White Paper

"Challenging the Norms"

Time Usage Model

For

Mobile Underground Mining Equipment

Prepared by

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RAK Developments

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His education combines both Mathematics and Psychology. Throughout his career he has focused on the use of systems, procedures and training to achieve changes in group behaviour and to achieve continuous improvement.

He is known for his work in the field of Mine Control which included the development and commercialisation of the Pitram product, one of the world's leading Mine Control systems for underground mines.

Since 2004 he has operated as an independent consultant across mining strategy, requirements, behaviours, systems and analytics. In his consulting he has worked with and assisted in the development of Time Usage Models for multiple clients including:

- BHP
- Rio Tinto
- Barrick
- Newmont
- Newcrest
- Goldfields.

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"Challenging the Norms"

Time Usage Model - Mobile Underground Mining Equipment.

Executive Summary

Over the last 40 years, Time Usage Models have been used as a basis for calculating performance indicators for mobile mining equipment and have developed from very simple to very sophisticated models. This development has paralleled the increased collection and analysis of production data that itself has been enabled by the evolution of underground voice and data communications along with the relevant information systems.

A Time Usage Model divides the hours that equipment is (or is not) used into standard components, by a hierarchical breakdown, so that measures of productivity can be used to compare performance of both people and the equipment.

The calculation of Equipment Availability, and thus the underlying Time Usage Model, has always been an extremely emotive topic. This is partly because different groups use time usage information for different purposes. The direct link between productivity KPIs calculated from these models and employee rewards just adds to the emotion.

This paper discusses the conflict in use by various stakeholders and proposes ways to address some of the more contentious issues.

Early systems had a concept of a Status Code. The simple status code functionality has proven inadequate, leading to the evolution of "work-arounds". These work-arounds have become the norm and unfortunately have become embedded in the next generation of models and the information systems that incorporate them.

This paper contends that the industry should stop building Time Usage Models to accommodate shortcomings in proprietary systems, but rather put pressure on vendors to provide appropriate tools to deal with the fundamental requirements.

There are many points of differentiation that are not clear-cut. Pitfalls are discussed as well as threats to success.

A framework of rules is developed as guidelines for how a Time Usage Model should be developed and applied. This will hopefully stimulate the on-going discussion as to how Equipment Availability and other components of the model should be calculated.

Contents

1 Introduction

There are two principles the author adopts whenever the subject is raised of how equipment availability and related indicators should be calculated:

Principle 1	Never enter any discussion as to how availability should be calculated
Principle 2	Stick to Principle 1 at all times

Joking aside, the rules around the calculation of Availability, Utilisation, Operating Efficiency and other related performance indicators is guaranteed to precipitate the most emotive of discussions, often irrational, biased and passionate.

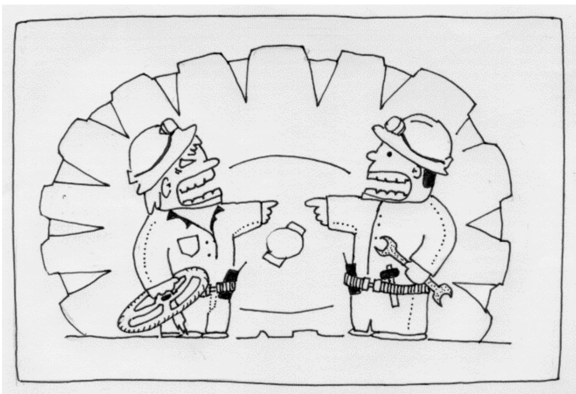
Why does the topic of time usage models elicit such volatile reactions?

A major contributor to this behaviour is that these indicators often represent a measure of people's performance (direct or indirectly). The underlying data is shared and those being assessed do not necessarily have control of the capture and management of data used to measure their performance. E.g. maintenance department may be assessed on reported equipment Availability. This Availability may be based upon data collected by production personnel who have a vested interest in blaming poor production on equipment reliability.

Likewise, having common data used to measure performance of different groups can lead to conflicting interpretations. E.g. a Production department may be assessed upon Use of Availability (UofA) and thus be motivated to reduce the reported Availability in order to make their UofA look better, while the Maintenance department are wanting to maximise their reported Availability KPI.

This can lead to each party maintaining separate sets of data or applying their own biased interpretation to the shared data.

The effect of this breakdown in communications is disastrous for the organisation. Antipathy characterises relationships and the "Us versus Them" syndrome thrives.



This paper intends to break these principles and discuss the issues around the definition of a Time Usage Model for equipment that forms the basis by which to calculate the common performance indicators.

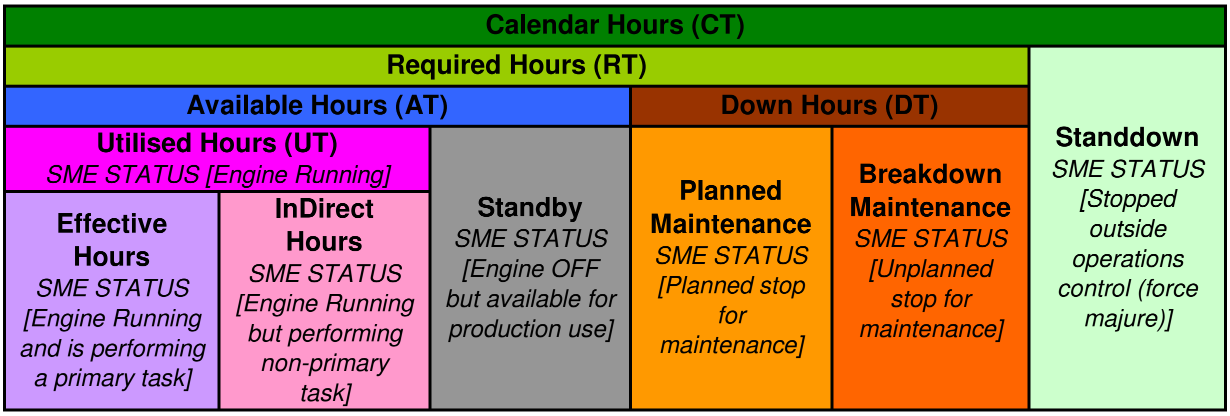
The examples described are largely drawn from underground sites however much of the discussion and suggestions are equally relevant to surface mining. The situation in the underground mining industry appears to be more complex, and the necessary close coordination required between multiple functions can lead to a greater emphasis on KPIs based on time.

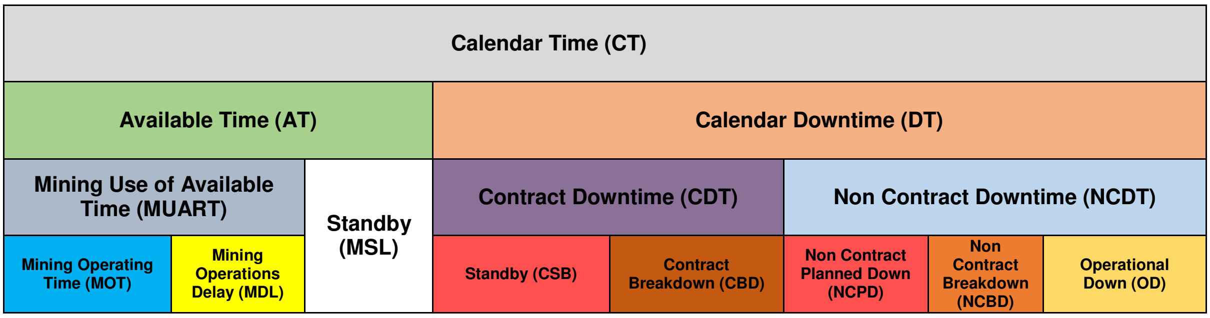
2 A Time Usage Model – What, Why and How

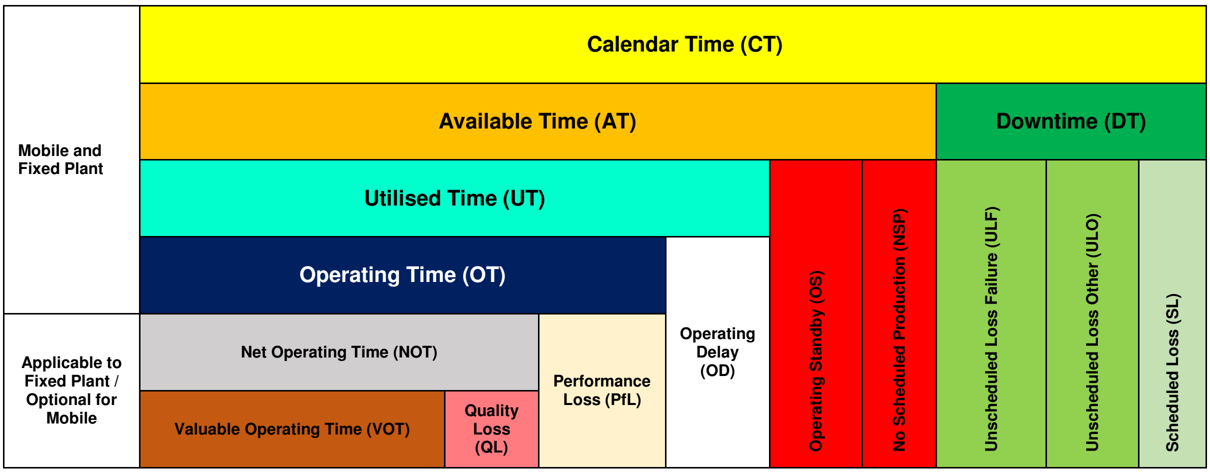
2.1 What is a Time Usage Model?

An equipment Time Usage Model (TUM) is a taxonomy whereby the actual elapsed durations that equipment spends in different activities (Critical States) are segmented and consolidated in a structured hierarchical manner.

The following figures are examples of Time Usage Models expressed as block diagrams and with their original colouring systems.







In summary, a Time Usage Model provides a structure for consolidation of equipment critical status data to produce key performance indicators such as availability, utilisation, operational efficiency etc.

2.2 Why do we need a Time Usage Model?

The various parties involved in producing and using operations reports require a common basis to ensure that KPIs presented for monitoring and decision making are generated in a consistent manner.

The Time Usage Model provides a framework for:

- Calculating consistent duration based performance indicators across multiple disciplines and, in the case of multi-site companies, across different mines facilitating objective comparisons.
- A set of high level rules to enable accurate collection of data for KPI calculations for identifying areas of improvement and tracking improvement.
- Enabling stakeholders (Production and Maintenance) to reference and align on the practical application of operations information.

2.3 Constraints

2.3.1 Communications Infrastructure

Underground mines struggle to deliver robust voice and data communications to active working areas particularly where there is frequent blasting. This can affect the level of differentiation regarding equipment activity that can be captured.

E.g. A jumbo may travel into a heading that does not yet have communications infrastructure. The jumbo will bolt the heading then move to drilling out the face. The options for recording this change of activity from bolting to face drilling are limited.

This issue is sometimes addressed by the use of Edge Computing devices for recording operational activity that can be later downloaded through automatic synchronisation once the equipment is reconnected to the network.

2.3.2 Human Intervention

Typically, data to support Time Usage Models is recorded by:

- a mine control room operator
- an equipment operator using a touch screen
- transcribed from operator Timecards (PLODS)
- a supervisor preparing an End of Shift report
- maintenance personnel

While online systems can automatically record some status information to indicate whether equipment is not operating, the reasons why it is not operating (by recording a status code) requires human intervention. The design of data capture needs to take account of the knowledge level of the person reporting the data. E.g. an equipment operator reporting a breakdown cannot be expected to carry out and report root cause analysis.

As this data is generated primarily by operations and maintenance field personnel, the options need to be limited, clear, easy to use and with minimal ambiguity.

Rule 1	Design of an equipment TUM should take into account the site capability to capture valid actuals data.

2.4 Developing a Time Usage Model

Several tier 1 and 2 companies with multiple mines have set out to define standard Time Usage Models. A lot of very good work has been done. These initiatives have, in general, been approached in a consensual manner. Unfortunately, they appear to end up as something akin to a lowest common denominator (often based on recording system limitations) and in other cases they have been dominated by the strongest business unit.

The intent of this paper is to take a different approach by returning to first principles and developing a series of logical rules.

2.5 Definitions

The term "Time" can be used with several different meanings:

- An instant in time, E.g. 12:35am
- An elapsed period, E.g. the time between 9:15pm and 10:45pm
- The aggregation of multiple elapsed periods, E.g. the time spent operating

This paper will use:

- Time - an instant in time.
- Period - Elapsed duration between 2 Times.
- Hours - The aggregation of multiple Periods.

2.6 Basic concepts

The term "Critical Status" refers to the activity the equipment is doing at any given Period.

An equipment unit is a single item of equipment that can be regarded as an entity in its own right, E.g. a loader, a truck, a jumbo, etc. Regardless of how an equipment unit spends its hours, those hours can always be classified with a Critical Status. At any point in time, an equipment unit can be classified as having one and only one Critical Status. E.g. Drilling, Relocating, Standby-not required, 250 hour service, Engine breakdown.

An equipment unit will have a Critical Status at all times. There is therefore a continuous timeline of critical statuses for each equipment unit and the start of a new status necessarily represents the end of the previous status.

Changes to an equipment unit's Critical Status are events that occur at an instant in time.

3 Calendar Hours vs Recorded Hours

3.1 Calendar Hours

A Time Usage Model begins with a basis of all hours, typically referred to as Calendar Hours. Calendar Hours represents the total number of hours an item of equipment "exists" for in the period under consideration. E.g. in a week, the total number of hours that a Jumbo can be accounted for is 24 x 7 = 168 Calendar hours

Calendar Hours

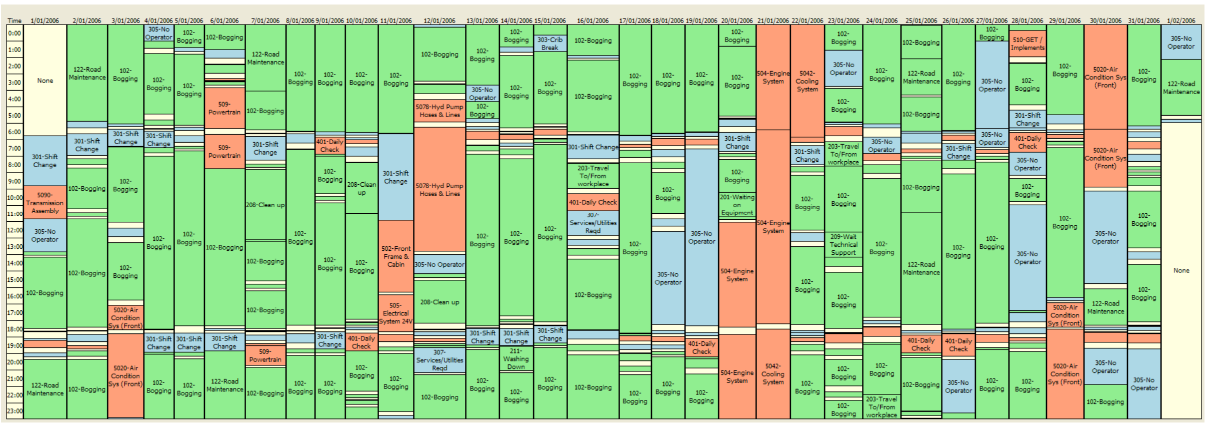
With current practices with mines operating 2 x 12 hour shifts each day, generally every day of the year, along with the development of data capture technology, means that most sites will be able to record all or close to all calendar hours. There are, however, legitimate cases to look at recorded vs unrecorded hours.

3.2 Unrecorded Hours

Unrecorded hours can occur in several situations.

Some hours can be unrecorded as a result of the process used to record. There may be short unrecorded periods between shifts. These occurrences of "unrecording" tend to be variable and are typically small, usually to the point of being insignificant and can be disregarded. In fact, it is better they are left as "unrecorded" rather than an assumption being made.

This example shows a day by day timeline of an equipment unit for a month where each column represents one day from midnight to midnight. The white sections show a number of small unrecorded periods.



Modern systems with more reliable and accurate recoding are resulting in a reduction of unrecorded hours.

There are cases where the recording of hours becomes impractical, E.g. Force Majure events such as cyclones. These are random and not particularly frequent.

There are cases where there are systematic situations where equipment hours are not recorded. Examples include:

A mine that operates 2 x 11 hour shifts each day with a half hour overlap each morning to hot seat operators. In this case, equipment hours are collected for 21.5 hours in each 24-hour day. This example is discussed further later.

Another case is where a mine will work a 5-day week. This generally occurs where the mine can out produce the downstream processing. With the mine not being manned on weekends, two days per week of equipment hours are not recorded. There is an underground mine in Queensland that works 4 day shifts a week and no night shifts for this very reason.

Calendar Hours	
Recorded Hours	Unrecorded Hours

There are risks in having unrecorded hours, particularly on a systematic basis.

In the author’s experience, all mines that have some type of systematic unrecorded hours invariably have some activity that occurs in the unrecorded periods.

A mine in South Africa ran on a 5-day week with an owner operator workforce. All activity was recorded. When the mine was behind target, casual contractors were brought in to operate on weekends. Apart from the output (Tonnes) the equipment hours used were not recorded.

The mine mentioned earlier that ran and recorded 21.5 hours per day would often bring production and maintenance personnel in to work on overtime in the 2.5-hour unrecorded window. Tonnes produced was added to the daily total, but the maintenance effort was not recorded. A “Planner” in head office decided that if the mine moved to a 2 x 12 hour shifts roster, greater production would be achieved. Unfortunately, the Availability, Utilisation and Performance Rates previously reported could not be achieved on the 12-hour roster. That mine ended up closing, partially because of this situation.

At this point, it is appropriate to list Rule 2:

Rule 2	Record all equipment for all calendar hours

This is not always possible and there isn’t a ‘one size fits all” solution, which leads us to Rule 3:

Rule 3	Users of Recorded Hours data must understand the basis by which they are captured.

3.3 Total Recorded Hours

On the assumption that most of this audience will be working at sites with 2 x 12 hour shifts working 24 x 7, the Total Recorded Hours correlate closely with Calendar Hours. From this point on, this paper assumes that this correlation exists and Recorded Hours can be treated as equal to Calendar Hours.

Total Recorded Hours (Calendar Hours)

One of the first tasks in doing any sort of analytics work with time usage data is to validate recorded hours against calendar hours. It provides a very useful first indicator of the quality and completeness of data being analysed.

4 Primary Classification of Hours

The most common high-level use of a Time Usage Model is to provide the framework for calculation of the three most basic KPI's:

- Availability
- Utilisation
- Utilisation of Availability

To enable the calculation of these KPIs requires that hours captured be classified into three high level categories:

- Utilised Hours
- Standby Hours
- Maintenance Hours

Total Recorded Hours (Calendar Hours)		
Utilised Hours	Standby Hours	Maintenance Hours

To provide a framework to enable consistent classification of hours into these categories requires some rules to guide capture of data.

4.1 Utilised Hours

For equipment that has a single power source (diesel powered boggers, trucks, tool carriers etc), a Utilised Hour can be described as whenever the engine is running

In this context, it is quite common to describe Utilisation as:

$$Utilisation = Engine\ Hours\ /\ Calendar\ Hours$$

The equivalent calculation in using the Time Usage Model categories is:

$$Utilisation = Utilised\ Hours\ /\ Total\ Recorded\ Hours$$

For equipment that uses multiple sources of power, it is possible to aggregate the hours of each power source. E.g. a jumbo drill accumulates diesel engine hours while travelling and electric compressor hours while drilling. In this case:

$$Utilisation = (Engine\ Hours + Compressor\ Hours)\ /\ Calendar\ Hours$$

For these cases, in the Time Usage Model, both Engine Hours and Compressor Hours are aggregated to be classified as Utilised Hours. This leaves the calculation unchanged:

$$Utilisation = Utilised\ Hours\ /\ Total\ Recorded\ Hours$$

Comparing the reported Utilised hours with Engine Hours or, where appropriate, Engine plus Compressor hours provides a powerful measure of the quality and completeness of the data.

Rule 4	Equipment is considered Utilised when the power source is running.

4.2 Standby Hours

The fundamental definition of an equipment unit being on Standby is that the source of power is turned off and operations are entitled to turn it on. I.e. the equipment is not under the control of maintenance.

Much of equipment Standby Hours can be attributed to process delays, this is discussed later.

$$Availability = (Utilised\ Hours + Standby\ Hours)\ /\ Total\ Recorded\ Hours$$

Rule 5	Equipment is considered on Standby when the power source is off and operations personnel are entitled to turn it on.

4.3 Maintenance Hours

Maintenance hours are when the maintenance function has responsibility for the equipment. I.e. operations cannot use the equipment.

Classifying hours as to whether they constitute Maintenance or not is one of the most emotive aspects of the discussion around an equipment Time Usage Model.

Arbitrary rules are sometimes needed since the classifications are not always clear cut. Take the question of when does Maintenance period start and finish.

If a Bogger is working at a face and has a hydraulic problem that prevents operation.

1. Operations report that the Bogger is Down (Requires Maintenance).
2. Operations are then directed to drive/tram the Bogger to the Underground Workshop.
3. Once the Bogger reaches the workshop it is assessed by maintenance and repaired.
4. Operations are then notified that the Bogger is repaired and ready to be collected.
5. The operator then trams the Bogger back to the face to recommence work.

When does the Maintenance period start and finish?

From operations point of view, the Bogger has been unavailable to work from the start of Step 1 (when it broke down) until the end of step 5 (when it arrived back at the face).

From the maintenance point of view, the first time they encounter the Bogger and can commence work is at the start of step 3 (arrival at workshop), and their involvement ceases at the end of step 4 (operations are notified the repair is complete).

There is no "absolute right" solution. Arbitrary rules are required; however, some logic can be applied. From the point of view of the equipment, it is in a state requiring maintenance and unable to be used by operations from the time that operations report the problem. That is when the Maintenance Hours commence. Similarly, the equipment is functional and able to be used by operations from the time that maintenance report that the repair is complete.

To summarise, the period from the first reporting of a problem until maintenance can access the equipment is maintenance cost and is classified as Maintenance Hours. Once maintenance has been completed, the equipment is available again. The period from maintenance being completed until the equipment restarts work is operations cost and is classified as Utilised or Standby hours.

Similarly, where in situ repairs occur, the travel hours for the maintainer to the job is treated as Maintenance Hours for the Equipment. Once the maintainer has completed the repair, the equipment becomes available and the maintainer's travel hours back to the workshop does not count against the equipment.

Rule 6	Equipment Maintenance Period commences at the Time when operations report the maintenance event.
Rule 7	Equipment Maintenance Period ends at the Time when maintenance notify operations that the equipment is repaired.

To complete the set of KPI calculations

$$Utilisation\ of\ Availability\ (U\ of\ A)\ =\ Utilised\ Hours\ /\ (Utilised\ Hours\ +\ Standby\ Hours)$$

or

$$Utilisation\ of\ Availability\ (U\ of\ A)\ =\ Utilisation\ /\ Availability$$

5 Secondary Classification of Hours

The above model was adequate for many years until, with improved access to data, the industry discovered Mean Time Between Failure (MTBF) and Mean Time To Repair (MTTR).

Calculating these KPIs required that Maintenance Hours be further sub-classified. The terminology alone has generated much emotive debate. Should these categories be:

Service vs Breakdown

Preventive (PM) vs Corrective (CM)

Planned vs Unplanned

Scheduled vs Unscheduled

"Scheduled vs Unscheduled" are immediately disqualified from this list as the concept of a schedule belongs to the process rather than the equipment. The place of Schedule in this discussion will be handled later.

The others all have subtle differences in meaning, but in the context of this exercise, the differentiation is not particularly important.

For this paper the Secondary Maintenance categories are labelled as Service vs Breakdown.

<table>
<tr><th colspan="5">Total Recorded Hours (Calendar Hours)</th></tr>
<tr><td colspan="2">Utilised Hours</td><td rowspan="2">Standby Hours</td><td colspan="2">Maintenance Hours</td></tr>
<tr><td>DOH</td><td>IDOH</td><td>Service</td><td>Breakdown</td></tr>
</table>

5.1 DOH – Direct Operating Hours

DOH -The equipment has a power source running and is performing a primary task.

This sub category is sometimes called Operating, Efficient Operating or other variations.

One of the differences when considering open pit and underground equipment usage is that open pit equipment tends to have a single job that it does. E.g. a shovel loads trucks, a blast hole drill drills blast holes etc. In underground, it is common for equipment to be used for multiple jobs. E.g. a jumbo can drill face holes and it can also drill and install rockbolts, a transmixer can haul concrete products or be used as a water truck.

Early open pit monitoring systems typically had a generic "operating" as the only DOH classification depending on the equipment type to infer the work being carried out.

In an underground Time Usage Model, it is desirable to discriminate between the hours equipment spend on different primary tasks.

- Blast Hole Drilling
- Bolt hole drilling
- Hauling shotcrete
- Watering Roads

5.2 IDOH – InDirect Operating Hours

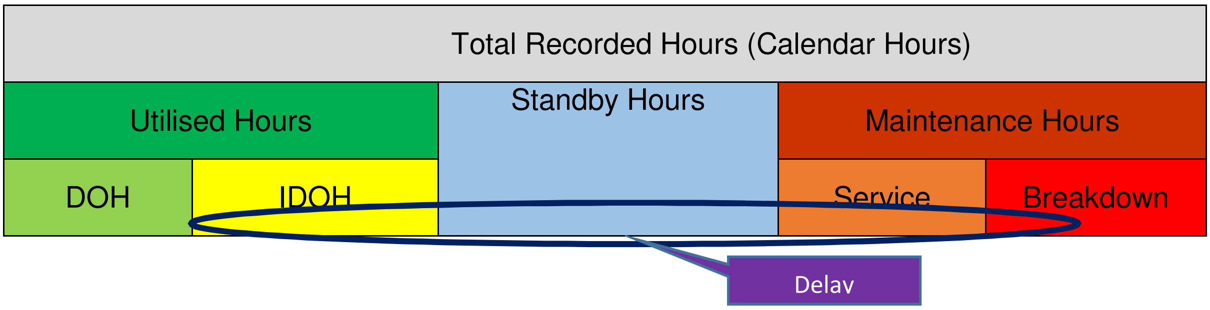
IDOH - The equipment has a power source running but is performing non-primary task.

In many Time Usage Models, this category is called "Operating Delay". The term Delay should not be used in a Time Usage Model for two reasons.

The term Delay is, by connotation, somewhat negative. The activities classified as "Indirect Operating" are all essential to the underground mining cycle. While they are not the primary job that the equipment performs, they should not be stigmatised as negative.

An underground manager described it as: "My best Bogger operator is also the one who does the most Clean Up, and I don't want Clean Up to have the negative connotations of being a Delay."

Secondly, Delay is a term that has become a de facto standard in dispatch systems to mean a short stoppage of reasonably confidently known duration that is considered by the dispatch optimisation algorithm. In this sense, a delay can belong to any of the TUM categories, except DOH.



Rule 8	The term "Delay" should not be used in a TUM.

In underground mines, equipment necessarily spends a greater portion of utilised hours carrying out InDirect Operating activities compared with equipment in open pit mines. Typically the period of work at a face is shorter and there is a much larger travel and set up overhead.

5.3 Standby

This paper does not split Standby into subcategories at this level. Many Time Usage Models do, however, it usually forms a "them vs us" type differentiation that doesn't really add any value.

There are a limited number of reasons a mobile equipment unit in an underground mining environment can be on Standby. Each of these may have a few sub categories, which are handled at the Tertiary States level below.

- No Work
- No Operator
- Prevented from doing required work
- Site practice (Meal break, Safety Meeting etc)
- Interaction with other equipment

- Operator stops equipment to complete a prerequisite task

5.4 Service Hours

Equipment is voluntarily withdrawn from operation for maintenance.

Typically, Service Hours are linked to:

- Periodic maintenance; Daily, Weekly, Monthly
- Duty cycle; 125 Hour, 250 hours, 1000 hour
- End of lifetime component replacement (could be considered as Duty Cycle)

$$Mean\ Time\ Between\ Service\ =\ Utilised\ Hours\ /\ Number\ of\ Service\ events$$

$$Mean\ Time\ to\ Service\ =\ Service\ Hours\ /\ Number\ of\ Service\ events$$

5.5 Breakdown Hours

A breakdown is where equipment stops operating because of a condition that requires maintenance or cannot commence operating as a result of as having a condition that requires maintenance.

Breakdown Hours include both failure and damage events, a differentiation which will be discussed later.

$$Mean\ Time\ Between\ Breakdown\ =\ Utilised\ Hours\ /\ Number\ of\ Breakdown\ events$$

$$Mean\ Time\ to\ Repair\ =\ Breakdown\ Hours\ /\ Number\ of\ Breakdown\ events$$

6 Tertiary Hours Classification

The Tertiary Hours Classification covers the Detail States – The Level that Data is Captured. A finite set of Status codes is required. Each Tertiary Status code is assigned to one of the Secondary subcategories in the model.

The author's experience is that sites require somewhere between 50 and 70 equipment tertiary status codes. More than 70 codes calls into question the practicality of capturing the data and the value it generates.

It is not always clear-cut where a Tertiary State should fit in the TUM.

E.g. The author has seen Refuelling classified as

- Indirect Operating Hours (Utilised)
- Standby
- Service (Maintenance)

Another case where the classification of a tertiary status occurs with pre-start or daily inspections. The debate is whether these should be classified as Standby or Maintenance hours. Perhaps it depends upon the party carrying out the inspection, if it is maintenance personnel then it is Maintenance hours however if the inspection is carried out by Operations personnel then it is Standby hours.

A real world set of equipment Status Codes is included as Appendix A. This is drawn from a mine site with no changes and provided as an example rather than a recommendation.

7 Issues that need to be addressed

Early open pit Dispatch and Mine Control systems were initially designed and developed around 40 years ago. While they generally had a concept of a Status Code, it was much more simplistic than modern requirements. These systems have migrated into the underground Mine Control area. However, status code functionality has proven inadequate, leading to the evolution of "work-arounds".

These work-arounds have become the norm and become embedded in the next generation of systems.

These include but are not limited to:

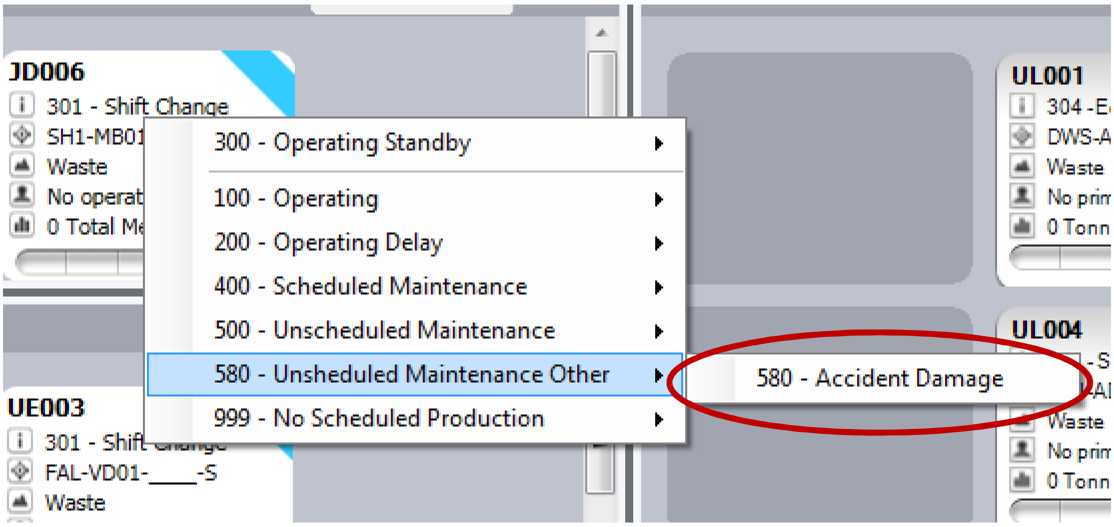
- Differentiating Failure vs Damage
- Identifying "Opportunity Maintenance"
- Schedule vs Unscheduled
- Limping equipment
- Waiting for Fitter/ Parts/
- Compensating for Heading Statuses

This paper contends that the industry should stop building Time Usage Models to accommodate shortcomings in proprietary systems but rather put pressure on vendors to upgrade their systems to deal with these requirements properly.

7.1 Breakdown Maintenance –Failure vs Damage

Breakdown Maintenance is usually classified at the Tertiary Status level against a major subsystem of the equipment type, E.g. Engine, Transmission, Hydraulics etc

A common practice is to have "Damage" or "Accident Damage" as one of the Tertiary detail options for Breakdown Maintenance. This practice results in loss of detail regarding the subsystem that has been damaged.



The above example shows recording of Accident Damage as a Tertiary Status. The information of what part of the equipment that required maintenance is then lost.

Date	**Time**	**Equipment**	**Tertiary Status**
20 July 2019	10:43:10	DT045	580 –Accident Damage

It is recommended that all breakdown events default to a sub classification of Failure and identify the major subsystem. An arbitration process is then required whereby authorisation is provided to classify an event as Damage rather than Failure

E.g. A breakdown maintenance event is recorded and defaults to Failure.

Date	**Time**	**Equipment**	**Tertiary Status**	**Failure/Damage Flag**
20 July 2019	10:43:10	DT045	502 -Front Frame & Cabin	Failure

Following the process of arbitration between operations and maintenance departments the event is reclassified as Damage.

20 July 2019	10:43:10	DT045	502 -Front Frame & Cabin	Damage

If an operations department controls the sub classification between Failure and Damage then no Damage will be recorded. Conversely if the maintenance department are in control then all failures will be classified as Damage.

The Failure vs Damage classification belongs to the occurrence of the breakdown event and is independent of the Time Usage Tertiary Status.

Rule 9	"Damage" is not a valid equipment Time Usage Tertiary Status.

7.2 Service Maintenance – Expected vs Opportunity

This author does not support the differentiation of Opportunity maintenance however it is sometimes built into contracts and KPIs so therefore must be considered.

Opportunity maintenance occurs when a functional equipment unit is not required by operations and not scheduled for planned maintenance but the maintenance department take the opportunity to perform required maintenance on that unit. In contract maintenance situations, there is an incentive to perform maintenance in these "Opportunity" windows.

A common mistake is to have "Opportunity" as one of the detail options for Service Maintenance. This practice results in loss of detail regarding the reason that maintenance has been performed.

Date	Time	Equipment	Tertiary Status
20 July 2019	11:56:05	DT045	480 -Opportunity

It is recommended that all Service maintenance events default to a sub-classification of Expected and identify the reason for the maintenance. An arbitration process is then required whereby authorisation is provided to classify a Service maintenance event as Opportunity

E.g. A service maintenance event is recorded and defaults to Expected.

Date	Time	Equipment	Tertiary Status	Expected/Opportunity Flag
20 July 2019	11:56:05	DT045	403 -250 Hour Service	Expected

Following the process of arbitration between operations and maintenance (contractor) departments the event is reclassified as Opportunity.

20 July 2019	11:56:05	DT045	403 -250 Hour Service	Opportunity

The Expected vs Opportunity classification belongs to the occurrence of the Service event and is independent of the Time Usage Status.

Rule 10	"Opportunity Maintenance" is not a valid equipment Time Usage Tertiary status.

7.3 Where Does the Concept of a Schedule fit in

The focus of this paper is an equipment Time Usage Model for reporting on mobile equipment working in an underground environment. The Time Usage Model is for classifying the summed actual durations that the equipment spends carrying out each activity i.e. "how long". On the other hand the Schedule is about "when" tasks will be carried out.

A schedule does not belong to the equipment. A schedule is part of the process.

A quote from a wise commentator and thought leader in our industry;

> *"it is a mistake to merge a schedule with the recording of operations information."*

Consider the following situation:

> *A jumbo commences drilling a heading at the allotted scheduled start time. It has some stoppages during drilling which result in the heading being incompletely drilled at the end of schedule time. The jumbo continues drilling. We cannot reasonably expect that the operator would even recognise that he has transitioned from scheduled drilling to unscheduled drilling, let alone record or report the transition. Furthermore, no change in operating status has occurred to the jumbo.*

There is a valid place for reconciling actual performance against schedule. Schedules are made up of Times that tasks are expected to start and finish. Therefore, scheduled times should be compared with timestamped events that occur to equipment and other resources.

Rule 11	The concept of Scheduled vs Unscheduled does not belong in an equipment Time Usage Model

The author has encountered many attempts at merging the concept of a schedule into an equipment Time Usage Model.

This is an example of an equipment Time Usage model from a real-world client that attempts to incorporate a differentiation between Scheduled and Unscheduled Downtime. Note how this results in duplication of elements in lower levels of the model.

<table>
<tr><td colspan="8">Calendar Time</td></tr>
<tr><td colspan="7">Required Time</td><td rowspan="4">Standby Time</td></tr>
<tr><td rowspan="3">Production Time</td><td colspan="3">Scheduled Downtime</td><td colspan="3">Unscheduled Downtime</td></tr>
<tr><td colspan="2">Process</td><td rowspan="2">Equipment</td><td colspan="2">Process</td><td rowspan="2">Equipment</td></tr>
<tr><td>Engine Off</td><td>Engine On</td><td>Engine Off</td><td>Engine On</td></tr>
</table>

7.3.1 Service Overrun

Service Overrun is often used as a Tertiary status at sites that have contract maintenance. A Service Overrun occurs when a Service maintenance period continues beyond the Scheduled end time for the maintenance. By requiring that the equipment Tertiary Status be changed to Service Overrun at that point, the absolute duration of the maintenance period and reason the maintenance was being carried out in the overrun period is lost.

Rule 12	Service Overrun should not be a Tertiary Status in an equipment Time Usage Model.

7.4 Limping – Rate Loss

In fixed plant operations Rate Loss is a well established concept.

Some underground mobile equipment types can operate at reduced capacity when part of the equipment is inoperable. This is most commonly seen with multi-boom Jumbos and Rockbolters.

There is no absolute right answer as to how this situation should be treated.

If a 2-boom jumbo has one boom out of action but continues to drill with the remaining boom, the jumbo complies with the criteria of having the compressor running and is classified as Utilised Hours. The activity of drilling is a Direct Operating Hour for a Jumbo, so "Drilling with One Boom" is typically classified as DOH.

An equipment can then operate with high reported availability and utilisation but low rate of performance as a result of operating in a compromised manner.

The following report tables show the performance of a fleet of 2-boom Jumbo drills and highlights that one was operating with one boom

Day Report - 13-Sep-2019

Development Drills	Utilised	Metres	Mtr/Hour	Standby	Maintenance	Avail %	Util %	UofA %
JU031	10.6	661.5	62.4	9.5	4.0	83.4	43.9	52.7
JU032	15.6	634.2	40.7	7.4	1.2	95.0	64.4	67.8
JU037	14.9	1075.2	72.2	7.7	1.6	93.3	61.5	65.9
JU040	9.9	124.9	12.6	11.2	3.0	87.5	41.0	46.9
Total	**51.0**	**2495.8**	**48.9**	**35.8**	**9.8**	**89.8**	**52.7**	**58.7**

One Boom

Equipment	Date	Time	Status	Duration
JU040	14-Sep-2019	02:50	117 -Operating One Boom	1.07

Rule 13	When equipment operates in a compromised manner, the period of compromised operation must be reported alongside performance reporting.

7.5 Waiting For Fitter/ Parts

Some sites have implemented Tertiary Statuses that classify a portion of the duration of a maintenance stoppage to some form of waiting. E.g.

- Waiting for Fitter
- Waiting for Parts

These serve to break a single maintenance stoppage in to several events thus compromising the duration of the stoppage.

There is a further temptation, that is regularly seen, to classify these Waiting statuses as Standby thus further compromising understanding of the duration of the stoppage period..

Regardless of whether the equipment repair has been delayed by waiting for fitter or parts the equipment is still stopped for maintenance.

Rule 14	Waiting statuses within a maintenance event should not be used in a TUM

7.6 Compensating for Heading Statuses

Open pits typically do not place very much emphasis on the status of locations and the systems’ functionality reflects this. As a result the list of equipment states that have evolved throughout the underground industry have often been used to compensate for the lack of the location (Heading) states capability in the systems used.. E.g. Standby No Water, Standby No Ventilation etc

Underground sites should actively monitor and record Location (Heading) state changes separately as well as the interaction of equipment and locations. This mitigates the need to have heading status implied within equipment states.

Rule 15	Do not use equipment Tertiary States to monitor and record Heading Status

8 Barriers to Success

8.1 Too Much Detail

In section 2.3 – Constraints, the limitations of Time Usage data capture are discussed. The amount of detail that can be reasonably captured in a valid manner is limited by the dependence on human intervention, the difficulty in sustaining underground communications and the sophistication of the recording systems.

8.1.1 Maintenance

The initial reporting of a breakdown typically comes from an operator. The level of detail required to support the Time Usage Model must take into account the knowledge limitation of the operator reporting the breakdown. An operator cannot be reasonably expected to carry out root cause analysis.

The author has witnessed many attempts at building detailed states into data capture for Time Usage. Invariably these are unsuccessful. The following example shows 18 subcategories below a major category of 507 – Hydraulics. Each of the subcategories was treated as a Tertiary Status code so the total duration of the breakdown event was accrued against the subcategory.

> *A client initiative by a group maintenance manager had resulted in around 200 detailed breakdown maintenance codes. These consisted of 22 major categories, including brakes, boom, engine, hydraulics, and many detailed subcategories.*

507-Hydraulic System
- 5070-Lift Cylinder – RH
- 5071-Lift Cylinder – LH
- 5072-Tilt Cylinder – RH
- 5073-Tilt Cylinder – LH

5074-Hoist Cylinder – RH
5075-Hoist Cylinder – LH
5076-Steering Cylinder – RH
5077-Steering Cylinder – LH
5078-Hyd Pump Hoses & Lines
5079-Steering Pump & Hoses
507A-Tank
507B-Filters
507C-Pumps
507D-Motors
507E-Coolers
507G-Cylinders
507H-Hoses Pipes & Fittings
507J-Drilling Controls

These were diligently rolled out across 3 Underground Mines. Analysis of data carried out 4 years later showed that the detailed maintenance categories were not used consistently at any of the sites. Only about 50% of the categories had ever been used, and 15 categories accounted for 90% of hours.

Rule 16	Do not attempt to capture too much maintenance detail in an equipment Time Usage Model.

8.1.2 Operations – Intra Cycle sub-states

Open Pit Dispatch systems introduced the mining industry to using technology to track components of truck cycles 40+ years ago. Being able to break a period of Direct Operating into component parts can raise some questions.

Consider a transmixer:

1. loading at a slick line,
2. traveling loaded to a face,
3. discharging to a Spraymec
4. Taking on Water to clean the bowl
5. Travelling back to slick line
6. Stopping to discharge water before arriving back at the slick line.

If our model has a Direct Operating state for the period that the Transmixer is operating E.g.

- Hauling Fibrecrete

The steps described are components of a cycle. The whole cycle is a Direct Operating activity. There can be difficulties in accurately capturing this level of detail within the cycle.

The author has seen sub components of the cycle classified as InDirect Operating thus compromising understanding of the duration of the Direct Operating activity Period.

Rule 17	Do not attempt to capture Components of the cycle in an equipment Time Usage Model.

8.2 Threats

KPIs can drive inappropriate behaviours. The behaviour around the KPIs can be affected by ownership of the data, who enters it and how it is reported. These behaviours can manifest in several ways.

8.2.1 KPI Manipulation

The simple case of manipulating the capture of data to boost your KPI.

> *E.g. A mine where there was a Business Improvement (BI) initiative to improve the utilisation of Trucks. The contractor's shift supervisors were beaten up every day over truck utilisation. These same shift supervisors were largely responsible for capturing the data used to calculate the reported truck utilisation, they quickly figured out that if they didn't record the actual time when trucks finished operating toward the end of shift but rather recorded the trucks as stopping right at the time of end of shift, the reported utilisation was inflated.*

8.2.2 Institutionalised practices

Site management will introduce or endorse practices that systematically bias reported KPI values. One of the most common practices is to sometimes not count durations associated with some of the equipment in a manner that inflates the reported KPI.

> *E.g. If a truck will be in the workshop for more than 3 days, remove it from having data captured. This will inflate the fleet Availability and Utilisation calculations.*

These examples of manipulating the capture of data to generate a particular reporting outcome destroy the value of the data for analytics.

8.2.3 Compromising Time Usage Model Structure

Another mechanism for biasing KPIs is to have a Tertiary status linked to an inappropriate Secondary Classification within the Time Usage Model (TUM). I.e. classify a Standby State as an IDOH state to improve reported utilisation.

Rule 18	Always capture data in a clear honest unbiased manner

9 Summary & Conclusion

9.1 Prioritise the Rules

In providing a priority to these rules, a combination of Rules 1, 2 and 18 are the most important.

Rule 1	Design of an equipment TUM should take into account the site capability to capture valid actuals data.
Rule 2	Record all equipment for all calendar hours
Rule 18	Always capture data in a clear honest unbiased manner

If a complete set of unbiased data is captured, our modern analytics tools allow for the data to be used in many ways.

In situations where there is a desire to manipulate reporting outcomes, do it in the reporting; do not compromise the raw data.

The next most important rule relates to users of the reporting outcomes.

Rule 3	Users of Recorded Hours data must understand the basis by which they are captured.

Simple guidelines are required to ensure that a consistent manner of capturing data is provided. As much of the data used is initiated by field operators and maintainers, the guidelines must be visible and easily understood. The following rules fall into this group.

Rule 4	Equipment is considered Utilised when the power source is running.
Rule 5	Equipment is considered on Standby when the power source is off and operations personnel are entitled to turn it on.
Rule 6	Equipment Maintenance Hours commence when operations report the maintenance event.
Rule 7	Equipment Maintenance Hours end when maintenance notify operations that the equipment is repaired.

Rules 8-17 address the problem that current systems are not adequate to support the type of analytics and reporting required. Never compromise the Time Usage Model and the supporting data to generate desired reporting capabilities.

Rule 8	The term "Delay" should not be used in a TUM.
Rule 9	"Damage" is not a valid equipment Time Usage status.
Rule 10	"Opportunity Maintenance" is not a valid equipment Time Usage status.
Rule 11	The concept of Scheduled vs Unscheduled does not belong in an equipment Time Usage Model

Rule 12	Service Overrun should not be a Critical Status in an equipment Time Usage Model.
Rule 13	When equipment operates in a compromised manner the period of compromised operation must be reported alongside performance reporting.
Rule 14	Waiting statuses within a maintenance event should not be used in a TUM
Rule 15	Do not use equipment Tertiary States to monitor and record Heading Status
Rule 16	Do not attempt to capture too much maintenance detail in an equipment Time Usage Model.
Rule 17	Do not attempt to capture Components of the cycle in an equipment Time Usage Model.

9.2 Multiple Views

It is valid to have multiple different views of Time Usage and multiple calculation formulae for what appear to be the same or similar metrics.

Availability calculated from the model described in this paper could reasonably be called "true" Availablity.

In a situation where maintenance is carried out by contract the Availability calculation may be different. E.g. Tyres and Damage may be treated as Standby for calculation of "Contract Availability".

The essential thing is that the underlying Time data is not compromised.

9.3 Where to Next?

It is apparent that the industry's requirements have evolved, but the models and systems to support them have not kept pace. This is particularly the case for underground mining, which initially adopted systems developed for simpler open cut operations, then went through a process of work-around additions to an inadequate base.

A number of detailed requirements were excluded from the equipment Time Usage Model developed above. These are all valid discriminations to be monitored.

- Differentiating Failure vs Damage
- Identifying "Opportunity Maintenance"
- Schedule vs Unscheduled
- Limping equipment
- Waiting for Fitter/ Parts/
- Compensating for Heading Statuses

The next step then is to provide models and systems that accommodate these and other emerging needs. Adding more detailed fields to the recording systems is preferable to the continual adjustment of the Time Usage Model.

The most challenging issue is how to handle Scheduled vs Unscheduled equipment hours. Current practices of splitting our Secondary classifications into Scheduled and Unscheduled creates an extremely complex model and compromises the capture of valid data.

Applying the concept of a Schedule is a different dimension, one that overlays time stamped data. The application of a Schedule concept should not be allowed to compromise the integrity of the data captured.

At present, technology cannot deliver equipment critical status change events reliably in all cases. Systems are still dependent upon human intervention. Future technologies such as increased automation and improved condition monitoring sensors may emerge that will replace human interactions and this may be the capability that takes us to the next level of productivity.

Appendix A

Direct Operating

Engine Running and is performing a primary task

101 –Operating
102 –Bogging
103 -Remote/Teleremote
104 –Backfilling
105 –Drilling
106 –Rockbolting/Scaling/Meshing
107 –Cablebolting
116 -Rehab Ground Support
117 -Operating One Boom
118 -Charging Face
120 -Services Work
122 -Road Maintenance
124 -Clean Out Drilling
125 -Moving Equip & Materials
127 -Stope Charging
130 -Retreat Services
131 -Extend or Retreat Cable
132 -Install services
133 -Pump Repairs
134 -Repair Services/Vent
137 -Inst Sec Grn Support
139 -Re-Bog

InDirect Operating

Engine Running but performing non-primary task

203 -Tramming to
208 –Clean up
212 -Broken/Bogged Rods
213 -Setting Up
214 -Towing
215 -Cleaning Equipment
215 -Rigging Up
216 -Rigging Down

Standby

Engine OFF but available for production use

301 -Shift Change
302 -Pre-start Inspection
303 -Crib Break
304 -Equipment Not Required
305 -No Operator
318 -Emergency
320 -No Materials:- Bolts, Mesh,
321 -Refuelling/Lubrication
322 -No Services:- Power, Water, Air,
323 -Safety Standby:- meeting ,
324 - Technical Support:- Geotech,
325 - Washing Down Face/Muckpile
326 - No Access:- Blasting
327 - Sleeping Shotcrete or Concrete

Service Maintenance

Planned stop for maintenance

401 -Daily Check
403 -0250 Hour Service
404 0500 Hour Service
405 1000 Hour Service
406 -2000 Hour Service
408 -01 Week Service
410 02 Week Service
411 -01 Month Service
412 -03 Month Service

Breakdown Maintenance

Unplanned stop for maintenance

501 -Braking System
502 -Front Frame & Cabin
503 -Rear Frame & Centre Hitch
504 -Engine System
505 -Electrical System 24V
506 -Fire Suppression System
507 -Hydraulic System
509 -Powertrain
510 -GET / Implements
511 -Tyre and Rim Assemblies
512 -Boom Assembly
515 -Rod Changer
516 -Drifter
519 -High Voltage Components
520 -Air Shank Lubrication
521 -Water Flushing Circuit
522 -Anfo Kettle
524 -Baskets & Controls
525 –Remote/Teleremotes
526 -Air Compressor System
527 -Feed Rail

Appendix B - Review the Rules

Rule 1	Design of an equipment TUM should take into account the site capability to capture valid actuals data.
Rule 2	Record all equipment for all calendar hours
Rule 3	Users of Recorded Hours data must understand the basis by which they are captured.
Rule 4	Equipment is considered Utilised when the power source is running.
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