ANOTHER PERSPECTIVE ON EQUIPMENT RELIABILITY IN A SUGAR FACTORY

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Abstract

The South African sugar industry uses mechanical efficiency (ME) as an indicator of down-time resulting from mechanical failure of plant and equipment. The limitations of this index are highlighted and alternatives are proposed. Mean time between failures (MTBF), mean time to restore (MTTR) and mechanical efficiency are discussed and the benefits and differences between them are highlighted. A theoretical model of the Malelane mill extraction plant has been developed to produce an expected equipment reliability figure. The calculated reliability is compared with actual equipment reliability.

Keywords: extraction plant, mechanical failure, equipment reliability, Malelane.

Introduction

ME as reported by South African sugar factories is a measure of the down-time incurred as a result of stops originating from mechanical failure. Malelane mill interprets mechanical stops to include mechanical, electrical and instrument stops. Operational stops are excluded from this category. Malelane Planned Maintenance Department uses this figure as a measure of equipment availability. Typical industry reporting uses mechanical downtime as a percentage of available time. Malelane's computation for time lost includes cane supply, foreign material and scheduled stops. Metal detector stops are categorised under foreign material stops. Malelane records all stops of one minute and longer.

The definition of operational stops is a source of controversy between operating and maintenance personnel since some stops which may be operational in nature may actually result from engineering design constraints; for example, an undersized motor tripping on overload which could be attributed to operator error due to exceeding design capacity. ME of a sugar factory is a global measure of down-time, ie only down-time that stops the production line is recorded as a stop. Where standby equipment exists, change-over to the standby due to mechanical failure does not impact on the reported mechanical efficiency. ME, from an engineer's point of view, is the effectiveness of the mechanical functioning of a machine.

Malelane mill finds itself in this situation with two extraction lines having a standby cane preparation line. Breakdowns on the cane off-loading and preparation lines do not incur production downtime except for the delay in switch-over. Engineering personnel at Malelane were keen to track the mechanical status of all plant and hence the need for an alternative measure.

MTBF and MTTR are measures that are extensively used by other industries. ESKOM has for several years used this measure on individual components of steam and power generation plants (Bradley, 1985).

Definitions of MTBF, MTTR, ME, reliability and availability

MTBF is defined as the average time between all failures occurring during any equipment's operating cycle, also referred to as the mission time. MTBF is equal to the mission time minus the failure times, divided by the number of failures. MTBF is a measure of equipment reliability and is represented in hours. It should ideally be as long as possible.

MTTR is the average time taken to restore the failed equipment, and is measured from the moment of failure to the moment the equipment is back in operation. This includes time spent on decommissioning, cleaning, waiting, maintenance, testing and re-commissioning. Hidden losses include artisan availability and ability, tool availability and condition, spares availability and lastly complexity of the task. MTTR is represented in hours and should ideally be as short as possible. MTBF and MTTR by definition include all stops that result in shut down as a consequence of machine failure.

Mechanical efficiency, from an engineer's point of view, is the effectiveness of the mechanical functioning of a machine.

Reliability is the probability that a system, or equipment, will perform in a satisfactory manner for a given period of time when used under specified conditions. The time factor for this measurement is based on one hour.

Availability is the per cent probability that a system will be ready or available when required for use. It excludes any maintenance time, operational down-time or any other time where the equipment is not available for normal duties. For example, where throughput is reduced due to partial failure the ME reporting system would not make the availability reduction visible. Availability, however, looks at each component and would therefore reflect the reduction.

The relationship between these parameteres is explained with reference to Figure 1 which shows downtime for Malelane mill for 11 September 1995. The portrayal shows that although the operation cycle was 24 hours long, the plant operated for only 20,02 hours and there were 11 failures amounting to 3,98 hours being lost. From this the failure rate (λ) will be:

$$\lambda = \frac{\text{number of failures}}{\text{total operating hours}}$$

$$= 549{,}45 \times 10^{-3}$$

$$\text{MTBF} = 1/\lambda$$

$$\text{MTBF} = 1{,}82 \text{ hours.}$$

In order to calculate the MTTR, the total hours lost due to failure must be added and divided by the number of failures, thus:

$$\text{MTTR} = 0{,}362 = 21 \text{ minutes } 42 \text{ seconds}$$

$$\text{Reliability, R(t)} = e^{-\lambda t}$$

$$\text{R(t) for one hour} = 0{,}577 = 57{,}7\%$$

$$\text{Availability} = \text{MTBF} / (\text{MTBF} + \text{MTTR})$$

$$= 83{,}41\%$$

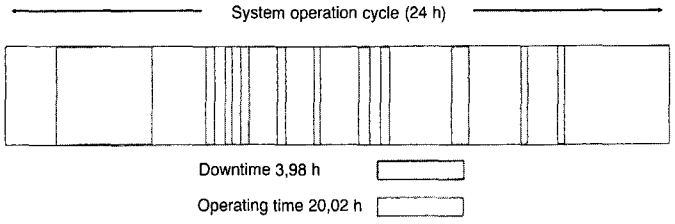

FIGURE 1: Malelane extraction plant operation and failure cycles over 24 h period

Comparison of reliability parameters and ME

The shortcomings of mechanical efficiency as a maintenance performance indicator by itself can be demonstrated by comparison of the two scenarios in Table 1.

Table 1
A typical example of ME, MTBF, MTTR, availability and reliability

Parameters	Scenario 1	Scenario 2
Mission time	24 h	24 h
Failures	1	12
Time lost per failure	72 min	6 min
Total time lost	72 min	72 min
Mechanical efficiency	95%	95%
MTBF	24 h	2 h
MTTR	72 min	6 min
Availability	95,24%	95,24%
Reliability	95,92%	60,7%

Both ME and availability are related to time lost and indicate 95%, however, according to Loock (1994), reliability indicates that there is a 60,7% probability that operations will not be interrupted every hour. The converse of this is that Scenario 2 has an unreliability of 39,3%. The relationship between these parameters over the past four years for the Malelane mill is shown in Figure 2.

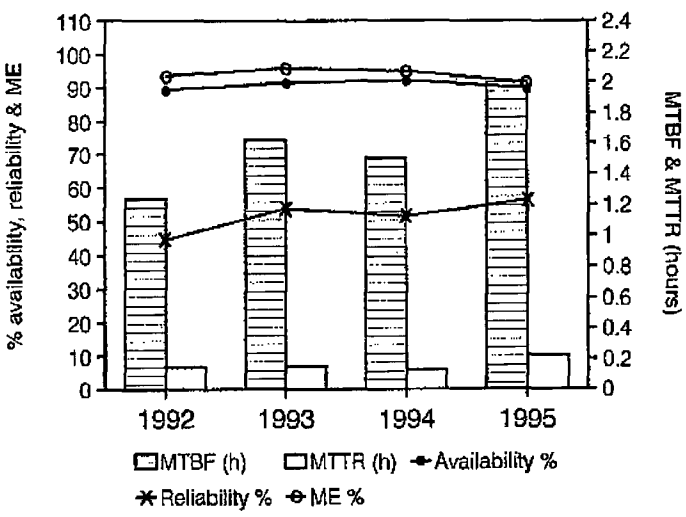

FIGURE 2: Graphic representation of MTBF, MTTR, availability, reliability and ME for period 1992-1995, for Malelane extraction plant

Mechanical efficiency fluctuated in the range of 92 to 96% whereas reliability, although low, showed a steady improvement. The MTBF also steadily improved from 1,6 hours to about 1,8 hours in a similar manner. The MTTR achieved is acceptable; however, MTBF must be increased to a more substantial time, ideally, to 320 hours or more. The preference for 320 hours is based on the traditional maintenance day for extraction plant being every fortnight. The stop will be then be eliminated by the maintenance actions on a stop-day. It should be noted that the main factor causing the interruptions is the metal detector. If these interruptions can be eliminated, a vast improvement in MTBF will be experienced. It may have a negative influence on MTTR because metal detector stops are usually very short and if they are eliminated, only the longer, more serious breakdowns will impact on MTTR. Reliability will be influenced positively.

Application of reliability principles to the Malelane mill extraction plant

The Malelane mill extraction plant consists of 24 different critical components in sequential operation. Failure of any one component stops the entire line. Each component has been broken down to its elemental level. Each element's theoretical reliability has been calculated based on failure rates obtained from MIL-STD-HBK-217 (1978) and Dhillon (1988) and are therefore typical for industrial equipment in use world wide. Data for slings and liners are based on Malelane historical records. Refer to the appendices for:

- a graphic representation of Malelane extraction plant (Appendix 1)
- Malelane road tipper equipment failure rates per day (Appendix 2)
- calculations and standard failure rates calculated per component of the extraction system (Appendix 3)
- Malelane mill downtime information for 1995-96 (Appendix 4).

These results show that the Malelane mill extraction plant should have a calculated reliability of 96,7% (Appendix 3) for one hour, but the actual statistical reliability obtained is far less than that. This is shown in Figure 3.

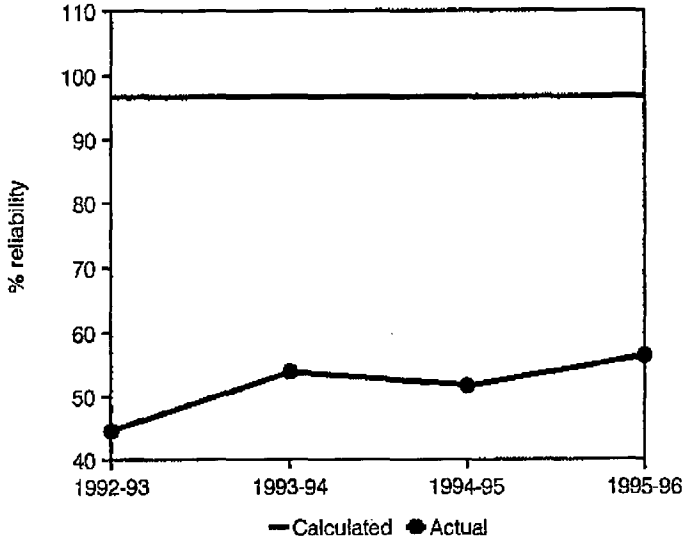

FIGURE 3: Graphic comparison of calculated vs actual reliability for period 1992-93 to 1995-96, for Malelane extraction plant

There is a large variance between calculated and actual reliability. It is also noticed that there was a steady improvement in reliability since the 1992-93 season. This coincides

with the introduction of reliability centred maintenance (RCM) where maintenance is aimed at the components that will effect reliability the most. The actual reliability figure is still far off the target of 96,7%, this being attributed to the high plant failure rate. This case is supported by the high incidence of short duration metal detector stops.

Inherent integrity improvement of any equipment has two approaches; the maintaining leg and the improvement leg. Both these paths must be covered in order to ensure real inherent improvement. This is demonstrated in Figure 4.

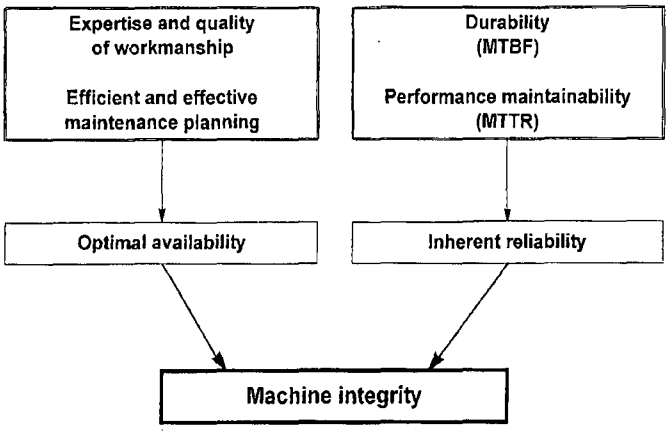

FIGURE 4: Equipment inherent integrity in perspective

Reliability improvement principles entail the upgrade of those components with low inherent reliability or to engineer out the cause of stops. Components with an inherent reliability probability lower than 96%, statistically constitute 20% of equipment failures which in turn will account for 80% stops. The tippler, road feeder table, cane knives and Nos. 1 and 2 mills are identified as sources of inherent unreliability and predicate management attention to be focused on these components of the extraction plant.

Metal detector analysis

The metal detector was not part of the theoretical calculations, since failure of the metal detector *per se* is negligible. The present interruptions caused by the metal detector on the shredder feed conveyor is a result of sequential interlocks. Therefore in Malelane's case these stops are not reflected in the ME reported figure and only impact on overall time efficiency reported figures.

In order to demonstrate the effect of the metal detector stops, Table 2 shows the effect when metal detector stops are eliminated. MTBF almost doubled and MTTR took an understand-able drop due to all the short duration stops being removed. Reliability improved by 26,7% and availability improved by a small margin. The significant improvement in reliability supports replacement of the metal detector with an electromagnet.

Table 2

The influence of eliminating metal detector stops

Metal Detector	Stops	MTBF	MTTR	Reliability	Availability
With	3 028	1,74	0,22	56,30%	88,72%
Without	1 864	2,96	0,34	71,33%	89,67%

Mill stops analysis

The unreliability of the Nos. 1 and 2 mill stops (mill overload and high chute level trips) was examined and the benefit to be derived if 90% of these stops can be eliminated is shown in Table 3. This enhancement resulted in MTBF being increased by 183%, MTTR increased by 156,7%, reliability improved by 45% and availability improved by 1%. MTBF and MTTR increase is dramatic but not of much significance. The minor change in availability verifies the stops as of short duration. The reliability improvement means that the probability of having a failure every hour has now been reduced by 45%. In this instance the last parameter is a valuable management tool that identifies the source of greatest benefit.

Table 3

The influence of reducing the mill stops

	Stops	MTBF	MTTR	Reliability	Availability
No enhancement	3 028	1,74	0,22	56,30%	88,72%
10% mill problems	998	4,93	0,57	81,64%	89,67%

Performance comparison of different mills

To demonstrate the benchmarking benefit of this concept two factories with similar extraction plants are compared in Table 4. Although Malelane mill has a better ME, Komati has a far better MTBF and reliability. This may partially be ascribed to the fact that most of Malelane mill's stoppages are short duration metal detector and mill stops. Komati mill does not have the high incidence of stops experienced at Malelane due to the installation of electromagnets and sophisticated mass flow devices fitted to the mills.

Table 4

Comparison of performances between Komati and Malelane mills (1993)

Mill	Mechanical efficiency	MTBF	MTTR	Availability	Reliability
Malelane	95,9%	1,62	0,15	91,57%	53,87%
Komati	89,8%	6,98	0,71	90,7%	86,7%

Conclusions

This study has revealed a discrepancy between calculated (based on general standards) and actual reliability of the Malelane extraction plant. Mechanical efficiency as reported by the sugar industry has two main disadvantages. Firstly, it is a global measure which only records down-time that results in a stoppage of the production line. Secondly, as a measure of availability it does not reflect the mechanical integrity of individual components of the production line. MTBF and MTTR can be applied to individual components and therefore provide the plant engineer with valuable diagnostic tools that can focus management attention on problem areas.

Reliability analysis is an objective tool that can enhance management decision making in engineering-out problem areas and/or upgrading equipment. Frequency of failures are not evident with ME reporting but MTBF fulfils this purpose.

The time span for every breakdown, encompassing known and hidden time consuming elements, is portrayed by MTTR. MTBF and MTTR are more suitable indices for the maintenance engineer as they relate directly to component integrity. Reliability and availability are more suitable for the Engi-

neering Manager as they portray a global perspective of a section or the entire plant.

Acknowledgements

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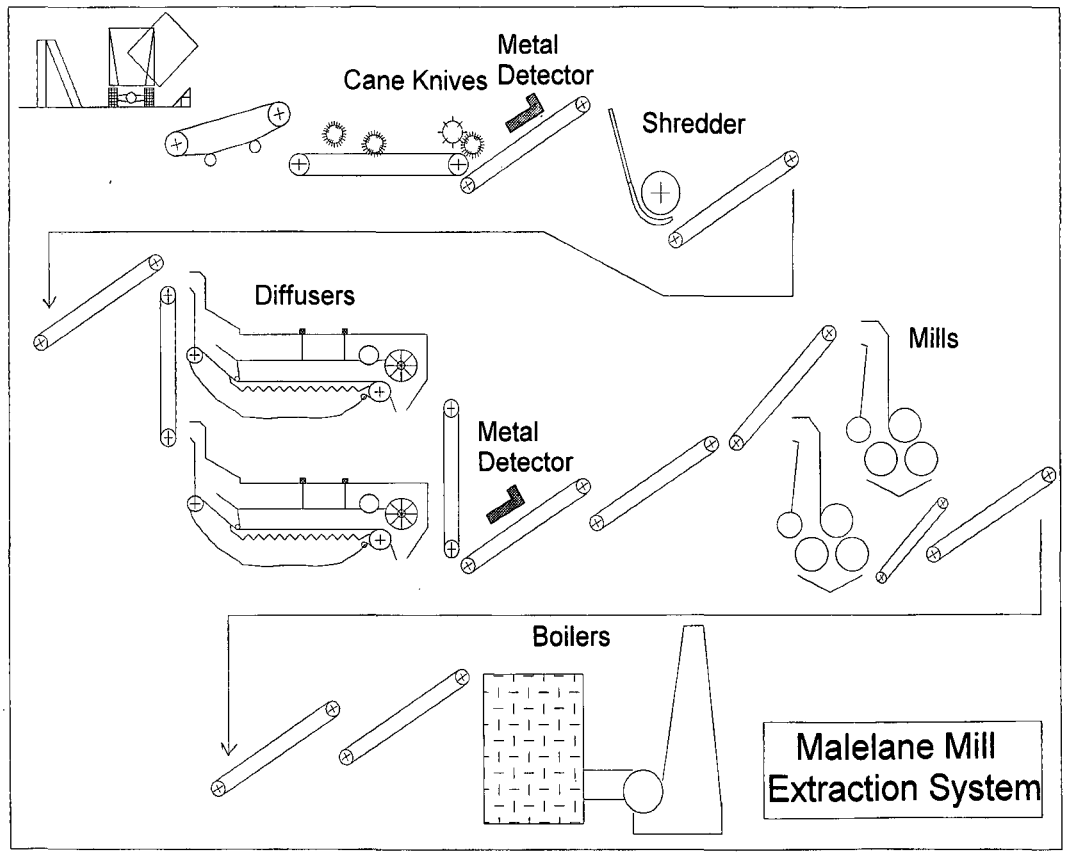
Appendix 1



Malelane Mill Extraction System

Appendix 2

Malelane road tippler equipment failure rates per day

Equipment	Failure rate per day
Hydraulic pumps	$1{,}57847 \times 10^{-3}$
Hydraulic hoses	$228{,}1542 \times 10^{-6}$
Hydraulic solenoid valves	$177{,}9603 \times 10^{-6}$
Hydraulic pistons	$2{,}135524 \times 10^{-3}$
Slings	$992{,}0635 \times 10^{-6}$
Electric motors	$2{,}0 \times 10^{-5}$
Electric switch-gear	$2{,}4 \times 10^{-5}$
Protection systems	$3{,}0 \times 10^{-4}$
Combined failure rate	$5{,}456667 \times 10^{-3}$

Appendix 3

Malelane extraction plant component failure rates, MTBF and reliability

No	Component	Failure rate	MTBF	Reliability
1	Tippler	5,4567E-3	183,26	87,725%
2	Road feeder table	14,2274E-3	70,29	71,073%
3	Main carrier	529,7770E-6	1 887,59	98,737%
4	Cane knives	2,0536E-3	486,94	95,191%
5	Shredder feed conveyor	551,2312E-6	1 814,12	98,686%
6	Shredder	1,5963E-3	626,46	96,241%
7	Shredder discharge	728,8220E-6	1 372,08	98,266%
8	Diffuser feed conveyor no.	1,3361E-3	748,45	96,844%
9	Diffuser feed conveyor no.	690,6220E-6	1 447,97	98,356%
10	Diffuser feed slat conveyor	611,7440E-6	1 634,67	98,543%
11	Diffuser no. 1	838,4020E-6	1 192,75	98,008%
12	Diffuser no. 2	836,8020E-6	1 195,03	98,012%
11 & 12	Diffuser nos. 1 & 2	16,5074E-6	60 578,78	99,960%
13	Diffuser discharge	456,2420E-6	2 191,82	98,911%
14	Mill feed conveyor no. 1	1,3361E-3	748,45	96,844%
15	Mill feed conveyor no. 2	644,8950E-6	1 550,64	98,464%
16	Mill feed slat conveyor	621,9310E-6	1 607,90	98,518%
17	Mill no. 1	2,1957E-3	455,44	94,867%
18	Mill no. 2	2,1957E-3	455,44	94,867%
17 & 18	Mill nos. 1 & 2	109,9407E-6	9 095,81	99,736%
19	Mill discharge conveyor	644,8950E-6	1 550,64	98,464%
20	Bagasse conveyor no. 1	339,0250E-6	2 949,63	99,190%
21	Bagasse conveyor no. 2	342,8650E-6	2 916,60	99,181%
22	Bagasse conveyor no. 3	342,8650E-6	2 916,60	99,181%
23	Slat conveyor no. 4	377,9570E-6	2 645,80	99,097%
24	Bagasse conveyor no. 5	631,6050E-6	1 583,27	98,496%
	Total system reliability			44,596%

Some basic calculations:

MTBF = the reciprocal of failure rate;
Failure rate = λ
MTBF = $1/\lambda$ = 183,28 hours or 7 seven days, 38 hours, 11 minutes and 48 seconds.

Reliability = $R(t) = e^{-\lambda t}$;
where t = 24 hours, $\lambda = 5{,}46 \times 10^{-3}$;
Thus, R(24) = 0,878, meaning the system has an 87,8% chance of surviving 24 hours without a failure.

The total system reliability in the above table means that there is a 44,6% chance that equipment will not fail in a 24 hour period. The hourly survival rate is thus:

$R(24) = 0{,}45$;
$R(t) = e^{-\lambda t}$ and t = 24, thus $0{,}45 = e^{-\lambda \times 24}$
$\log 0{,}45 = -\lambda \times 24 \times \log e$
$0{,}351 = \lambda \times 24 \times 0{,}434$
$\lambda = 0{,}034$ failures per hour,
and MTBF = 29,72 hours.
$R(t) = e^{-\lambda t}$
Thus $R(1) = e^{-0{,}034 \times 1}$
$R(1) = 0{,}967$

which means there is a 96,7% probability that the Malelane mill extraction plant system will operate satisfactorily for one hour.

Appendix 4

Malelane mill downtime information for 1995-96

Category	Time lost (hours)	Frequency	Average downtime
Cane control	5,35	35	9 min 10 sec
Metal detector	58,45	1 164	3 min 1 sec
Electrical power station	30,55	38	48 min 14 sec
Instrumentation	11,15	10	1 h 7 min
Mechanical power station	122,68	69	1 h 47 sec
No cane supply	502,37	172	2 h 55 min
Other reasons	16,75	15	1 h 7 min
Process power station	76,72	104	44 min 16 sec
Process operations factory	45,02	212	13 min 22 sec
Stone contamination	3,65	55	3 min 59 sec
Scheduled planned stop	291,13	30	9 h 42 min
Electrical extraction	36,82	161	13 min 43 sec
Mechanical extraction	213,95	962	13 min 21 sec
Mechanical raw house	4,17	1	4 h 10 min
Total downtime	1 418,74	3 028	

The above table gives all stops experienced in a 33 week crushing season. Cane supply and scheduled stops were removed from the calculations as none were related to equipment failure, although maintenance was performed during the latter. The operation cycle was thus 33 weeks, amounting to 5 544 hours. Interferences amounted to 1 418,74 hours minus 502,37 (cane supply) and 291,13 (scheduled stops), giving a mission time of 4 918,76 hours.

The failure rate, λ = 2 826 / 4 918,76
$\lambda = 574{,}54 \times 10^{-3}$
and MTBF = 1,741 hours
or = 1 hour 44 minutes and 26 seconds.
To calculate MTTR, the number of stops must be divided by the time lost, which is:
MTTR = 625,24 / 2 826 = 0,22 or
= 13 minutes 17 seconds.
With this type of performance, the reliability and availability will also be fairly low:

$R(t) = e^{-\lambda t}$
Thus $R(1) = e^{-0{,}574 \times 1}$
R (1) = 0,563 = 56,3%
Availability = MTBF / (MTBF + MTTR)
= 1,74 / (1,74 + 0,22) = **88,72%**