Maintenance Scheduling of Earth Moving Equipment at the Klipspruit Colliery

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Why build a Model?

"We build models to understand a particular phenomena or characteristic of a system. We build models to understand the relationship between cause and effect. We build models to improve our understanding because with a good model comes discovery, with discovery come understanding and with understanding comes control.
DISCOVERY - UNDERSTANDING - CONTROL"

- www.CrowdDynamicsLtd.com, April 2009

Abstract

An investigative study of BHP billiton's Klipspriut colliery is done to determine the best design for a maintenance workshop that services track and tyre based Earth Moving Equipment (EME). The workshop is under construction and management requires a design that will optimise the number of entities and minimize the throughput time of the workshop. There are different factors that in infuence the number of entities ranging from warranty commitment to quality of service.

By optimizing the throughput of the workshop the mine would have access to more EME's which will result in a more productive mine.

The simulation is done with Arena software and is modelled according to a generic model of maintenance systems. The proposed system design throughput is used to measure the theoretical designs productivity.

The simulation provides different improvements thus a optimal design can be chosen depending on management's interest.

The number of shifts worked on the mine is increased with 33 percent if the bays are divided 3:1 for tyre based services. A 78 percent increase in the productivity is obtained by extending labour from five days to seven days. This will increase labour cost but will result in a more productive facility.

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Chapter 1

Introduction

1.1 Background of BHP Billiton

BHP Billiton is the world's largest diversified resources company, employing more than 38 000 people in 25 countries with interests in minerals ranging from such as copper, coal, manganese, iron ore, uranium, nickel, silver to liquefied natural gas, oil and diamonds(DeepSA, 2008).

BHP Billiton Energy Coal South Africa Limited is one of the largest energy coal exporters in the world, operating in 5 different collieries (Khulata, Klipspruit, Optimum, Douglas and Middelburg) in Mpumalanga, South Africa of which Klipspriut is the youngest and also the main focus of this project. The Klipspruit Colliery in Ogies is the first new mine to be established by BHP Billiton Energy Coal South Africa Limited in more that a decade. The new mining activities at Klipspruit, established in 2003, utilise the latest technologies in order to ensure that the colliery becomes a leader in the latest production methods, labour practises, environment-, health- and safety issues(DeepSA, 2008).

Klipspruit currently produces over 4 million tonnes of coal with a workforce of 111 full-time employees and 500 contractors.(DeepSA, 2008)

1.2 Introduction of the Problem

1.2.1 Klipspruit Colliery

As mentioned in the previous section, the Klipspruit colliery is a young development by Ingwe Coal, a division of BHP Billiton. Ingwe's vision is to develop a mine that is the leader in the latest production methods and technologies in order to acquire optimal productivity. In essence, if all systems of the mine, including support systems, deliver optimally the productivity of the mine will grow at a greater rate than anticipated.

One of the facilities that is in the design phase is a four-bay support system that services the earth-moving equipment. This includes all the tyre- and track-based vehicles that are active on-site. Aspects that have to be taken into consideration when designing the workshop are:

- Amount of each type of machinery that has to be serviced
- Warranty aspect of each service
- Time deviations of services
- Breakdowns that cannot be attended to in the field
- Amount of bays assigned to each type of vehicle base

The maintenance support system is currently outsourced to an external maintenance company due to the unavailability of the workshop. By the time construction of the workshop is completed and the workshop is utilised (anticipated to be completed during June-July 2009) the delivery of all the earth-moving equipment will be finished. From here onwards minimal outsourcing will be required.

1.2.2 Warranty Service

One of the most important parts of buying an EME is acquiring an after sale agreement that includes a warranty for the equipment, which is only applicable to an EME if a service is conducted every 250 worked hours. The supplier offers a lenient gap of 50 hours for the service to be conducted before the warranty becomes obsolete.

Service Numbers	Scheduled Hours of Machine	Duration of Service(Hours)
1	250	5
2	500	5
3	750	4
4	1000	8
5	1250	4
6	1500	5
7	1750	4
8	2000	48

Table 1.1: Service Details

The warranty is of fundamental importance to the mine, thus the Earth Moving Machine (EMM) will be relieved of working duty if it approaches the 50 hour gap deadline. The service time differs depending on the amount of hours that an EME has worked. The different times for services are shown in table 1.1.

1.3 Project Aim

The current design of the workshop assigns two bays to track-type EMEs, and two are assigned to tyre-based EMEs, even though the number of track- and tyre-based vechiles differs. There are 10 track-based vehicles and 30 tyre-based vehicles active on the mine (the description and amount of EMEs that will be delivered is shown in appendix A).

An investigation into the effect that the number of bays assigned to track- or tyre-based EMEs have on the productivity of the mine, will be done by means of simulation. The influence of shift time deviation will also be investigated.

Other workshop distributions will be investigated to determine the optimal value of assigned bays to track and tyre based vehicles. The simulation will generate mathematical data regarding the queue lengths, waiting time and resource utilization from which conclusions will be drawn.

It should be noted that the current situation at other maintenance workshops is not of concern, but the opportunity exists to make these workshops more productive and thus increase the productivity of the mine's individual output. The optimisation can be done by integrating the data of the Middelburg mine with the Arena simulation program to find a optimal solution. A more productive maintenance program results in less vehicles to queue and this will in turn result in a bigger workforce on site, as well as equipment warranties that last longer due to better scheduling of work.

If simulation is optimal and the workshop does not deliver sufficient results, mathematical optimization should be used to determine the amount of services to be outsourced in order to create a profitable workshop that contributes to the efficiency of the mine.

1.4 Simulation Modelling

According to LTS Consulting a simulation model is an effort to replicate a real life situation to investigate the implications of the system and how it will be affected by varying circumstances. By changing variables, predictions can be made about the performance of the system. Discrete event simulation is often used to model various systems in industries ranging from health care to manufacturing. Arena simulation software is used in the Klipspuit colliery project(LTSConsulting, 2008).

1.5 Project Question

With the information regarding the Klipspruit colliery and simulation modelling the objective of the project is to develop a simulation model that will investigate the maintenance scheduling at the workshop of the mine. Thus, a research question is compiled as follows:

> Given the amount of Earth Moving Equipment, maintenance equipment, shift times and workbays, what is the optimal assignment of bays and shift durations to be used in order to maximize productivity of Klipsruit colliery's maintenance workshop and mine?

1.6 Project Methodology

By executing the project's aim, the main deliverable is a working simulation model of the EME workshops which is applicable to the Klipspruit colliery. The document will show different scenarios of the workshop, of which changes will be made to assigned number of bays and working hours.

The EMEs will only be affected by the service time, the amount of bays (assigned to different types of EMEs) and unavailability of parts. Areas which are not considered but may have an influence on the real-life situation is man-power availability, working enthusiasm and travel time from the mine to workshop.

It should also be noted that the simulation study only focuses on the tyre based vehicles as this is the type which has the greatest possibility to create bottle necks. When the simulation is finished track based vehicles will be integrated into the simulation to verify the decisions regarding the variable aspects.

Assuming that each week has five working days, of which all are worked every week, and two days for a weekend (where only the mine is operational and not the workshop) the simulation follows a fairly trivial flow. Entities are created and move towards the mine. This is a seven day schedule and entities are only directed towards the workshop when their service is due. After the workshop is completed the entities return to the normal schedule of working on the mine.

The simulation will use mathematical distribution to determine the time values for each process. These distributions are computer generated with the time-study values as inputs.

1.7 Document Structure

In Chapter 2 maintenance scheduling and simulation is reviewed in literature. The most important areas of a generic maintenance system are discussed and compared to the simulation that is planned at Klipspruit. Chapter 3 will discuss the conceptual model and assumptions regarding the model, as well as the computer model.

Chapter 4 will analyse the results of the simulation and provide improvements, while Chapter 5 concludes findings of the project and offers suggestions for future research relating to the development of maintenance modelling.

Chapter 2

Literature Review

2.1 Maintenance Scheduling

Mr S.A Oke Oke (2004) reasons that maintenance scheduling spans across a wide variety of research fields, mostly dominated by mathematics, computing and engineering. Maintenance scheduling is applicable in the aviation industry, vechile fleet management, process industry, road and railway maintenance and refinery- and production facility(Oke, 2004).

Maintenance scheduling was first introduced in 1972. The development of the field was slow due to the complexity of the mathematics involved. Ground breaking work was done on maintenance scheduling using integer- and linear programming, simulation modelling and a probabilistic approach(Oke, 2004).

2.1.1 Breakdown of Maintenance

The complexity of the procedures that machines undertake is directly related to the level of skill required to maintain the machine. Production work time is maintained by developing maintenance groups to ensure that workers do not experience down-time.(Paz and Leigh, 1994)

Control measures are also implemented to control the inventory of special parts. Mr. Noemi PazPaz and Leigh (1994) reasons that as reduction of repair cost became important, periodic inspection and repair became part of the maintenance function. It is essential to use scheduling effectively, as it is the main factor that determines productivity. Studies have shown that without maintenance scheduling productivity of workers reached an estimated average of 40 percent. Due to this fact certain maintenance policies exist, which are covered in the next section(Paz and Leigh, 1994).

Maintenance Policies

Maintenance is implemented by adopting certain policies depending on entity type, process type and duration of the process. Maintenance policies can be divided into two categories(Paz and Leigh, 1994):

1. Policies for reducing frequency of failures are further divided into:
   - Preventative Maintenance: Maintenance to keep on item in specific condition. Based on earliest expected failure time.
   - Early Equipment Replacement: Replaced before first failures can occur.
   - Predictive Maintenance: Maintenance is done in advance of breakdown.
   - Rebuilding of equipment (Paz and Leigh, 1994)
2. Policies for reducing the severity of failures are further devided into:
   - Speeding the repair task by modular equipment design
   - Alternate output during repair by alternate job routing (Paz and Leigh, 1994)

Historical data has to be analysed to schedule preventative maintenance, whereas predictive maintenance is performed by measuring a specific range of data concerning the output of machine that has to conform to certain limit values.
If the facility has a machine that is easily repairable and it is not critical to part productivity, the run-to-break policy can be implemented. This policy implies that the machine runs until it breaks and it is then repaired or replaced(Paz and Leigh, 1994) .

2.2 Technique

Due to the complexity that the Klipspruit model leads to when using mathematical programming, simulation modelling will be used. Simulation modelling will provide the opportunity to reconstruct the model towards a more complete and optimized answer. Mathematical scheduling will require a program that uses complicated mathematics to obtain an answer that requires editing.
The simulation model can also be repeated with different inputs and will require that the optimal situation be determined by inspection. The amount of different factors that constrains a mathematical programming problem can cause this amount of optional answers to exceed a million. Thus, with the use of a generic model for maintenance systems that is reviewed in the following section, the Klipspriut Collieries maintenance problem will be solved using simulation modelling.

2.3 Conceptual Simulation Model For Maintenance Systems

The model, that is designed by Duffuaa, Ben-Daya, Al-Sultan and AndijaniDuffuaa et al. (2001) from King Fahd University of Petroleum and Minerals, is broken down into different sub models to indicate the importance and the effect that some of the areas have on the model(Duffuaa et al., 2001).
A model requires planning, scheduling control and deployment to be developed for planned and unplanned maintenance. The key areas that in uence a maintenance system are:

- maintenance load
- maintenance resources
- maintenance planning, scheduling and execution;
- maintenance support functions
- reports and performance measures(Duffuaa et al., 2001).

Maintenance interacts with many different areas of a business whether support- or main-function. Figure 2.1 (page 10) indicates how maintenance interacts with its own support functions as well as how maintenance interacts with the rest of the organisation. The maintenance function has a continuous feedback and improvement function in maintenance planning as well as in its interaction with the rest of the organisation. It is also important to take note of the priority listing of entities which serves as a constraint.(Duffuaa et al., 2001)
Maintenance scheduling is divided into different sections, of which the critical areas are analysed.

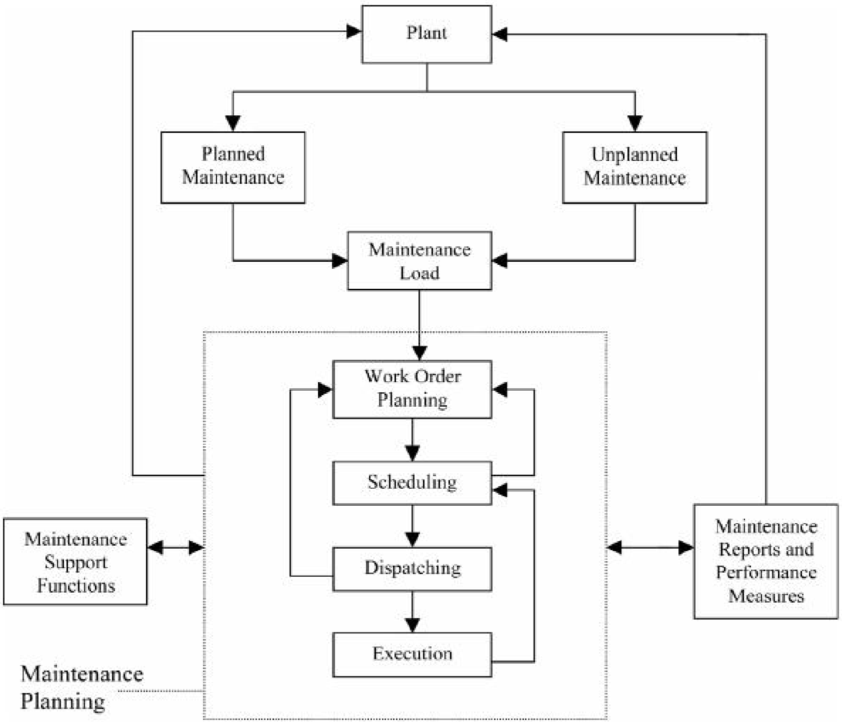

Figure 2.1: Maintenance Process

(Duffuaa et al., 2001)]

2.3.1 Input and Maintenance Load

All simulations need an input or a create module. The function is to generate different values for certain entities and areas, for example priority, time values and quality values.

This will create the maintenance load that divides the generated load into a critical load and a super load of which both consist of planned and unplanned maintenance.

The load which relates to planned maintenance is known in advance and this determines the crew mix and job sequence. The unplanned maintenance is triggered by a probability distribution that is based on time studies. All planned and unplanned maintenance is combined to form the maintenance load.

2.3.2 Planning and Scheduling

This is regarded as the most important module of the whole simulation as it forms the base of the simulation and all areas interact with the simulation through this process. A detailed diagram of the process ow is provided in Figure 2.2. The purpose of this module is to plan, schedule, monitor and execute all the jobs that move through the maintenance department. The following steps form the planning and scheduling module:

1. The maintenance load is the starting point of this process. The first step differs, depending on whether the type of maintenance is planned or unplanned. The crew size, mix and priority are known for planned maintenance as well as the entity's priority. The same data is generated for the unplanned maintenance with a probability distribution.

2. Maintenance spares and material availability is checked by using a sub model.

3. Equipment and tool availability is checked by using the appropriate module which is described in Section 2.3.3

4. The job ordered is prepared and scheduled if the resources are available.

5. The job is executed and data pertaining to the job is recorded.

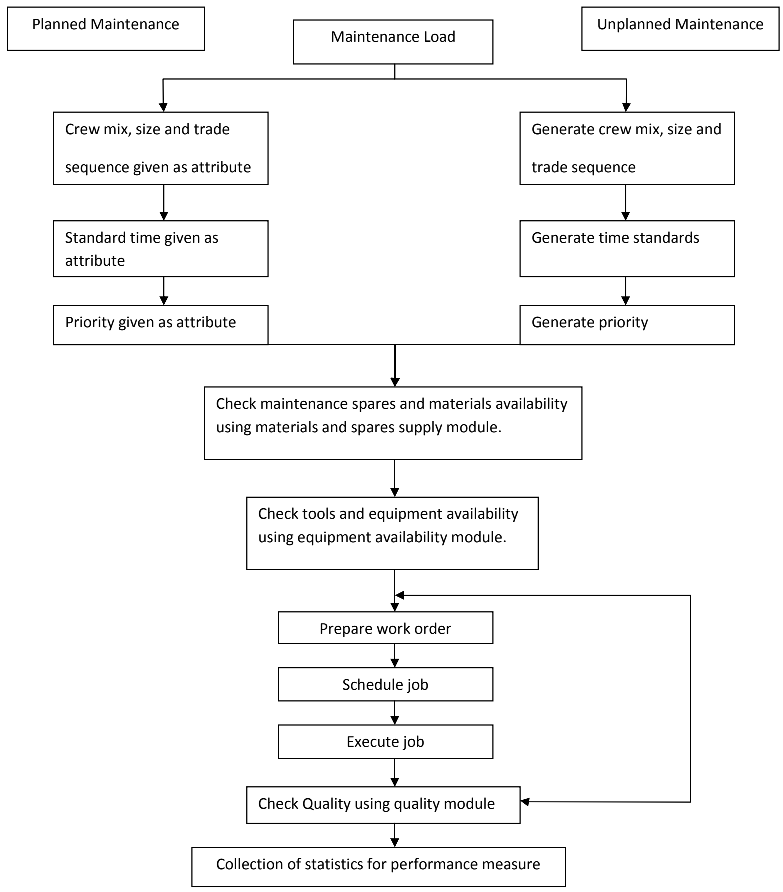

Figure 2.2: Planning and Scheduling

(Duffuaa et al., 2001)]

6. The quality of the job is checked by using the quality module. If the quality of the job does not meet the required standard the entity is sent back for the job to be repeated. The data is recorded for performance measures(Duffuaa et al., 2001).

2.3.3 Sub Models

The tools and equipment as well as materials and spares are sub models of the base of the simulation. These modules check the availability of the specifc area. If this item or area is not available, the execution of the model is delayed until it becomes available.
The quality module is also a sub model but if the quality is not up to standard the entity is redirected to be serviced again. This process is displayed in Appendix A.
Performance measures are put in place to analyse the system and to ensure that continuous improvement occurs. The performance measure can be divided into three parts, namely:

- Maintenance effectiveness
- Maintenance administration
- Maintenance cost (Duffuaa et al., 2001)

2.4 Generic Klipspruit Colliery

The model provides a good framework for the simulation of the Klipspuit colliery to be based upon. The Klipspruit colliery is also a maintenance system that has interaction of different components such as quality, equipment and different priority levels. The most important focus of the simulation is to optimise the through put and the model provides a broken-down view of each area which will indicate problematic opportunities.
Areas that are not the same when comparing the model with the colliery are manpower availably, as well as the super load of the colliery which will not be taken into account. The workshop bays are scheduled as equipment, thus equipment availability will not be taken into account either.

Chapter 3

Data Preperation

3.1 Conceptual Model

It is imperative to understand the flow of entities between processes before conducting the computer simulation. A generic approach to the major phases of simulation modelling is shown in the Figure 3.1 (page 14). The conceptual model furthers the understanding of the compilation and is the genesis of nearly all simulation models.

3.1.1 Method

The first step in creating the conceptual model is to obtain enough information from the management of the colliery to get an overview of the current operations. The current practises were understood by conducting site visits and conducting interviews with the designers and the engineers working on the colliery.

A baseline for the conceptual model was constructed and approved by the management. The baseline was refined and improved through prolonged research and brainstorming(Snyman,2008).

The output of the simulation will identify congestion of entities at key areas. Some of these areas are the normal day time- and high-priority services, quality control, breakdowns and parts availability.

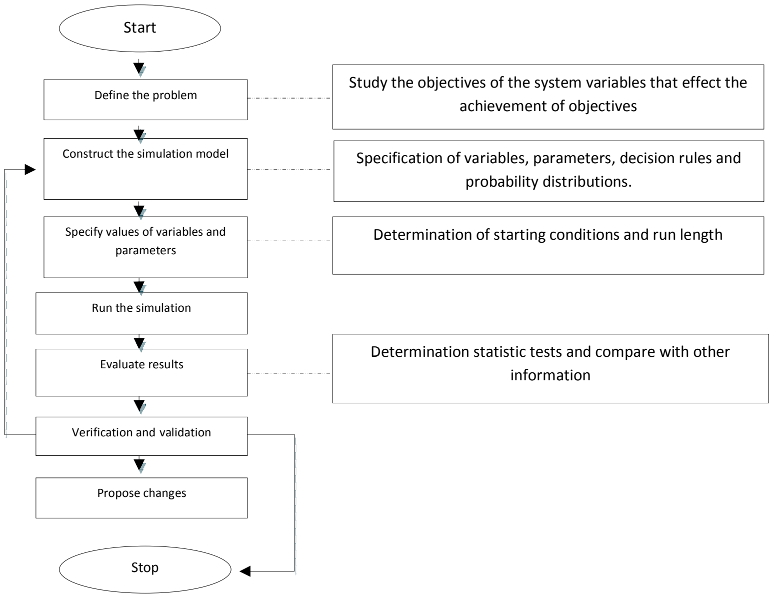

Figure 3.1: Major Phases in a Simulation Study

(Snyman, 2008)]

3.1.2 Normal Day-time Service

This area is the colliery's main workshop and all earth moving equipment is scheduled to move through this workshop. The workshop runs on ten-hour shifts where operations commence daily at 5 am. The 10 hour shifts will be extended until the last service of the day is completed.
EMEs (Earth Moving Equipment) are flagged every 250 hours to advance to the workshop in order to undergo a mandatory warranty service. These services vary in length from 4-, 5-, 8- to 16 hours.

3.1.3 High-Priority Service

The warranty of the EME allocates a 50 hour gap for the services to be completed. If EMEs approach the workshop and the queue for that current day is full they are transferred back to the mining pit to continue work and will then be called in for service the following day. If the EMEs are not serviced before the gap is reached they are removed from active service and are placed on a high-priority waiting list to be serviced.

These high priority EME's will be serviced before any of the normal day time services are performed. The high priority service is conducted within the same workshop as the normal day time service.

3.1.4 Availability of Parts

Due to human error and deviations from planned situations, parts for services are not always available. In this case the servicing of the EME that is queued for service is placed on halt while the unavailable parts are delivered. The EME for servicing which is delayed, does not occupy a bay, thus service of other EMEs continues as scheduled.

3.1.5 Quality Control

To keep the mine working at an efficient rate the quality of a sample of the services should be inspected. If the quality of the sample does not meet acceptable standards the services have to be repeated. A vehicle that fails the quality test is not marked as high priority, due to its ability to work if there is still time remaining on the 'warranty gap'. Therefore, the destination of a vehicle which fails the quality test depends on the amount of hours that the vehicle has been in use.

3.1.6 Breakdowns

The occurrence of a breakdowns is an unplanned event and the level of repair required should be investigated and identified. An EME can be repaired in the field if the damage is minor or if the repair process is trivial and does not require workshop equipment.

If it is a bigger problem, the EME requires a workshop and a high priority repair is to be conducted, which implies that the resources used to service the normal day time service and the scheduled high priority services will instead be used to repair the EME that has broken down.

Bottlenecks in the breakdown department are parts availability, quality control and resource allocation in the workshops. Breakdowns do not have their own allocated workshops, thus these repairs are also done in the normal day-time service workshops. The field service is not done within a workshop so the delay only impacts the relevant EME and not the rest of the mine.

3.1.7 Earth Moving Equipment

Only certain amount of the EMEs that are delivered for servicing are critical to the working environment and the efficiency of the mine. These EME will be referred to as the critical load, while the rest of the EMEs will be referred to as the mass load.

The simulation will mostly deal with the critical load as its services and down-time impacts on the efficiency of the mine. The model simulates the tyre based EMEs as these are the largest in number.

3.1.8 Theoretical Model

As the efficiency of the mine is determined by the amount of coal that the colliery can produce, the efficiency of the EMEs will be the determined by the amount of coal that can be transferred in a certain time frame. To ensure that the workshop contributes to the efficiency of the mine it has to service vehicles in the shortest possible time and highest quality manner possible in order to avoid congestion in the workshop.

To ensure that our model mirrors reality as closely, possible time studies will have to be done on the following aspects:

- working time per day of different EMEs
- actual duration of a scheduled 4-,5- and 8-hour service
- waiting time for delivery of unavailable parts
- duration of a breakdown (both services performed in the field and the workshop)

Data-gathering will be done on:

- unavailability of parts
- quality-test failure
- breakdowns that occur

The simulation software used to model the system provides an application to determine the mathematical distribution for the data gathered. This makes it possible for computer-generated distribution functions to be used in the computer model. This is also the required input for Arena.

3.1.9 Earth Moving Equipment Process

For the purpose of this study, a tallied hour rate will be used for the tyre-, lubrication- and mechanical services. This rate will be the assigned rate of 4-, 5-, 8- or 16 hours.

The time it takes one EME to travel between the mine and the workshop is not taken into account as the mine and the workshop is situated very close to one another.

3.2 Computer Model

The theoretical model that is described in the previous section of this document is altered into a computer simulation. The simulation will be developed with the use of Arena software. At the end of the simulation a report is generated to obtain results from which conclusions regarding the system can be drawn. Some of the statistics that are included in the reports are queue-length and queue-time values, entity statistics, process details, time related attributes and user-specified statistics.

The simulation model will be constructed around the generic model Duffuaa et. al. Figure 3.2 (page 18) provides a graphical representation of the top level of the simulation model. The layout of the model in Arena and a short description on Arena is provided in Appendix B.

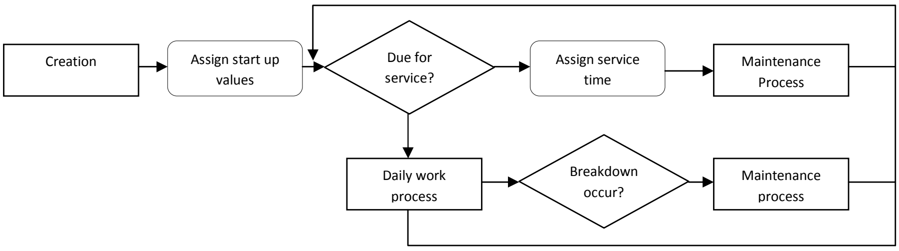

Figure 3.2: Top Level of Maintenance Process

3.2.1 Creation

All the entities are created in 12 different create nodes which are combined into one module on Figure 3.2. Different quantities of tyre-type vehicles are created, of which the Caterpillar 777 has the most entities. The quantity of each entity can be seen in Table A.1 in Appendix A.
The entity will move towards an assign node. There are two attributes assigned to each entity namely:

- Worked hours: All the EME's will be assigned a value from a mathematical distribution in order to determine the amount of hours that the EME has already spent on the mine. All attributes are assigned in values between 0 and 250, representing the number hours prior to the first mandatory service.
  The assumption that EMEs have different work levels has to be made in order to exclude poor resource utilisation and to bring the model closer to reality.

- Level of service: This attribute has to be assigned to the EME to indicate whether the entity has any time left on the allocated warranty gap. This attribute, in correlation with the work hours-attribute, triggers if an entity should be removed from the mine and queued for high level priority service.

3.2.2 Service Decisions

All the entities that have been created are sent through a decide node. The decide node has two directions, according to the parameters that were assigned by the previous module, to which the entities are sent. The EME can be sent to the mine or to the workshop in order to be serviced. Table 3.1 on page 18 depicts the parameters for which an entity is sent for service.

If the worked hours for the EME fall between the stated values and the service level is as indicated then the entity will be directed to the workshop, otherwise it will be directed to the mine.

Parameter	Worked Hours Gap	Level of Service
1	250 and 300	0
2	500 and 550	1
3	750 and 800	2
4	1000 and 1050	3
5	1250 and 1300	4
6	1500 and 1550	5
7	1750 and 1800	6
8	2000 and 2050	7

Table 3.1: Parameters to Trigger Service

3.2.3 The Mine

The simulation for the mine is very trivial and forms part of the model as a sub model. As the entities enter the sub model, labelled Daily Work Process (Figure 3.2 page 18), they arrive at a process node, which determines the amount of work that the EME does that particular day. This is done by using a random distribution. There is no queue at this process.

Following the process node is an assign node to update the worked hours attribute. The amount of hours that the EME spent on the mine is added to this attribute. The EMEs exit the sub model and approach the breakdown decide node.

This node decides if a breakdown occurred. This choice is made by probability

- in other words, it is achieved by analysing historical data. If the EME suffers a breakdown it is moved to the breakdown sub model. Alternatively it is sent back to the Service Decide-node.

3.2.4 Workshop Queueing Conditions

If the entity's attributes fall within one of the parameters specified in Table 3.1 (page 19), the EME will move towards the workshop to be serviced.
The assign nodes, labelled 'Assign Service time', introduce a new attribute towards the entity, mainly the service duration. The value assigned to this property depends on the level of service (from level 1 to level 8) that the entity requires. The service duration varies between four hours and two days. Table 1.1 (page 3) indicates the different service durations.
The assign nodes connect to a sub model labelled 'Maintenance Process'. Figure 3.3 (page 21) provides a view of the layout of this sub model. There are mainly three different results that can occur as entities move through this sub model.

Normal Day Workshop

There is only one set of requirements to enter an entity into this queue. The first node is a decide node which determines the total value of all the service times in the queue of all the workshops. If this value is more than 10 the entity will bypass the first workshop-option, as the queue for that day is already full and the entity will not be service on that particular day. To enter the Normal Day workshop queue the sum of the value must be less than ten.
Another decide node follows, which stipulates that the time of arrival must be between 5am and 3pm to enter the Normal Day workshop queue, thus the entity arrives in the given window.
The final decide node that the entity must pass in order to enter the specific workshop determines whether the current day falls on a weekday as the workshop is not active on weekends. If the entity complies with this parameter it will be included in the Normal Day workshop queue. Table 3.2 (page 22) summarises the conditions for entry into the Normal Day queue.

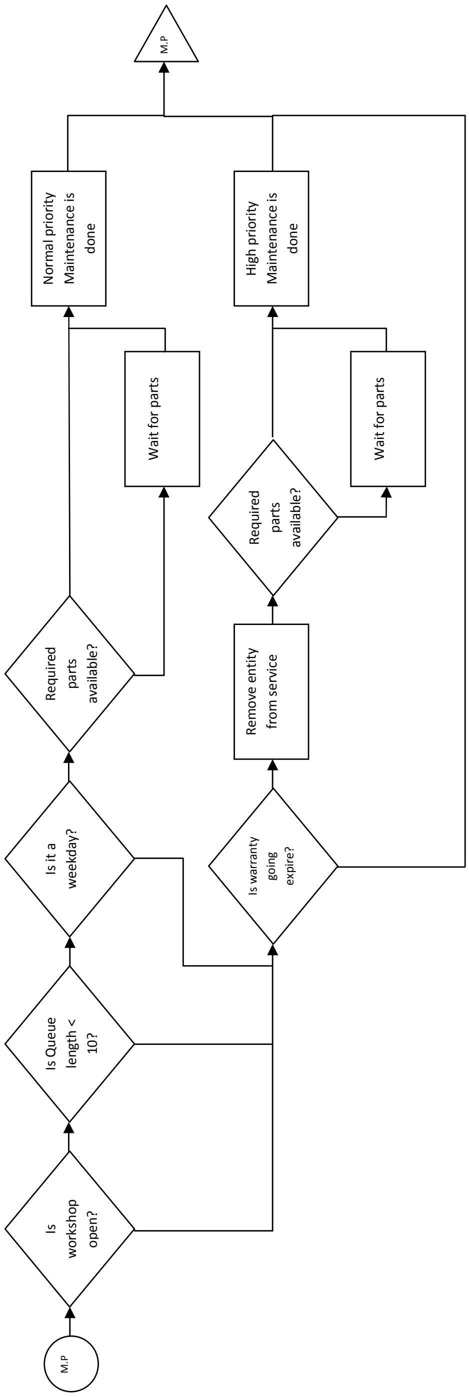

Figure 3.3: Submodel of Workshop

Condition	Yes or No
Queued entities service time less than 10 hours?	Yes
Arrival time between 5 a.m. and 3 p.m?	Yes
Arrival on Saturday or Sunday	No

Table 3.2: Conditions to Enter Normal Day Workshop

High-Priority Queue

There are three ways of entering this queue. As the entity arrives at the first decide node the sum of the service times of the queue length can be less than 10 to send it to the next decide node, which depends on the time at which the entity arrives at the workshop - this can also be in the time window. If the entity enters the final decide node either on a Saturday or on a Sunday the final condition will be true (if this was a weekday it would be identical to the first case and it would qualify for the normal week day queue).

Meeting the above conditions will send the entity to the decide node named 'Warranty expire node'. This node examines the amount of time that is left on the warranty gap before it becomes obsolete. If the value is less than 20 the EME is taken out of service and placed in the high priority queue. This workshop will service its load before servicing the normal work day load. Therefore the entity should have a gap value of less than 20 hours to access this queue.

The second and third sequences of conditions to enter the high priority queue are listed in Table 3.3 (page 23). An entity must be directed away from the first workshop and should have a gap value of less than 20 hours.

Bypass All Workshops

The three conditions that were stipulated for the high priority queue are the same conditions that the entity has to meet in order to bypass all the queues and continue work on the mine. The only difference is that the warranty gap should be in excess of 20 hours. The warranty expire decide node will send the entity back to the mine. Table 3.4 (page 24) summarises these conditions.

Condition	Yes or No
First Condition	
Queued entities service time less than 10 hours?	Yes
Arrival time between 5 a.m. and 3 p.m?	Yes
Arrival on Saturday or Sunday	Yes
Worked hours within 20 hours of the expire value?	Yes
Second Condition	
Queued entities service time less than 10 hours?	Yes
Arrival time between 5 a.m. and 3 p.m?	No
Worked hours inside 20 of the expire value?	Yes
Third Condition	
Queued entities service time less than 10 hours?	No
Worked hours within 20 hours of the expire value?	Yes

Table 3.3: Conditions to enter high priority workshop

3.2.5 Workshops

The entities will enter the workshop and will be serviced according to the service duration attribute that is assigned to them. As there are only two workshops (starting model) the high-priority queues load will be serviced first and then the normal day-load. If the entity receives a two day service the process will be reset and the scheduled services will be repeated from one to eight at the appropriate time.

3.2.6 Breakdowns

When an EME leaves the mine and the breakdown decide node indicates that a breakdown has occurred the entity would move to a sub model labelled 'Breakdown workshop'.

Figure 3.4 (page 25) displays a flowchart of the sub model. The first module is a decide module that uses a random distribution to indicate if the repair can be done in the field or if the entity should be sent to the workshop.

If field service can be performed a hold entity is put in place to delay the entity under review. For this service no resource that is of importance is used.

Conditions	Yes or No
First Condition	
Queued entities service time less than 10 hours?	Yes
Arrival time between 5 a.m. and 3 p.m?	Yes
Arrival on Saturday or Sunday	Yes
Worked hours inside 20 of the expire value?	No
Second condition	
Queued entities service time less than 10 hours?	Yes
Arrival time between 5 a.m. and 3 p.m?	No
Worked hours inside 20 of the expire value?	No
Third condition	
Queued entities service time less than 10 hours?	No
Worked hours within 20 hours of the expire value?	No

Table 3.4: Conditions to Bypass Workshops

When the entity has to go to the workshop, the highest priority is assigned to the entity and it is placed in the relevant queue. When the entity is repaired no value changes are made to any of the attributes as it was not a warranty based service.

3.2.7 Availability of Parts

Before an entity moves into a queue the necessary parts for repair should be available. With the use of a decide node, which uses a random distribution, parts availability is checked. If the parts are not available the servicing of the entity is delayed until the parts arrive. This is applicable to the Normal Day queue, the High Priority queue and the Breakdown queue, as well as to field service.

3.2.8 Resource Scheduling

The workshop entities run on two schedules, namely Normal Day schedule and Graveyard schedule. On a Normal Day schedule two workshops are available from 5am to 3pm or until the work load for the day is completed. This schedule

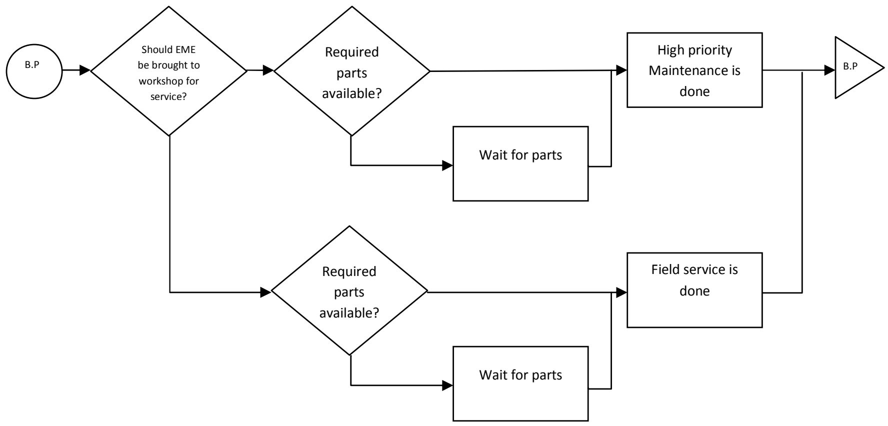

Figure 3.4: Submodel of Breakdowns

applies to all three the types of workshops mentioned above.
The Graveyard schedule only services breakdowns and only has one workshop available. This resource is available from 3pm until 11pm or until the load for the day is completed.

3.3 Output

The simulation model for the Klipsruit Colliery runs for a year. When the simulation is complete, statistical data is generated, at which point entity-, queue- and resource data is available. The most important data gathered is:

- waiting time and number of entities in Breakdowns queue
- waiting time and number of entities in Normal Day queue
- waiting time and number of entities in High Priority queue
- the total time for entity to move through a scheduled service

- the amount of entities taken out of service due to warranty expiry
- amount of EMEs bypassing the workshops
- amount of times the EMEs have had to wait for parts

The desired output of the model should minimise all of the above mentioned values. The EMEs should move through the workshop while minimising the length of the queue. The High Priority queue should not take any entities out of service due to warranty issues and parts availability should improve.

3.4 Influential Factors

The following factors in influence the model output and take the form of variable data that determine the efficiency of the workshops:

- random distribution of working hours
- probability of breakdown occurrence
- random distribution of available parts
- probability of workshop breakdowns
- amount of bays assigned to tyre based EMEs.

The factors that in influence the model that take the form non-variable data are:

- the minimum amount of vehicles in the system
- the warranty conditions
- service times
- total amount of bays
- resource availability.

Chapter 4

Results and Discussion

The Klipspruit Colliery will first be simulated in the way that management proposed the implementation of the maintenance workshop. This simulation's results will be compared to other simulations of the colliery's working with different variable data, which will provide management with a few different options, as they should decide what is feasible. Arena simulates the colliery for a year and this simulation is repeated ten times in order to generate an acceptable average.

4.1 Managenent Proposal

The data that is generated from this particular simulation will be compared to all the other simulations as this is the current design. The bays are distributed evenly between the tyre and track based EME's.

The maintenance workshop has three different areas namely the Normal- , High Priority-, and Breakdown workshops, of which the High Priority queue has the largest waiting time (almost two hours). Of the 268 services that occurred during the year 100 were of high priority, where the entity was removed from service to meet its warranty obligations.

Some entities approached the workshop just to be sent back to the mine due to different reasons which included day of the week, time of day or the queue length. This event happened 312 times.

4.2 Distribution of Bays

Of the forty EME's on the Klipspriut Colliery twelve are track-based and the rest are tyre based - thus, a different distribution of work bays is the next simulation that will be investigated. If the simulation has a distribution of 3:1 for tyre based EME's the average waiting time in the queue is less. The workshop has a through put of 392 entities, of which 157 are high priority and will be removed from the mine. This is more than the management proposal but overall it proves an improvement of productivity for the workshop.
Due to this change the mine increased the amount of shifts that workers worked with 33 percent which will lead to more coal being mined, and to a more profitable organisation. The increase in shifts that the mine operates on is the reason why the number of High Priority entities increased.
The one bay of track EME's will cause a small amount of drag but the system will be more efficient with the bays divided in the same ratio as that of the EMEs.

4.3 Workshop Operations

Currently the mine has two shifts, one where two bays operate from 5am to 3 pm and another where one bay operates from 3pm to 11pm. These shifts are applicable to every day of the week except Saturday and Sunday. A simulation will be done to extend the workshop hours for two bays until 11pm as well as to investigate the outcome should the workshops be made operational during weekends.

4.3.1 Time Extension

With the workshop running 16 hour shifts it will have to be divided into two shifts. This will result in bigger salary expenses but the average waiting time for a service will be lower than the current design. A massive 393 services occurred during the year of which only 57 were high priority services. The number of shifts that were worked during the year were 6960, which is less than the three bay simulation.
This option results in increased expenses but proves a feasible productivity.

4.3.2 Weekend Work

The mine is currently working on a 24-hour shift, seven days a week, while the maintenance workshop is only working 10 hours a day five days a week. If the workshops are extended to seven days a week the improvement to throughput is conciderable. A total of 476 entities are serviced of which only 19 is removed from service and 136 are sent back to the mine without service. This equals a productivity increase of 78%. The mine will have a 12% increase in shifts compared to the management proposal.

By extending the work through weekend it is important to remember that additional cost such as over time payment for maintenance workers will have to be included in the budget.

If the weekend work is extended to 16 hour shifts, the model will be more productive but the expenses increase more than the productivity does.

Chapter 5

Conclusion

The simulation's results provide opportunities for improvement in different areas. The productivity of the mine is enhanced by 33 percent if the layout of the workshop is changed to 3:1 in the favour of tyre-based vehicles. This is a logical approach, as the EMEs of the mine is divided in the same ratio. This decreases the percentage of EME's that are removed but does not solve the problem, as 38 percent of the services are still high priority.
In comparison to this, if the shift durations are prolonged to encompass weekends the productivity of the mine increases to 18 percent but the workshop shows a increase in throughput of 78 percent.
If the mine needs to be optimized the different bay distribution is the best option as this will financially be the optimal solution. The change in shift times would be the best option if the workshop needs optimization. Maintenance workshop labour costs will increase by a minimum of 40 percent.

> *"Another flaw in the human character is that everybody wants to build and nobody wants to do maintenance."*

Kurt Vonnegut (1922 - 2007)

Appendix A

Appedix A - Figures

Quantity	**Mode**	**Description**
2	D11T	Track Type Tractor
1	D10T	Track Type Tractor
3	PV275	Overburden Drills
2	EMC720	Atlas Copco EMC 720 Drill Rig Coal Drill
1	834H	Wheel Dozer
4	993k	Wheel Loader(Front end Loader)
12	777F	Off-Highway Truck(Haul Truck)
2	16M	motor Grader
1	422	Backhoe Loader
1	988H	Tyre Handler
1	988H	Cable Realer
2	246B	Bobcat
1	CAR740	Water Tanker
2	CAT740	Diesel Tanker
2	Massey Ferguson	Tractor
1	UE	150 Tonne Lobed
1	CAT IT 14 G	Integrated Tool Carrier
1	CAT TH 414	Telescopic Handler

Table A.1: Earth Moving Equipment to be Delivered

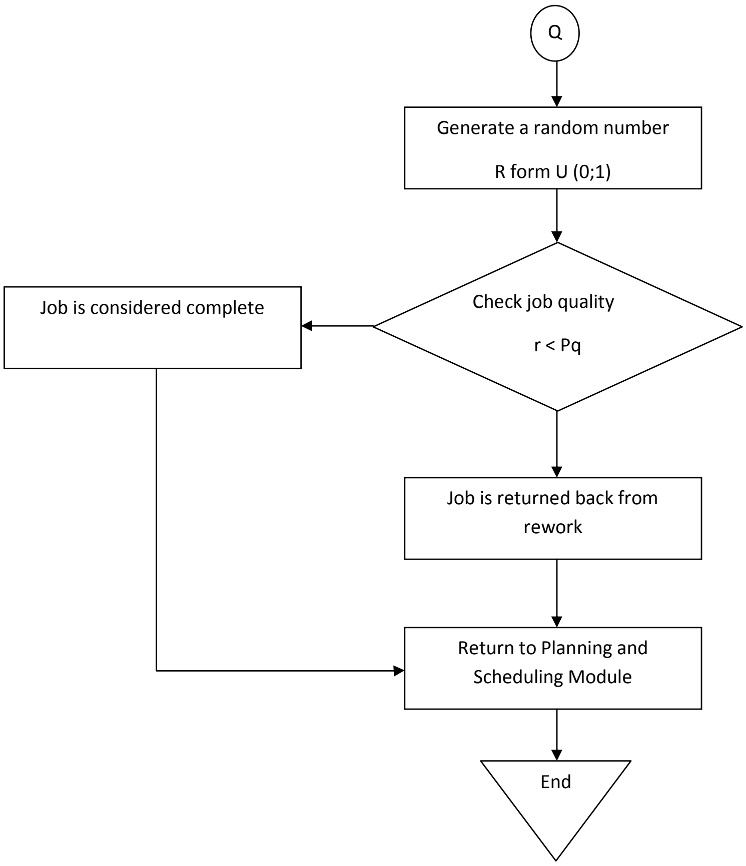

Figure A.1: Quality Module

Appendix B

Appendix B - Arena

Arena uses generic flow chart modules to illustrate the process that is simulated. The EME's in the simulation are entities and they move between modules or nodes. These entities are created in a Create-module. This module can edit the distribution in which entities are created, the time between entity arrival and the names of the entities.

The entity would then move from the creation node to the module connected to it. This can be any module except a Dispose-module. The dispose module is used to take the entity out of the simulation - this is normally the final part of the simulation. The current simulation doesn't use a dispose node as all the vehicles stay on the mine and it is important to update a vehicles properties regarding the model as its time spent on the mine increases.

A decide node is used to execute decisions. This can be done either by chance or by condition. The decide node consists of the ability to provide the user with two or more options.

In the simulation of the Klipspruit colliery an assign node follows the create node. An assign node has the ability to assigns entity pictures, attributes, variables and the type of entity.

A process model is one of the most important modules in the simulation model as this is the module that uses resources to process the entities. The duration, resource and delay type can be assign. A schedule to determine the resource's working hours can be defined and the amount of resources utilised can

be changedcite.
The hold entity is nearly the same as the process entity due to the fact that it occupies the entity for a specified period of time. This time delay value can be changed. A Record node captures the data, at a specified point in the model. All the above mentioned modules are shown in Figure3.

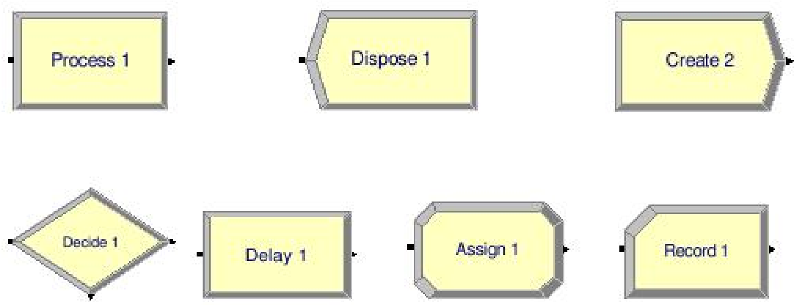

Figure B.1: Modules of Arena software

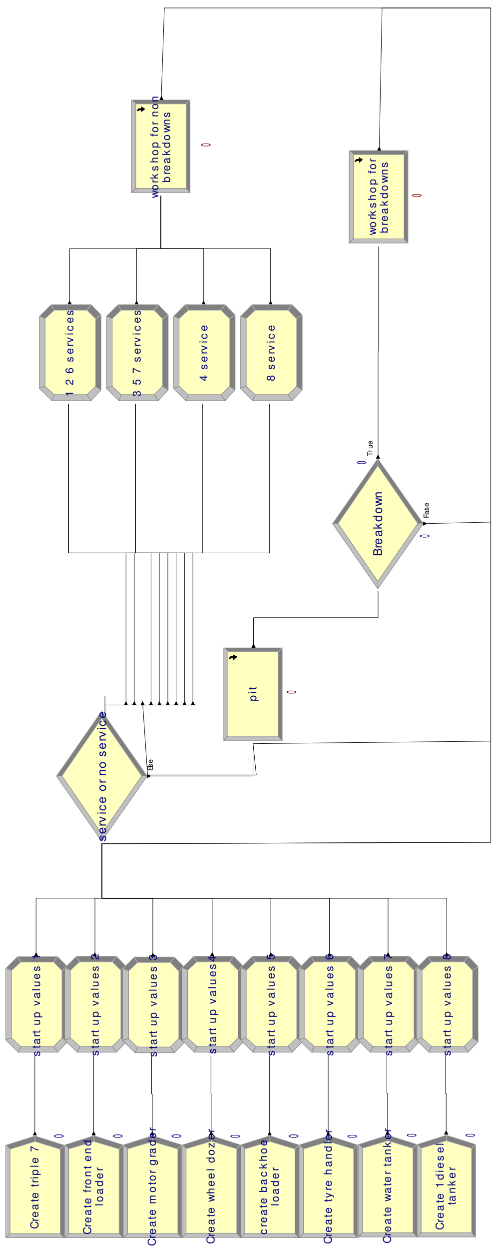

Figure B.2: Top Level of Arena Simulation

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