27 June 1989, careful subsampling and testing gave the following standard deviations among sets of 8 results on samples of different sizes.

Size of Sample (g)	s.d. of pol %	s.d. of Brix %
12	0.33	0.46
25	0.39	0.57
500	0.11	0.24

Variation between results will include testing variation which will be a negligible fraction of the variation for the smaller sample sizes. The sampling error s.d. should decrease as $m^{-\frac{1}{2}}$ for mass m . The analytical error will be largest for small sample mass. Using the results for 25g since these had a larger s.d. and it is desirable to be conservative, it appears that the sampling s.d. for pol is approximately given by $2m^{-\frac{1}{2}}$ where the mass m is in grams. For $m=2000$ this gives a sampling error s.d. of 0.04% pol. This amount of subsampling error is acceptable even for a single consignment, given that other sampling errors have larger standard deviations. This suggests that use of the Waddell mill is not essential.

Note however that hand sample reduction from 10kg is not excessively inconvenient. Samples of 20kg are frequently reduced by hand sampling in South Africa.

We now need to consider the size of the primary sample. For an 800 tonne/hour milling train, a one-second sample would be $800000kg/3600sec \times 1sec = 222kg$.

Let us plan on handling a primary increment of 300kg. Hence sample reduction required is

$$300kg \text{ to } 10kg$$

i.e. a ratio of 30 to 1.

Now it is desirable for good estimation of the quality of a single primary sample to take about 5 non-empty secondary subsamples. For grower-miller equity we must be

careful to take an unbiased sample from the primary sample — If fewer than about 5 subsamples were to be taken then a random start should be included in the circuit for starting the flaps after the conveyor system has been started.

If 5 subsamples are to be taken, a subsample has size 3sec and a 30 to 1 reduction is to be made, then sample reduction will take

$$30 \times 5 \times 3\text{sec} = 450\text{sec} = 7.5\text{minutes.}$$

We need to investigate whether evaporation or deterioration over this time period is a problem.

This is acceptable for grower-miller equity, but is too slow to be used for grower-grower equity because a few (say 5, the South Africans use 6) primary samples need to be taken from each consignment.

A two-stage subsampling device may be necessary if the system is to be used for grower-grower equity — Will there be enough height and space available to add on to any proposed system to extend its operation to handle grower-grower equity if acquired?

What is “commercially acceptable” accuracy?

There is no absolutely correct answer to this question. Consider the following arguments.

1. The average bias of the first expressed juice system is not known. It might be of the order of 2% (of pol as a fraction of cane \simeq 0.26% of pol as a fraction of juice). The bias probably varies from mill to mill, between varieties of cane, and from season to season. We need to do better than this.
2. Growers and millers need to discuss the compromise between accuracy and cost of sampling and testing. A bias of 1% means a difference in payment of about 30cents/tonne of cane. It would seem silly to pay, say, 50cents/tonne of cane in order to remove such a bias, since a negotiated settlement would leave all parties better off.
3. The discrepancy between parallel South African systems is as much as 0.75% of total pol and 2% of total brix. Some of this discrepancy may be due to imperfections in the juice scales system, but as a first approximation suppose that all the discrepancy is due to DAC. We might hope to do better than this because our scheme would be designed to reduce biases rather than primarily for precision, but we should not expect to do much better unless our experiments expose weaknesses of the South African methods.

The precision of the sampling and testing should be sufficient for the bias to be the dominant source of error.

It may be appropriate to test for fibre less often than for pol, given that the current test method for fibre is time consuming. Composite samples might be used for fibre determination.

How many samples?

Biases are not reduced by taking more samples. The likely bias due to a moving gate sampler is to be estimated. There will also be small biases due to evaporation, sample deterioration and imperfections in testing methods. Hand subsampling is probably biased also.

Errors associated with single samples are:

- Error of assuming that a sample is typical of the tonnage which it represents. This will be taken to have a standard deviation of $\simeq 1.6\%$ pol. The basis for this figure is that Owen Crees of the Sugar Research Institute provided data on the pol and brix for all rakes of cane delivered to Mossman mill for weeks 1 to 9 and 13 to 19 of the 1989 season. The sample semivariograms (see Gy (1982) for a detailed explanation) at lags 1 to 10 averaged

0.87, 1.26, 1.45, 1.54, 1.58, 1.60, 1.60, 1.58, 1.57, 1.59

for pol and

0.70, 1.01, 1.17, 1.23, 1.27, 1.28, 1.29, 1.28, 1.27, 1.29

for brix. The semivariogram is half of the squared difference between rakes which are a given distance apart. Lag 1 means adjacent, lag 2 means next to adjacent, etc. A conservative approximation to the semivariogram is that it is constant, namely 1.6, and in this case the error of assuming that a sample is typical of the tonnage which it represents has a standard deviation of 1.6.

Alternatively, note that much of the variation between adjacent rakes comes from variation between varieties. Reference 3 gives the pol for 27 consignments of cane delivered to Bingera (s.d.=1.00% pol) and for 19 consignments of cane delivered to Isis (s.d.=0.92% pol).

Since a conservative design is required, we use the larger estimate of variability

- Sampling error associated with hand subsampling according to Buchanen and Brokensha (1974, Table 9) s.d. $\simeq 0.21\%$ pol. This is probably an overestimate since cane preparation has improved since that experimental work was done.
- Fundamental sampling error in taking sample of 2000g of prepared cane if there is no further preparation. s.d. $\simeq 0.04\%$ pol.
- Testing error variance. s.d. less than 0.1% pol.

The total variance of the errors from all these sources need only add the first two of the variances since estimates of subsampling error variance include fundamental sampling error variance and testing error variance, so the total standard deviation is estimated to be

$$\sqrt{1.6^2 + 0.21^2} = 1.61.$$

One sample every h hours for a 120 hour crushing week would give an s.d. for the mean of $120/h$ samples of $1.61/\sqrt{120/h}$. Over a longer period, the standard deviation would be smaller as can be seen in the following table.

Period	Interval between samples						
	7.5 min	15 min	30 min	1 hr	2 hr	4 hr	8 hr
1 day	0.12	0.16	0.23	0.33	0.46	0.66	0.93
1 week	0.05	0.07	0.10	0.15	0.21	0.29	0.42
4 weeks	0.03	0.04	0.05	0.07	0.10	0.15	0.21
26 weeks	0.010	0.014	0.020	0.029	0.041	0.058	0.082

If cane averages 13% pol throughout the season, then the coefficients of variation in total payment from millers to growers due to inaccuracies in the sampling and testing of prepared cane are given by dividing the standard deviations above by 13%. (This neglects uncertainty in the estimated fibre, which is a reasonable first approximation.)

Period	Interval between samples						
	7.5 min	15 min	30 min	1 hr	2 hr	4 hr	8 hr
1 day	0.89	1.26	1.79	2.53	3.58	5.06	7.15
1 week	0.40	0.57	0.80	1.13	1.60	2.26	3.20
4 weeks	0.20	0.28	0.40	0.57	0.80	1.13	1.60
26 weeks	0.08	0.11	0.16	0.22	0.31	0.44	0.63

Some intuitive explanation of what it means

To use prepared cane sampling for grower-miller equity and to use first expressed juice for grower-grower equity means that prepared cane results will be used to calculate an adjustment factor to be applied to the payments calculated according to first expressed juice.

Example

Suppose that the first expressed juice method found that consignments of cane delivered in a particular week were valued at \$5000, \$6000, \$10000, ... and \$3000. Suppose that the total of these is \$1 000 000, but that prepared cane sampling indicates that the

total value of cane delivered to the mill during the week was \$1 010 000. The correction factor for the week would be

$$\frac{1\ 010\ 000}{1\ 000\ 000} = 1.01.$$

The growers would be paid \$5050, \$6060, \$10100, ... and \$3030. Correction factors could be worked out for some period other than a week, but the choice of period is not critical and the South African system uses a one week period.

That prepared cane sampling is used for grower-miller equity means in this case that the total payment from millers to growers, \$1 010 000, is determined by prepared cane sampling. That first expressed juice is used for grower-grower equity means in this case that the relative payments to growers are in proportions determined by the first expressed juice method.

Remarks

Some effort should be made to monitor the first expressed juice results corresponding to the results based on the sampling of prepared cane, even if the first expressed juice results are not explicitly used.

It is important to ensure that it is not possible for mills to send cane of low pol through the mill at times when a sample of prepared cane is likely to be taken — or to send cane of high pol through when a sample is unlikely to be taken. This is crucial for acceptance of a payment system based on sampling of prepared cane. If sampling is done less often than once per small rake then the time between samples should include a random component. Best would probably be that the time between samples be the sum of a dead time and an exponentially distributed component.

All that is really required for an improvement to the current system is correction factors to modify the current payment system based on first expressed juice. In principle, results from one mill could be used to estimate correction factors for the major varieties and these correction factors could then be used for all mills. Politically, this would be a can of worms. Table IV on page 12 of reference 4 indicates that similar correction factors comparing Coefficients of Work calculated using first expressed juice and using juice scales were 1.005 (mill 4), 0.990 (mill 10), 0.989 (mill 2), 1.002 (mill 9), 0.990 (mill 11), 0.972 (mill 1), 0.967 (mill 8), 1.014 (mill 12), 1.011 (mill 5), 1.006 (mill 7) and 1.003 (mill 3). This was in 1962, but differences between districts and between milling trains are likely to be of similar magnitude today.

Possible use of prepared cane sampling for grower-grower equity

The proposed options for sampling prepared cane include ones which would enable sampling of prepared cane to be used for grower-grower equity. The only extra requirement for grower-grower equity is that samples be handled sufficiently quickly.

It is always desirable to subsample the primary samples quickly in order to reduce evaporation and deterioration.

In order to demonstrate the precision of the proposed system it will be necessary to use it in parallel with the existing system. This would be easiest if several primary samples could be taken from large consignments of cane enabling accurate determination of the quality of those consignments of cane by sampling of prepared cane as well as first expressed juice.

Possible use of first expressed juice as well as prepared cane for grower-miller equity

The component of error associated with the taking of primary samples could be reduced by using measurements on first expressed juice as covariates. This means that it would be possible to take into account whether the prepared cane being sampled had a high or low pol relative to the other cane crushed at about the same time. This would have the disadvantages of not making the system separate from the first expressed juice system and requiring a system for accurately identifying the corresponding samples. However it would have the advantage of improving the accuracy of sampling.

Instead of the first component of error which was taken to be 1.6 in the section "How many samples?", there would be error of sampling apart from that explained by the results for first expressed juice. It is estimated that this would have a standard deviation of about 0.43% pol since this was the precision for hatch sampling estimated by Brokensha (1984) based on duplicate hatch samples. Hence the total standard deviation would be

$$\sqrt{0.43^2 + 0.21^2} = 0.48.$$

One sample every h hours for a 120 hour crushing week would give an s.d. for the mean of $120/h$ samples of $0.48/\sqrt{120/h}$ and over a longer period the standard deviation would be as seen in the following table.

Period	Interval between samples						
	7.5 min	15 min	30 min	1 hr	2 hr	4 hr	8 hr
1 day	0.03	0.05	0.07	0.10	0.14	0.20	0.28
1 week	0.02	0.02	0.03	0.04	0.06	0.09	0.12
4 weeks	0.01	0.01	0.02	0.02	0.03	0.04	0.06
26 weeks	0.003	0.004	0.006	0.009	0.012	0.017	0.024

Again, assuming cane averages 13% pol throughout the season the percentage variation in total payment from millers to growers due to inaccuracies in the sampling and testing of prepared cane is given by dividing the standard deviations above by 13%.

Period	Interval between samples						
	7.5 min	15 min	30 min	1 hr	2 hr	4 hr	8 hr
1 day	0.27	0.38	0.53	0.75	1.07	1.51	2.13
1 week	0.12	0.17	0.24	0.34	0.48	0.67	0.95
4 weeks	0.06	0.08	0.12	0.17	0.24	0.34	0.48
26 weeks	0.02	0.03	0.05	0.07	0.09	0.13	0.18

The reason why greater precision is achieved by making use of first expressed juice results is essentially that the first expressed juice results can be used to tell us whether our prepared cane samples were from rakes with high, low or average pol compared to the average of all rakes.

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Appendix 1: South African bias tests

Below is a photocopy of some South African tests for bias in a flap sampler operating with three seconds to sample and three seconds to reject.

CB.11.18.48

10th September, 1970

FLIP-FLAP SAMPLER TESTS

The Flip-Flap sampler has been installed at the discharge end of the Rietz Pre-breaker to replace the rotary sub-sampling table. The timing device has been set to give equal cuts of sample and reject.

The total amount of cane sub-sampled was collected separately and analysed.

10 Preliminary tests were conducted to assess the efficiency of the sub-sampling.

Test No	SAMPLE					REJECT				
	Brix	Sucrose	Fibre	Purity	Moisture	Brix	Sucrose	Fibre	Purity	Moisture
1	16.95	14.24	16.58	84.01	66.47	16.66	14.02	17.44	84.15	65.90
2	15.96	13.70	14.88	85.84	69.16	15.81	13.55	15.36	85.58	68.83
3	17.88	15.91	15.06	88.98	67.06	17.93	16.05	15.47	89.40	66.60
4	16.90	14.23	17.29	84.20	65.81	17.17	14.45	17.74	84.16	65.09
5	16.35	14.52	17.49	88.81	66.16	16.34	14.41	16.60	88.19	67.06
6	16.37	14.50	16.08	88.58	67.55	16.45	14.63	15.00	88.94	68.55
7	16.28	14.05	14.73	86.30	68.99	16.24	13.97	15.17	86.02	68.59
8	14.17	12.40	15.01	87.51	70.82	14.31	12.50	14.71	87.35	70.98
9	14.20	12.17	14.60	85.70	71.20	13.91	12.07	14.30	86.77	71.79
10	15.84	13.86	13.29	87.50	70.87	16.17	14.16	13.04	87.57	70.79
Ave.	16.09	13.96	15.50	86.76	68.41	16.10	13.98	15.48	86.83	68.42

Appendix 2: Estimating segregation of prepared cane on a belt

The belt conveyor was stopped at about 1.50 pm Monday 16/10/89 at Racecourse Mill. Sixteen samples of cane were taken, representing the top and the bottom halves of the blanket of cane, four approximately equal subdivisions across the width of the belt, and two positions along the length of the belt (referred to as the "shredder end" and the "mill end"). Jeff Loughran took the samples at one position and Charles Ivin took the samples at the other position.

The samples were taken as quickly as possible and placed into sealed, labelled plastic garbage bags. There was an average of about 10kg in the bags. The bags were taken to the Sugar Research Institute in an air-conditioned vehicle at about 2.15 pm and kept out of the sun.

The shredder-end samples were stored at 4°C and the mill-end samples were all kept at room temperature while they were mixed and the following subsamples were taken.

- Disintegrator sample: 2000g.
- Moisture sample: 1000g.
- Ash sample: 200g.
- Ash sample: 200g.
- Moisture sample: 1000g.
- Disintegrator sample: 2000g (or less if original sample was small).

The mill-end samples were chilled at 3.30 pm.

The shredder-end samples were taken out of the freezer room at 3.15 pm and were processed similarly. They were returned to the freezer room at 5.00 pm.

The first samples were tested before all of the second samples. Measurements of the percentages of brix, moisture and ash are given in the following Table 1, below.

The final three pages of this report give analyses of the data using the computer package Genstat. The first page analyses the brix results, the second page analyses moisture results, and the third page analyses ash results.

The analysis of variance table indicates how much of the variation is due to various causes. The *samples stratum* deals with variation amongst the 16 samples. Factors explaining some of this variation are

			weight	brix		moisture		ash	
M	T	1	10.36	19.22	19.15	68.90	69.16	0.70	0.68
M	T	2	7.46	19.27	19.14	69.11	69.02	0.73	0.76
M	T	3	9.06	19.00	19.13	68.94	68.89	0.72	0.75
M	T	4	13.68	19.30	19.18	68.85	68.76	0.80	0.87*
M	B	1	6.88	19.08	19.38	68.71	68.88	0.74	0.72
M	B	2	7.54	19.19	19.24	69.14	68.98	0.74	0.73
M	B	3	7.20	19.09	18.49*	69.08	69.32	0.72	0.73
M	B	4	17.66	19.02	19.25	68.99	69.17	0.74	0.76
S	T	1	5.44	19.08	19.44	68.99	69.09	0.73	0.72
S	T	2	6.64	19.07	19.25	69.12	69.15	0.78	0.80
S	T	3	7.06	19.04	19.09	68.75	69.16	0.76	0.71
S	T	4	13.78	19.21	19.39	69.29	69.12	0.74	0.74
S	B	1	9.66	19.16	19.33	69.12	69.43	0.71	0.74
S	B	2	11.36	19.20	19.33	68.96	68.80	0.81	0.95*
S	B	3	8.14	18.96	19.13	69.16	69.20	0.80	0.73
S	B	4	13.48	19.25	19.25	69.25	69.50	0.71	*

Table 1: Measurements on bias across belt

One measurement of brix appeared to be an outlier. It was treated as missing for the analysis given below, and was estimated to be 19.2.

One measurement on ash was missing. It was estimated to be 0.72.

Two measurements on ash were surprisingly large and this was found to be due to the presence of small stones. Since such outlying results will occur in practice these results were included in all data analyses.

where:— the difference between the mill end and the shredder end,

across:— the differences between the four slices across the belt,

deep:— the difference between the top and bottom of the blanket of cane,

across.deep:— the change in the difference between the top and bottom across the width of the belt, and

Residual:— which is the amount of variation not explained by any of the above factors.

The *samples.*Units* stratum* deals with variation between replicate samples. These samples would be expected to exhibit less variation than in the *samples stratum*, because there are fewer ways for differences to arise. The only factor explaining some of this variation is the possible systematic variation between first-tested and second-tested samples which is listed as rep.

For the brix analysis, the residual mean square in the *samples stratum* is less than that in the other stratum. This is somewhat surprising, but an F test indicates that the difference in mean squares is not statistically significant. I would combine the residual terms across strata, giving residual sum of squares of 0.1799 on 21 degrees of freedom and a residual mean square of 0.008567. After adjusting the standard error and allowing two standard errors, the estimated difference between bottom and top of the blanket of cane is

$$0.006 \pm 0.065\%.$$

For moisture, the estimated difference between bottom and top of the blanket of cane is

$$0.087 \pm 0.162\%.$$

For ash, the estimated difference between bottom and top of the blanket of cane is

$$0.004 \pm 0.049\%.$$

Other points to note from these analyses are as follows.

- The brix results increased by $0.109 \pm 0.072\%$ between first-tested and second-tested samples. Moisture increased by $0.080 \pm 0.093\%$; and ash increased by $0.011 \pm 0.025\%$.
- Estimates of subsampling and testing error variance can be obtained from the residual mean square in the second stratum. These are standard deviations of
 - 0.09 % brix,
 - 0.13 % moisture, and
 - 0.035 % ash.

***** Analysis of variance *****

Variate: brix

Source of variation	d.f. (m.v.)	s.s.	m.s.	v.r.
samples stratum				
where	1	0.00364	0.00364	0.76
across	3	0.12703	0.04234	8.87
deep	1	0.00030	0.00030	0.06
across.deep	3	0.02053	0.00684	1.43
Residual	7	0.03341	0.00477	
samples.*Units* stratum				
rep	1	0.09445	0.09445	9.03
Residual	14 (1)	0.14649	0.01046	
Total	30 (1)	0.42574		

***** Tables of means *****

Grand mean 19.188

rep	1	2		
	19.134	19.242		
where	MillEnd	shredder		
	19.177	19.199		
across	1	2	3	4
	19.230	19.211	19.080	19.231
deep	top	bottom		
	19.185	19.191		
across	deep	top	bottom	
	1	19.222	19.237	
	2	19.182	19.240	
	3	19.065	19.095	
	4	19.270	19.192	

*** Standard errors of differences of means ***

Table	rep	where	across	deep
rep.	16	16	8	16
s.e.d.	0.0362	0.0244	0.0345	0.0244

Table	across
	deep
rep.	4
s.e.d.	0.0489

(Not adjusted for missing values)

***** Analysis of variance *****

Variate: water

Source of variation	d.f.	s.s.	m.s.	v.r.
samples stratum				
where	1	0.14988	0.14988	2.86
across	3	0.03521	0.01174	0.22
deep	1	0.06038	0.06038	1.15
across.deep	3	0.20248	0.06749	1.29
Residual	7	0.36695	0.05242	
samples.*Units* stratum				
rep	1	0.05040	0.05040	2.89
Residual	15	0.26185	0.01746	
Total	31	1.12715		

***** Tables of means *****

Grand mean 69.062

rep	1	2		
	69.022	69.102		
where	MillEnd	shredder		
	68.994	69.131		
across	1	2	3	4
	69.035	69.035	69.063	69.116
deep	top	bottom		
	69.019	69.106		
across	deep	top	bottom	
	1	69.035	69.035	
	2	69.100	68.970	
	3	68.935	69.190	
	4	69.005	69.227	

*** Standard errors of differences of means ***

Table	rep	where	across	deep
rep.	16	16	8	16
s.e.d.	0.0467	0.0809	0.1145	0.0809

Table	across
	deep
rep.	4
s.e.d.	0.1619

***** Analysis of variance *****

Variate: ash

Source of variation	d.f.(m.v.)	s.s.	m.s.	v.r.
samples stratum				
where	1	0.002135	0.002135	0.44
across	3	0.021274	0.007091	1.46
deep	1	0.000118	0.000118	0.02
across.deep	3	0.010057	0.003352	0.69
Residual	7	0.033968	0.004853	
samples.*Units* stratum				
rep	1	0.001028	0.001028	0.83
Residual	14(1)	0.017287	0.001235	
Total	30(1)	0.084942		

***** Tables of means *****

Grand mean 0.7513

rep	1	2		
	0.7456	0.7570		
where	MillEnd	shredder		
	0.7431	0.7595		
across	1	2	3	4
	0.7175	0.7875	0.7400	0.7602
deep	top	bottom		
	0.7494	0.7532		
across	deep	top	bottom	
	1	0.7075	0.7275	
	2	0.7675	0.8075	
	3	0.7350	0.7450	
	4	0.7875	0.7328	

*** Standard errors of differences of means ***

Table	rep	where	across	deep
rep.	16	16	8	16
s.e.d.	0.01242	0.02463	0.03483	0.02463

Table	across
	deep
rep.	4
s.e.d.	0.04926

(Not adjusted for missing values)