Focus on Uptime – what about Downtime?

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Summary: Business focus is generally directed to measuring uptime as a valid performance indicator for plant and equipment reliability. Uptime provides us with a direct relationship between production and losses that necessarily occur in every business process, regardless of whether it is continuous or batch processing, concerns manufacturing or services. It is of course the desire to achieve and maintain design reliability of the whole production system during the Operations period to assure the maximum throughput and equipment availability can be sustained. Often this is achieved by redundancy of installed equipment and other measures that are designed to minimise downtime. The question raised and investigated in this paper is the understanding of downtime and how it can influence our ability to increase uptime as a result. Can we really say we understand what the equipment downtime that causes us production losses or increased cost consists of, all of which reduce the revenue and therefore profit. The hypothesis of this paper is that with better understanding of downtime and what it is made up of, uptime can not only be improved, but also reduce cost of operation and maintenance. Taken in the holistic concept and framework of Asset Management, understanding downtime can substantially improve production / manufacturing / services competitiveness and profitability.

Keywords: Downtime, Reliability, Availability, Asset Management, Uptime

1. INTRODUCTION

Uptime is a very commonly used Performance indicator – we measure the production capability of systems in this term – what was the uptime for our Assets in the past and what do we need in the future? Form that measure, other operations and performance indicators can be derived, such as equipment effectiveness, utilisation and more. We can formulate our expectations from the Asset in the future, making this measure a target for Asset performance. We are getting more and more used to expressing needs in positive numbers and as a positive outlook. It can often be found that these 'positive' measures are well accepted and give a good view of what is 'to be'.

What such a positive measure often does not easily reveal is the more 'negative' aspect of operations and often do not reveal underlying reasons for achieving a certain performance or uptime, or provide sufficient focus to make improvements. Let us consider how downtime can be used as a driver for improvement of uptime.

2. ORIGINS OF DOWNTIME

What is downtime? When asked what Asset Managers or Plan Managers know about downtime, they are usually very knowledgeable on what causes major delays in production or what the main reasons for shutdowns in a process plant are. Asking about the less obvious reasons for incurring downtime results more often then not in vague understanding of downtime, and is usually attributed to many reasons but those that are at the root of the lost production time.

Fundamental to the understanding of production losses or 'bad performance' of Assets is the classification of failures, the understanding what a failure is. A useful discussion of equipment failure is found in literature and also in (the now superseded) British Standards for Reliability, the Dependency Standards and ISO 14224 and other related ISO standards. Fig. 1 provides an indication how failures can be systematically classified to provide a structured view on what types of failures generally occur in systems or in equipment.

The reference to understanding of failures is often limited to the Branch of extended failure and there to the 'complete failure' branch. This can be usually tracked to the complete outage of a system or subsystem resulting in production loss. In most of our dealings with failure mode recognition, be it for purposes of root cause analysis or Reliability Centred Maintenance or other production related elements; we restrict ourselves to the recognition of sudden failures and at times of gradual failure. Most often the gradual failures are observed to be an interpretation of two mechanisms, namely ageing or degradation of equipment. Often systemic and organisational failures that contribute to unsatisfactory Asset performance are not recognised.

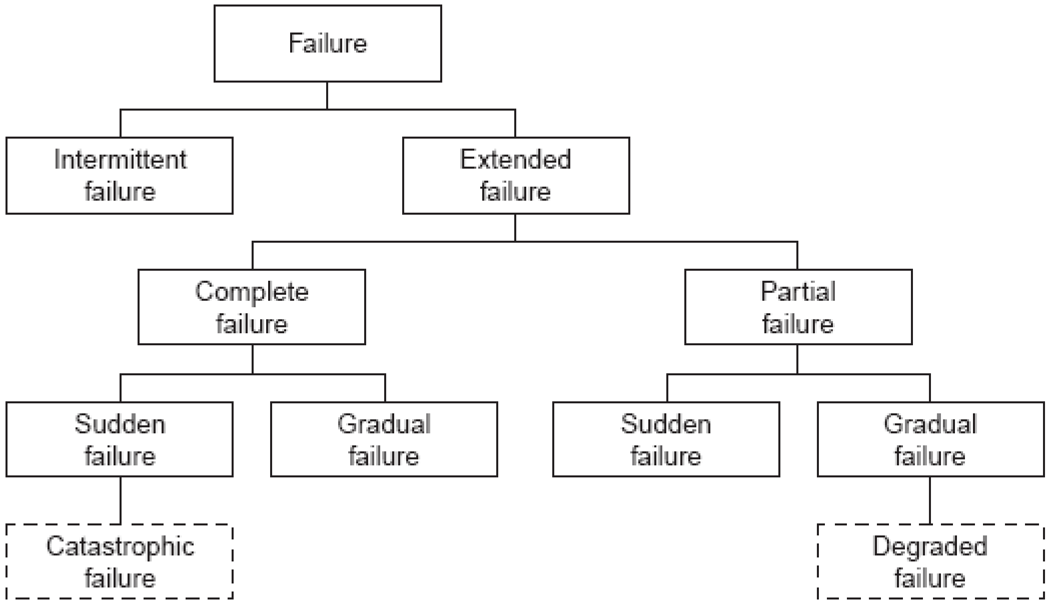

Figure 2-1, Failure hierarchy[1]

From Figure 2-1 we can determine that often the intermittent failures do not receive as much attention as sudden failures may receive and the way we pay attention to degraded failures. But we also need to understand where failure originates. Rausand suggests the following structure of failure causes:

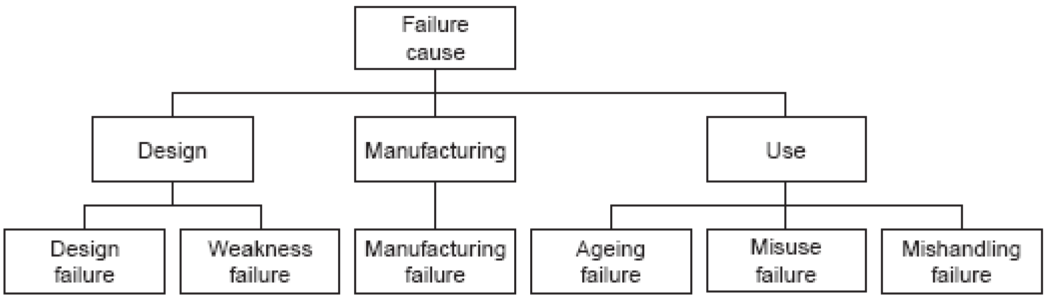

Figure 2-2, Failure causes[2]

In operations we find that the attribution of failure is to ageing; misuse and mishandling failures are in many organisations not recognised. Why is that, we must ask ourselves? Without having Industry based statistical backup information, in discussions with plant operators and maintainers the Author has found that it is generally accepted that operating instructions and procedures are 'well structured and prevent us from making mistakes'. And we do look after our Assets, but we recognise that accidents can occur and mishandling might occasionally require additional repairs or investment. This was the consensus among 5 Refinery Operators and 4 Offshore Oil and Gas Businesses in the Asia Pacific Region and by 2 European Operators. One European Operator suspected that there may be more then equipment ageing involved in losing production or incurring downtime. It appears from informal interviews that the manufacturing businesses might have a better handle in the organisational failures but are not always able or prepared to address them.

There is currently no serious research available that would give an indication how many failures are attributable to misuse, and mishandling, with only some attempts to quantify ageing and reasons for design failure impact. Nor is there any deep reaching understanding about the cost associated with the above failure causes. It is a lamentable situation that often we do not understand in our own operations which failure causes are the main problems for us. It is only through the application of risk-based methodologies that an understanding of such failure causes can be uncovered and opportunities emerge to reduce the failure causes. But why is the understanding of the failure causes and their repeat occurrence so important? It is of course through the effects of failure that we incur downtime and this leads directly to increased cost be it through production losses, extra resource requirements, overtime payments and in extreme cases the premature replacement of Assets or abandonment before value was extracted. Neglecting to fully understand the origin of failure and failure causes will result in “grey losses” that are not obvious but can cause significant losses to profit and profitability.

Barringer[3] states in his determination of Process Reliability that failures are events of composite contributors and summarises failures as ‘Hidden Factory’. The cost attributable to this hidden factory is largely dependent on the clarity of understanding of the origin and reduction of downtime, among other elements such as configuration, capability and maturity of equipment, organisation and processes. All of these elements are again influencing factors for downtime.

3. DETERMINATION OF DOWNTIME

Best in class Asset Management Organisations have a variety of modelling tools on hand to estimate the outcomes of some of their business processes. In terms of determining the losses of plant and equipment that may be caused, Reliability models are of great value. These models are useful for manufacturing, process and service organisations alike, identifying typically the estimated uptime, estimated downtime and system capability related to the plant output. Along the way, they also provide information about the opportunities for improvement.

A key data element for improvement is the determination of unplanned events (usually based on plant experience) but always based on historical facts. The mean time to failure is often the major failure frequency measure. Each of these events of course has associated repair time and hence equipment downtime. Based on the criticality of the equipment to the production process, total or partial loss of capacity may result.

The criticality of downtime becomes clear when the equation for Availability is considered:

$$\text{Availability} = \text{Uptime} / (\text{Uptime} + \text{Downtime})$$

What is downtime then? Or what does it include? Which parameters really matter? Perhaps we start with a review of what downtime is. It is simply put the period of time during which the equipment, subsystem or system is unable to carry out the functions it is required to perform[4]. Some might disagree and state that downtime is measured from the time the equipment has failed to the time production was fully resumed. In practice, the statement is never really this black and white. There are generally other ways of managing equipment failure either by continuing to operate with reduced throughput or by using standby equipment that may either fully or partly support the process and the failed equipment or circumstances (demand) that allows repaired equipment to remain off line at times of reduced production rates.

3.1 How is downtime measured

Historically, before the advent of powerful desktop computers, downtime was generally diligently recorded on equipment record cards and production shift logs. This may today still be the case in some instances, but records are most often relegated to various databases in a computer and may be managed and maintained by various groups (data owners). It is in process and service industries often found that there is no single comprehensive repository of the downtime data. Or it is pointed out that the Computerised Maintenance Management System (CMMS) is the data warehouse for all such maintenance related information. But what do we see in those systems? A huge quantity and great variety of data is recorded and stored, but that data has too often little real value for reliability engineering and downtime determination. In our highly automated and computerised world many parameters are either logged manually or automatically or are expected to be logged in these systems. The segregation of data ownership also makes the reasons for data collection and their use less transparent and recognisable. As not all equipment is under automatic or computerised control, a mix of collection, analysis and storage processes and systems are required when all parameters should end up being stored in a common location that can be queried through a common access and report system.

The Manufacturing Industries appear to be somewhat better off, if they adhere to principles of Total Productive Maintenance (TPM), 6 Sigma methodologies and the likes. It appears easier to determine the lost production due to downtime when pieces can be counted, then when customers are dissatisfied or continuous processes are involved (soft or intangible targets). Whichever Industry needs to measure downtime, accurate data is essential as illustrated by Nakajima[5] and many others that have written about managing production uptime.

3.1.1 What are typical elements for downtime determination?

While the paper deals mostly with the process Industry, the elements that constitute downtime are the same in every Industry. The minimum standard for downtime determination can be identified as:

- Definition of what constitutes failure (specific for each system/subsystem/component or equipment)

- Exact time when the failure occurred
- A meaningful failure description or use of a standardised failure code (this must be searchable in the repository)
- A suspected cause of failure (this must be searchable in the repository)
- A confirmed failure description or use of a standardised cause code (this must be searchable in the repository)
- A repair description that indicates what actually was wrong and why (this must be searchable in the repository)
- A verified description of the failure impact (this must be searchable in the repository)
- The duration of the repair and reinstatement of the equipment
- The time / date of handover and acceptance by Production of the equipment
- The time period from completed repair to actual start up
- The time when planned downtime is required and the equipment is taken out of service
- The duration of the planned downtime up to completion of maintenance (handover)
- Possible standby time
- Impact of Planned Maintenance
- Tool time (time taken for actual work)
- Utility time (time taken to prepare and resource)
- Waiting time and explanation for the incurred time (idle time, where no work could be carried out for various reasons) for instance waiting for spare parts, specialist tools etc.

The list above is not exhaustive, but indicative of what would be required to effectively record downtime in the first instance and provide sufficient background information for analysis. Simplified, the above can be summarised into two states of being: Available or Unavailable.

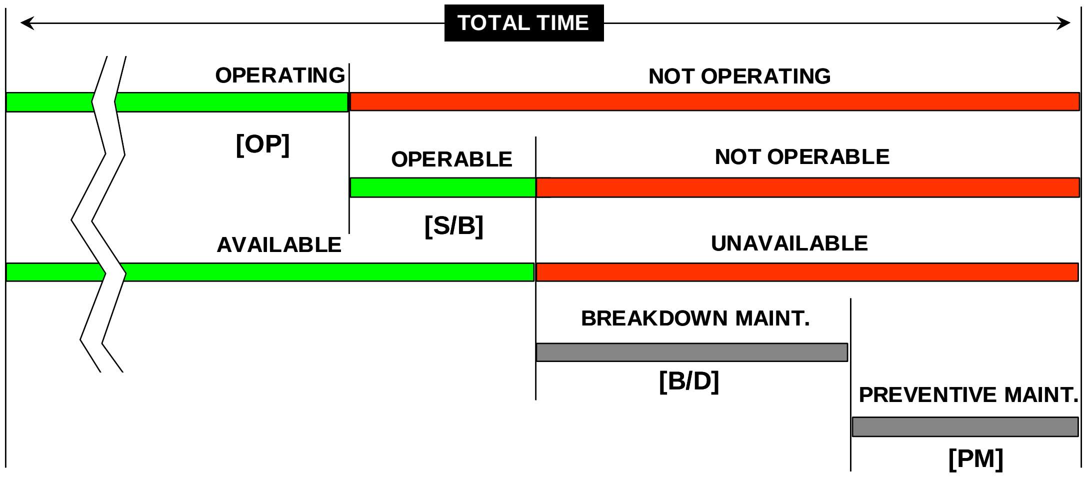

Figure 3-1 – Availability graph

Fig.3-1 shows more detailed the various states equipment, subsystems or systems can be in. It may be seen that it is important to know whether the item(s) are operating and / or operable. Calculating Overall Equipment Effectiveness (OEE) would also require knowledge of these various states. The operating state of equipment is of course the usage period, but if equipment is operable, it is in a state of readiness but not used by a conscious decision or a demand situation (usually less / no demand).

It can further be seen that items are either in operating or non operating state. Not operating can have various causes, it might be that the equipment is not required, is under planned overhaul or is due to be mothballed. The status of 'not operating ' will always mean equipment being "off line". Similarly, 'not operable' indicates defect or rectification and being off line for that eason, as otherwise equipment would be 'operable'. In the 'not operating' state the equipment cannot be used due to defects or other reasons that would prevent equipment to be operable (for instance intrusive maintenance). Availability is then the state of being either Operating [OP] or operable [Stand By].

It should now become clearer that any event either planned or unplanned will need to be considered as downtime. Planned downtime could be incurred due to maintenance events (the aim here is to provide optimised maintenance intervals as well as maintenance durations to minimise production loss causing downtime) or opportunity maintenance events that can be planned ahead. Breakdown maintenance is the response to any failure that reduces the equipment performance beyond an acceptable level or causes unplanned stoppages.

3.1.2 Non work related delays

In addition to tool time and preparation time, it should to be determined what causes the additional downtime. For instance, it may not bee feasible to hold high cost spares that are infrequently consumed. As an example, reciprocating compressors may fail in a variety of ways, but failure of the cross heads and other running gear may be rare. If such a failure occurs, there may be 6 months to 9 months waiting time to manufacture and install these specific parts. Anyone involved in managing Optimisation would want to know about this situation, as the resulting production losses could be prohibitive. On the other hand, this is also related to managing exposure and risk to the business. Without understanding what the cost is of not having a spare part available, incorrect decisions can result that may well prove even more costly.

Similarly, it may be decided to oustsource maintenance work. If on the occasion of a breakdown the repair crews need to be mobilised and take several days to respond, this needs equally to be known, as it will also impact production. Of course there may be other related delays that need to be observed, such as depressurisation, flushing, cleaning and generally making safe the equipment prior to commencing work. It might also be related to obtaining work permits and access approval.

In areas it might also be an issue that only less competent people than elsewhere are available to carry out work, which will inevitably lead to quality concerns and may also require longer downtime periods.

This may be further complicated by adjustment / tool changing times, alignment etc in manufacturing and batch type processes. Smith lists several other related periods and classifies besides the tool time (repair work time) access time, logistics time and admin time[6].

3.2 Mean time between Repair (MTBR)

Commonly, the MTBR is a most useful benchmark measure. This KPI is also useful in determining maintenance effectiveness and quality of repair / maintenance tasks. Building on the definitions above (Fig. 3-1), MTBR would be calculated by analysing time between repair events. This will not necessarily coincide with the time to failure, as there will be ‘reaction time’ to respond to the failure such as the making safe, deciding on repair scope, ordering of materials from stores and other safety, technical and logistics related activities and the mobilisation of specialist resources. Repair time starts when the work actually commences, excluding the preparation times. The benchmark would be indiscriminate of the times the equipment may be operable or actually operating and does not evaluate repair duration. In determining and managing downtime, it is useful to know how frequently equipment has to be taken out of service either for planned or unplanned work.

3.3 Mean Time to Repair (MTTR)

This measure takes into account the time it takes from a failure to a restoration to operable status (the total incurred downtime). This would be the ‘true’ measure of downtime. It is here that all the delay times mentioned above would need to be factored in. Once a failure occurs, the delay to prepare for repairs is part of this measure. Similarly, planned repairs would be measured in the same way. Both KPI’s for unplanned and planned repair times have specific purpose, namely if the failure repair time is measured only, it becomes an element of reliability. If the planned repair time is measured, it becomes indicative of capability (competency) and quality of repairs. Combined, the KPI’s will of course become a measure of Availability in the classical sense explained above.

MTTR could also become a measure of maintainability – if it is difficult to repair certain failures or carry out planned routine tasks, the design may not be focussed on optimised uptime. The mean time to repair is dependent on the type of failure (ref. Fig 2-1) that occurs. It is an essential task of Reliability Engineering to monitor the types of failure and the repair times and to analyse the consistency of failures and restoration times. Recurring failures should be further investigated (using methodologies such as Root Cause Analysis) as part of Defect Elimination Management. MTTR therefore becomes a trigger for improvement activities that can be justified by the underlying analysis based on accurate data and cost assessments.

In assigning cost to the Mean Time to Repair and associated resources and production losses due to the failure modes, it becomes clear where and how the losses are incurred. It now becomes possible to identify the life cost improvements or the life cycle profit that can be achieved through improvement either to design conditions or to meet revised requirements. This is illustrated in Fig 3-2. The cost categories in each section are indicative of typical categories, which of course vary somewhat between Industries and Services.

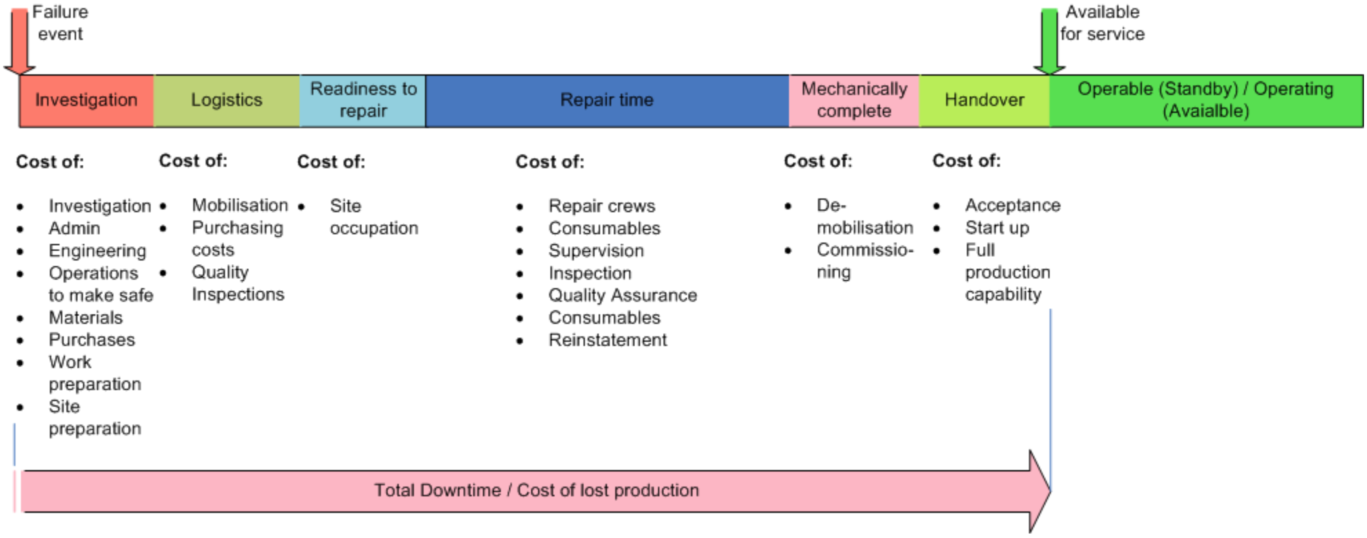

Figure 3-2 - Generic elements of repair cycle (Downtime-cost and duration)

Time and cost are cumulative and need to be appropriately identified to enable optimisation and improvement. The premises for cost assignment must be clearly defined and sources for the various cost categories must be available to all that are involved in the analyses and cost assignment. It is also crucial to understand how the failure consequences matter over time – there may be different costs associated with the duration of downtime. Record keeping is crucial to capture all downtime, assign costs and capture the findings during and of the repairs.

4. FREQUENCY OF DOWNTIME INCURRED

If taken for the unplanned (failure) events, frequency of downtime becomes a measure for reliability. Simply viewed, it can be stated that the expectation of an item or a population of items in similar services and operating conditions is operating as required, is the probability that these items will be found operational. For example, if we look at a machine in a specific time frame 10 times and we expect to find (and actually find) the machine operating 9 times, we have a 90% probability that the machine is operational (not failed and incurring downtime).

The frequency of failure is of course only part of the reliability picture. More information is required to conclusively determine reliability, which again is based on the downtime elements listed in section 3.1 and possibly others. Statistical data analysis is elementary in determining reliability, but it all starts with the appropriate and disciplined capture of data. The most useful outcome of reliability analysis is the understanding of failure characteristics (such as through Weibull Analysis) and its implications in the optimisation of reliability and maintenance for instance through application of the failure characteristics to determining relevant maintenance tasks and intervals avoiding the failure mode consequences. This of course is a core objective of methodologies such as Reliability Centred Maintenance (RCM).

The commonly used measures for reliability are only time related; they do not give by themselves any indication of production (or other) consequences or in which pattern failures occur, nor necessarily what component causes failure. This has to be added and used to build an appropriate database that once again can assist in identifying downtime and ‘bad actors’. Quantitative analysis of the reliability characteristics of equipment / subsystems / systems can further assist in pinpointing the opportunities for sustainable improvement thereby reducing downtime and setting the foundation to make Reliability and Maintenance the driving elements in achieving Life Cycle Profits. This concept of Life Cycle Profit is the inverse of Life Cycle Cost, where the profit element points to the savings that Reliability Engineering and Maintenance Optimisation make to reduce cost of equipment over its life time - hence profit.

4.1 Mean Time Between Failure (MTBF)

This term is often used to characterise the average lifetime of an item or population of items in similar services and operational conditions. It is simply the ratio of service hours achieved to the number of failures in the population for replaceable items[7]. When the MTBF is associated with the incurred consequences of the failure (generally the downtime), the risk to the business and the exposure from operating with the chosen equipment become tangible and can be used to drive improvement programs. For non repaired items, this also cold mean that pending on failure consequences, a risk based maintenance program could be developed.

4.2 Mean Time to Failure (MTTF)

This measure is very similar to the MTBF, it is the ratio of cumulative service time to the total number of failures in the nominated period. This can be used as a measure for the average value of the operating life at which failure occurs. This measure is useful for repairable items. It is important here to determine the period to measure. Is the MTTF inclusive of repair time? It should by necessity be exclusive of repair time, the measure should be directed at operating time only. This means, it would be inclusive of standby time ('operable' status) and failures that may occur during this time, as well as the failures during operating time. It seems that often the repair time and standby time are part of the time to failure determination that will result in incorrect assessments, showing more optimistic values.

This KPI can be used as a measure of effectiveness of a preventative maintenance program (where it exists) and verification that the chosen maintenance strategies are achieving the required cost as well as uptime targets (minimised losses). As a measure of unreliability, it can provide the Reliability Engineer with a very good indicator where things go wrong. Together with the associated downtime for a failure and its cost, MTTF analysis can be used to trigger maintenance improvements (optimisation) and should be used to initiate Root Cause Analysis to eliminate the failure modes. Clarity of understanding of the definitions and measures of downtime and its constituent components is vital to enable consistent interpretation and results.

5. FREQUENCY OF PLANNED EVENTS

Measuring the frequency of downtime events can be extended to measure also the frequency of planned interventions. This can be termed the Mean time between Maintenance when all maintenance events that incur downtime (as an example) are plotted against a time line, for instance the period between major machine overhauls or plant turnarounds. The measurement of the planned downtime frequency for equipment can also assist the planners to optimise maintenance. When used as a lead KPI it indicates the required efforts for the planned period, and when used as a lag KPI, it would show the achieved maintenance (compliance). When combined with the MTTF in analysis as described in section 4.2, it becomes a map of equipment performance and Maintenance effectiveness.

5.1 Mean Time between Maintenance (MTBM)

MTBM can be used as recognition of the number and frequency of planned maintenance events on equipment level or plant level. It can provide the planners with a visual aid to aligning and optimising the maintenance events, but can also be used to track compliance with the maintenance plans, as well as indicate the number of planned events that are performed, usually intrusive maintenance events. When actual events are plotted against the plan, it can become quickly visible where maintenance delays occur and may cause future problems. It may also indicate where maintenance is carried out too frequently, and can be used as a challenge of existing maintenance plans to optimise the interventions if equipment reliability and downtime consequences support a different (less onerous) maintenance effort.

By itself, MTBM does not give indication of downtime incurred, only the frequency in which downtime will be required for equipment maintenance. When used in quantitative analysis of plant performance, this can be combined with the downtime requirements to indicate the estimated availability (uptime) of the system / subsystem / equipment.

To complete the picture of MTBM, it can be combined with the unplanned interventions that occur during the observation period. This can quickly provide an overview of the planned maintenance program effectiveness, and can be used as the trigger for maintenance strategy reviews and reliability / maintenance optimisation programs.

The example in Fig 5-1 gives an indication of the output described above. For this particular equipment it can be seen that the maintenance strategy was at 6 months interval, but the corrective work was at 1+ month (average). This may be acceptable but this graph does not provide us with sufficient information about the corrective (unplanned) work consequence. If the consequence was insignificant then this could be an acceptable strategy and no change is needed. If this means though that every month there is a sizeable consequence, then the strategy should be changed. Further analyses need to be undertaken to enable this judgement and determine appropriate actions.

In 2001 the maintenance strategy was changed to 20 months, but the tracking shows that corrective work was undertaken in 7-month intervals. Again, this may be acceptable but would require more detailed analyses in respect to consequences of the downtime. It is sufficient however to keep an eye on this equipment to monitor its performance better and understand the implications of strategy optimisation.

From the above process descriptions it should be obvious that managing Reliability and Downtime requires a strong commitment to establish a competent reliability organisation in an enterprise. The roles and responsibilities for Reliability Management, Maintenance Management and optimisation need to be clearly defined and should be guided by Asset Management principles and requirements. Managing downtime and in turns reliability is after all an important business function.

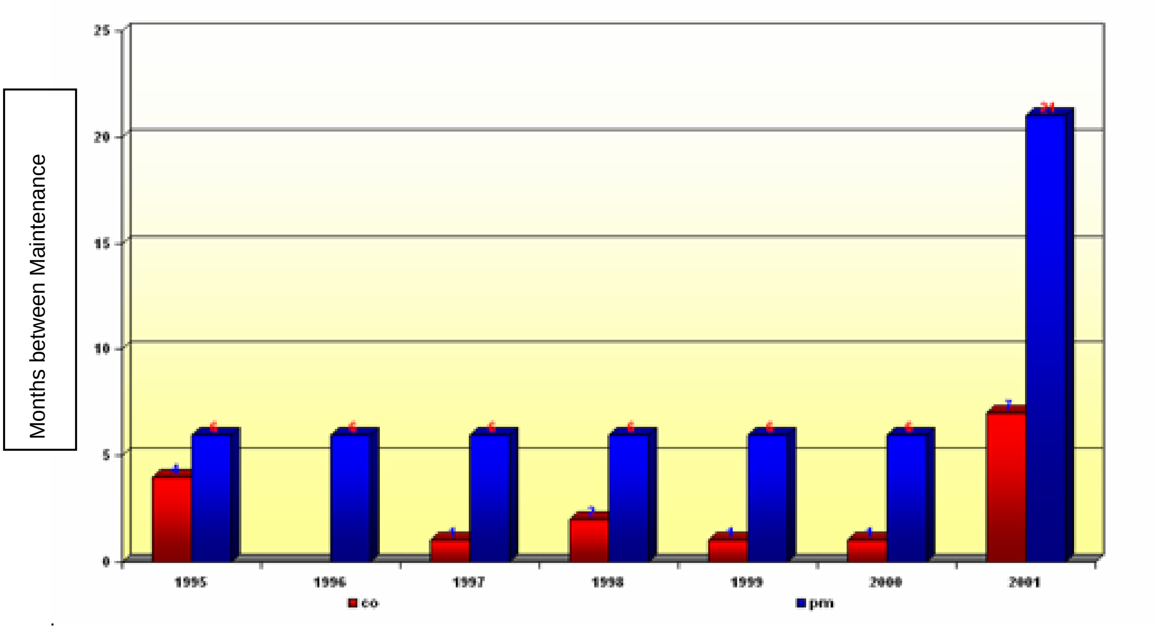

Figure 5-1 – Example Chart for MTBM graph

The analysis of downtime incurred from planned maintenance requires specific attention and challenge, as the trend to reducing downtime will inevitably lead to a change from intrusive to mainly non intrusive activities, such as equipment and performance monitoring. Typically it is found in Refineries and similar process industries that between 60 to 70% of planned maintenance tasks are intrusive, the associated downtime may not be affordable in the future. Non-intrusive maintenance should be a targeted at 40% to 50% and the rest might still require equipment to be taken out of service.

Maintenance optimisation and reduction of downtime can also be achieved by other means such as strategic planning for turnarounds and campaign type maintenance. Wherever possible, these activities can be cost effective as the challenges for this type of maintenance is indeed to reduce downtime and therefore production losses to a minimum.

5.2 Turnarounds (planned shut downs)

Typically, turnarounds are massive undertakings that are required in the process Industries (and other Industries) to maintain equipment that is normally required on line as key process equipment and cannot be fully serviced through online methods. Examples are heat exchangers, reactors, catalytic process vessels and the likes. Of course gas turbines, drag chains and other major rotating machinery or static equipment also fall in the same category. These large events are of course also an opportunity to fit in as much other work as can be managed. But often this has proven to be difficult to manage and extensions to turnarounds are common occurrences. This is either in extension of the Turnaround duration or by additional smaller events that are planned for the period of the Turnaround cycle time.

These significant events should be planned up to 18 months or more ahead of the actual date. This will enable sufficient time to procure all the required materials and secure required resources, and will also enable sufficient time to challenge scope and execution. Ideally, turnarounds are executed like projects, with defined start dates and definitive finish date, and having milestones identified as control points that need to be met. A dedicated task force with clearly defined accountability and responsibilities should be established to drive the work and assure the timely conclusion of the work. Imperative is of course the constant communication with all concerned and a clear understanding of the work that is required and the reasons for the work. Structured scope challenges are as much a necessity for successful Turnaround management as are the definitions of the acceptance criteria of equipment by Operations well in advance, to enable resumption of production with the least interruptions during plant restart.

Another essential aspect of managing Turnarounds is to analyse the whole event after completion and extract learning from the various elements and events making up the Turnaround. Here too an import focus should be the analysis of the Turnaround duration to find out how the non-production time can be reduced. The same discipline in recording failures and failure causes as well as repair outcomes is essential as for routine planned maintenance and breakdown maintenance. One of the most often heard reasons for not meeting Turnaround target durations is that there were surprises when opening equipment or it was discovered that unplanned work was required. This can have disastrous effects, as no doubt we all have experienced. One Company was constantly over running their target duration by as much as 50% and thought that this was a normal occurrence for Turnaround work. Their analysis of work carried out was virtually none existing, their challenge process was very weak and the management of people (Contractors) during the Turnaround was left to the Contractors personnel without sufficient engagement of the Company personnel in determining work flow and people competency. They now carry out amongst other improvements, a thorough downtime analysis and have now reduced their Turnaround duration by 20% form target dates and are contemplating to increase the cycle time by one year.

The result of this downtime analysis can clearly be used to further improve the duration of the next similar Turnaround and ultimately also to challenge the Turnaround cycles. The commonly 4 year cycle is often pushed to 6 years now and in best in class cases in Refineries to 8 years. But this is only possible by understanding what scope is really required during the Turnaround and understanding the risk of not carrying out some of the work traditionally required at more frequent intervals. The downtime analysis is the best way to lead the challenge and the optimisation.

If a lesson can be taken from Turnarounds for managing downtime, it should be that a strong focus on the tasks at hand is needed, whether planned or unplanned work is required, a clear understanding of the criticality of the work to be undertaken, and the need to plan well for any resources and materials (spares) that may be required. For unplanned work this has of course additional challenges that must be overcome (ref. Fig 3-2).

6. DOWNTIME TRACKING AND MONITORING

Now that we have explored some of the reasons why downtime is important and how it can become a catalyst to initiate improvement activities, it remains to be considered how best to make downtime visible. Many would argue that it is a simple task to record the time an item fails and then when another event in the workflow is completed, downtime can be identified and most likely that comes from the Maintenance Management System. Thinking back to section 3 which explored the various definitions and aspects of what is important for downtime, we see that there are a number of different aspects to be considered:

- Which equipment is critical to safety and production and needs to be monitored for optimum downtime?

  The Asset Register has to have the relevant equipment identified and the information what is critical in the production plant must be available to any of the recording systems that is used for process management. This is needed to remind Operators of equipment status and enable the initiation of appropriate actions due to failure or malfunction. Without clear and consistent identification of these items, their significance may be missed in the analyses of the flood of data that is presented to Reliability and Maintenance engineers daily.

- Time of failure of the item needs to be clearly identified:

  Where would that most logically be recorded? Usually there are some forms of electronic process control systems installed (such as a DCS system or control computer). Is it possible to log the failure unambiguously as such in this system or does it require a separate failure tracking system? Often a combination of production logs, maintenance records and production charts is used to determine the failure time of equipment. Reasons for failure, when collected, are also often hidden in more then one place and require Detective qualities of a Sherlock Holmes to locate them and then to make sense of them.

- Time tracking for work preparation time and actual start of repair times is required:

  While it seems that the recording of failure and the raising of a work order to initiate the preparation work and the actual rectification work is sufficient, if prevention of failures and minimisation of downtime is a purpose of the Maintenance Management process, then the elements that contribute to the downtime must all be known and tracked. Only then can we really understand the cumulative effect of smaller and large delays on lost production. Generally there is no specific mechanism used to track theses delays and a separate database or recording mechanism makes the integrated view of the downtime more difficult yet again. Work orders tend to be equally indiscriminate, as there are often only cost centre records available for accrued time, not the time stamps when work was actually carried out and completed. To manage the various start times and activities becomes difficult, but can be set up appropriately when these items are considered during the configuration of control, management and recording systems and when reporting features are designed for these systems.

- Spares and procurement delays

  Lead times are generally well known and the purchasing departments are often quick to respond to materials requests. But often we do not capture adequately the time it takes for a supplier to provide the goods or how long it really takes to get to the location where they are required. While it seems not so important, it might highlight some flaws in the transport system or in preparation of routes and site to receive the goods. Improvement opportunity or otherwise can only be identified through capturing the data and making the information available across the boundaries of departments.

- Quality activities

  These include inspections at repair sites, locations where maintenance (or turnaround) is conducted, installation inspections and inspections during manufacture. These are activities that may also need planning as they can hold up the work if not readily planned. It should be standard practice to inspect the maintenance work, especially of complex systems, to assure that the equipment will perform as required. And who has not heard of failed pressure tests of vessels or piping, or weld problems shortly after start up of equipment due to lack of inspection and assurance of competency and suitable work procedures? Planning for quality assurance activities is as essential as the panning of the work as the consequences of failure for equipment after repair / maintenance is too great and too costly.

- Accurate repair times

  Why would we ant to know accurate repair times? Time is money and the cost of a corrective work hour is generally between 3 to 7 times greater then the cost of planned work. And besides, as we have seen, it is important to understand the actual time the work takes to enable accurate determination of losses and the opportunity to improve processes, practices, procedures and competency. Accurate and standardised methods of collecting the repair times are essential. The Maintenance Management System is generally the tool that captures the time for repairs, but often the set up of the time capture mechanism is not intuitive and not focussed on the required outcome, namely a simple and quick way for Technicians to enter time and other data without being forced to take shortcuts or think about places where to put the data. Only if accurate repair times are known, can planning be meaningful.

- Handover and start up

  Good work practice dictates that the work when completed, be handed back to the owner, usually the Operations group. The owner needs to have assurance that the equipment is ready for start up and that they can carry out the required steps to reinstate the process and start production again. As this all takes time, the time span required for these activities is important. And it is not a factor that can be thrown in with repair time, as it is not repair, it is start up. And as far as maintenance is concerned, repair is completed. This position may be challenged, but the point here is that the equipment is ready for start up and should therefore be put back into operation. If there is spare equipment that is on duty now, this handover and restart may be a long time off. Therefore it cannot be counted as repair time, it is already 'operable'. Reliability calculations often fail as the times collected are incorrect and are not really reflective of the actual repair times; they often are inflated, deflated or plain incorrect times that are recorded for the greatest variety of reasons.

Workflow must accommodate these elements and steps. It is most likely an unavoidable necessity to restructure the workflow and the work processes to enable focus on the Reliability improvement and downtime optimisation. The current organisation structures are often unsuitable for reliability focussed maintenance and continuous improvement. While there are many process models, these can only be a guidance of what is required; every organisation needs to have their own organic way of determining their actual requirements to put in place a reliability organisation that can deliver sustainable and continued results supporting the business.

Companies in the Asian region that were visited by the Author and were wishing to restructure found, that in their Organisations a prevalent opinion is in place that Reliability engineering does not work. When analysing their Reliability Organisation it was almost always found that Management did not have the right appreciation and understanding of what Reliability engineering must contribute to an Organisations' well being. When the job description for Reliability engineers were examined and interviews with the incumbents conducted, it was observed that many are required to produce graphs of performance and identify bad actors, or are required to provide data for benchmarking. This is truly missing the need and contribution of reliability engineers to the business. One element must be the determination to reduce downtime and to provide fact based suggestions for improvement for individual equipment, sub systems and systems. Not understanding downtime will often lead to all kinds of activities that are intended to improve an unsatisfactory situation, but diverts form the real source of lost revenue. The following section provides some ideas of how some of the downtime and repair times can be made visible and used to track performance and provide information on what requires work and optimisation.

6.1 Relationship of cost, failure and risk

Downtime presents risk. At the highest level, if the Company is seen as unreliable a supplier due to random and excessive downtime, it will not be able to compete. Alternatives are to throw more money at the systems to compensate for downtime as much as possible, but that will often end up being fire fighting, costing even more money and resources and spells more trouble for the enterprise. Downtime also presents risk to individuals, as the pressure 'to get back up and running' is a precursor to not only missing vital information about failures and increasing cost, but also to taking shortcuts which inevitable will result in injury. Understanding downtime then has more than one benefit, it potentially reduces workload in the future thus enabling better quality workmanship in repairs and maintenance, lesser risk of repeat failures and lesser risk to safety.

The following table can be taken as an equipment record card that tracks machine performance and provides some of the information required to manage downtime, increase uptime and make cost effective decisions about the equipment. This example uses a 3 year maintenance cycle, the period between major overhaul of a pump. The top half of the table provides operational and cost information. As this is intended as an example, there may be other costs and elements that may be required for an enterprise to adequately represent their targets and values.

The second half of the table provides performance information including downtime. Downtime in this example is modelled on the total downtime incurred (the pump was spared and in non critical service) including all logistics and similar delays. The better the table is conditioned to display the information, the more value it has. With records like this, it is now much easier to compare with original equipment specifications the actual performance and make decisions about the suitability and affordability of this type of equipment in its service.

The information shown is an example of how the various elements of repair time, delay times, failure frequency etc. should be readily available through the repository of all related data, the CMMS. In practice, it is not so and it is also not always the case that the information can be assembled more or less ‘automatically’ by another software program. While it is important to manage all this data, it is often a costly step to develop 3rd party software that can tie all this together. But perhaps in the future, when Maintenance Management Systems become real business performance support systems it might be possible to configure reports that can provide information in such a manner and also enable the transfer of critical data to other more specialised packages that will provide statistical and cost information as well as enable dynamic assessment of risk and maintenance strategies, perhaps even allow the identification of opportunities to most effectively reduce downtime.

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Total
Operating cost	$500	$505	$500	$520	$520	$480	$3,025
Maintenance cost	$1,000	$1,200	$800	$1,400	$1,800	$800	$7,000
Spare parts	$300	$600	$400	$500	$500	$1,200	$3,500
Contract costs	$0	$1,000	$2,000	$0	$300	$2,200	$5,500
Overhaul	$0	$0	$5,000	$0	$0	$6,000	$11,000
Repair cost	$200	$0	$0	$300	$200	$0	$700
Indirect costs	$1,900	$2,280	$1,520	$2,660	$3,420	$1,520	$13,300
Support Labour	$0	$150	$500	$0	$0	$650	$1,300
Total:	$3,900	$5,735	$10,720	$5,380	$6,740	$12,850	$45,325
							Average
Utilisation	80%	78%	65%	78%	75%	78%	76%
Target	75%	75%	75%	75%	75%	75%	75%
MTBF [days]	60	55	49	56	50	48	53
Mean Repair time [h]	3	4	40	5	7	45	17
Uptime [h]	1,600	1,400	1,300	1,550	1,400	1,280	1,422
Downtime [h]	400	550	700	450	500	700	550
Standby [h]	0	50	0	0	100	20	28
Availability	75%	61%	46%	71%	64%	45%	60%
Annual production time	2,000	2,000	2,000	2,000	2,000	2,000	
Replacement cost	$150,000	$150,000	$150,000	$150,000	$150,000	$150,000	

Table 1 – Equipment performance record example

Table 1 would benefit also from recoding failure characteristics parameters such as mean life, especially if there are fleets of similar equipment, characteristic life and limits of expenditure –when would it no longer be practical to repair the machine and it should be replaced.

7. CONCLUSION

Asset Management is all about understanding and managing capability. Being able to plan for elimination of failures through maintenance is managing risk in support of the business and fundamental to good Asset Management. Prevention and eliminating failures through maintenance will provide the balance of 'must have downtime' (the uncompressible part of a system that continues to fail and could only be further reduced by investment and design out if economically viable) and activities to keep systems on line and producing at their optimum.

Managing downtime is a complex process. It requires an interactive and cooperative approach between various groups in an Organisation that are responsible for production, reliability, operation, engineering and maintenance. It requires Management to understand how Reliability engineering can improve equipment performance to the status of its designed capability. That in turn often requires some reorganisation and definition of roles, responsibilities and accountabilities that may be different to what is practiced at present. Workflow must also change to instil the discipline to provide the required data that can be transformed into performance information, useful to initiate optimisation activities. This information must also be seen as valuable Company knowledge that must be preserved the same as financial records and knowledge about transactions.

The proposition is that instead of attempting to increase uptime with changes of plant configuration, it might be more profitable to look for improvement in downtime (risk reduction, lost production) and eliminate those elements that continuously provide bad performance. Typically bad performances are experienced not only in the areas of failure characteristic changes due to ageing of equipment, but also misuse of equipment and consequential failures and maloperation (for instance operating equipment outside its design capability) related failures. To counteract these sources of downtime, attention needs to be paid to the three main elements in Asset Management, namely People, Processes and Tools, combined with methodologies applied. Managing downtime for sustainable results is managing knowledge about the Company's Assets, physical (the plant and equipment), resources (the people and their competency), and organisational (the processes, methods and tools). Once the company knowledge base is managed consciously, better decisions can be made and the humans are in charge of a well functioning production or service system that operates at minimum risk and meets stakeholder expectations at all levels.

Managing Downtime therefore should be priority on the Agenda of all organisations practicing Asset Management.

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[1] Marvin Rausand, System Reliability Theory, 2005

[2] Ibid

[3] H. Paul Barringer, P.E. and Woodrow T. Roberts, Jr., Ph.D.: Process Reliability: Do You Have It? - What's It Worth To Your Plant To Get It; AIChE; Paper presented in 2002

[4] A similar definition is given at Plant Resource Centre; www.plant-maintenance.com/terminology

[5] Seiichi Nakajima, "Introduction to TPM", Productive Press, 1988

[6] David J Smith, "Reliability, Maintainability and Risk", 5th edition, Butterworth Heinemann, 1997

[7] Patrick O'Connor, "Practical Reliability Engineering", 4th edition, J. Wiley and Sons, 1992