Abstract. In a world where capital resources are a scarce commodity, return on assets and OEE rule supreme. Organizations need to continually chase process reliability and performance to remain competitive. Textbooks abound with maintenance and process improvement strategies and frameworks. Outside of strongly regulated sectors such as the airline and petrochemical industries, maintenance has traditionally been regarded as a necessary evil and continues to escape the attention of senior management.

With increasingly sophisticated simulation platforms, including Arena (Rockwell) and Delmia (Dassault Systemes), it is possible to design models that mimic closely the behaviour of complex systems and allow the user to predict future performance and cost based on historically observed behaviour and current decisions. On top of this, these models need to incorporate a user-interface for decision-making in real time. Examples of real-time decisions include repair versus replace, matching of rotables, improvement action, how many times to overhaul before discarding, level of opportunistic maintenance, level of managed condition, level of stores, optimum level of maintenance capacity and many more.

Two simulation models have been developed, one that deals with the maintenance of a complex and high speed industrial process and the other for improvement of this industrial process based on reliability condition, performance and critical process data. The first model is machine-centric whereas the second model is process-centric.

This paper describes in some detail the philosophy and working behind these models.

1. INTRODUCTION

Simulation has been used for a number of decades for the purpose of gaining insight into how a production system will respond to specified changes. Such changes include revision and re-design of plant layouts, investigation and improvement of processes and procedures as well as optimisation and maintenance procedures and strategies, all with the intention of improving profitability, ROA and OEE. Simulation is widely used for such projects and problems because the user has the ability to model highly complex systems that are subject to events of a stochastic nature, thus allowing the user to mimic true to life circumstances based upon prior analysis.

It is by now well known that one of the key indicators for maintenance health is the ratio between planned and unplanned work. This ratio is, by many experts, ideally pegged at 85/15%. For process efficiency, the measure is OEE, and world best practice indicates a level of at least 80%.

In many industries, actual performance still falls well short of these two measures. One reason is the complexity of the equipment coupled with the difficulty of improving reliability and the wide range of possible maintenance strategies and actions over the lifetime of the equipment. Another important issue is, in order to escape the vicious circle of spending too much time on unplanned repair work but having insufficient budgetary resources to improve the underlying causes, the organization needs to build a “business case” for spending money in this area. And this business case needs to demonstrate the return on this investment based on improved reliability, performance and life.

In light of the recent global economic downturn and the projected recovery period, the importance of an effective and cost efficient asset management strategy has become more obvious than ever before. Not only is the asset management strategy required to service the needs of the production system but it must also fall in line with the overall business strategy and budgetary constraints. A detailed asset management model is required to guide companies through the process of managing assets. The asset management model should contain information such as generation and execution of work, strategic, budgetary and financial information as well as operational performance measures and results.

In today’s environment organisations deal with multiple concurrent strategies, actions, disturbances, market and competitive forces, regulatory changes and technology trends and advances, some of which will impact the organisation in the short term, others in the medium to long term. A key objective is to be able to predict the likely outcome or range of outcomes associated with these influences and actions, in terms of predicted outcome and to chose those strategies that have the most likely and sustainable economic benefits to the organisation and its stakeholders. The ability to optimise the life cycle of capital equipment and
associated ownership costs directly supports the competitiveness of a company and is therefore highly critical. In addition the asset management strategy must also take into account details of when a machine or process is to be replaced and how this new technology will affect the capability of the remaining machines on the line. During times of financial hardship it is critical that businesses not only account for every dollar but extract the maximum return from it whilst minimising commercial risk. Traditionally it has been difficult to estimate and forecast the benefit arising from maintenance and process improvement. As a result, many organisations have been reluctant to make investment in this critical area. It is for this reason that a robust business case must be developed in order to obtain additional resources.

The proposed solution is a simulation tool that closely mimics the performance, behaviour and condition of the complex asset and forecast how these characteristics may change in the future. It includes a real time reliability and performance monitoring system coupled with an adaptive simulation model. The simulation model is adaptive in the sense that the internal and external conditions are not static; rather the environment and problem itself are expected to be dynamic. The variables that drive it are continuously updating when new information becomes available. In this way the model can be used to analyse maintenance activities and strategies and other proposed changes to the system with accurate estimates for the expected return on this investment and overall system performance.

In order to achieve this it must first be recognised that the system’s condition and reliability profile are dynamic and therefore continuously changing and degrading. It is a key priority for a company to monitor the reliability and condition of critical components within the system in real time based on hours of usage or production output in order to confidently forecast and ultimately prevent forthcoming failures in a cost efficient manner. A key issue and indeed problem is the overwhelming volume of data required to drive a simulation model and the associated costs of sustaining these data flows. A “standard software” based interface was developed to manage and sustain the data flow and analysis. Monitoring of the reliability profile is performed using an Excel based interface which also contains failure analysis data. This failure analysis data will also be used in the simulation model to mimic the failure distribution of the physical assets.

The capability of this model will go beyond that of models in literature that focus specifically on maintenance activities alone and will also encompass other asset management decisions, for example technology and process improvement.

An asset management case study is currently underway whereby the simulation model being developed is used to model a food processing line. The purpose is to give management teams the ability to make crucial decisions in real time to gain the most desirable outcome and provide senior management with a variety of scenarios that these decisions can lead to. These decisions will not be only be restricted to those in the short term but will also include medium and long term decisions to help shape the health of the assets in the future.

Another reason that makes this research significant is that this tool must be designed for simplicity. The people that will be using this tool are not engineers by profession and come from various trades (mostly electrical). It is therefore a design requirement of this tool to facilitate decision making and interpretation of results by non-experts in simulation.

2. LITERATURE REVIEW

Maintenance improvement projects that utilise simulation for optimisation have been widely reported in literature. The purpose of these simulation models and frameworks are quite diverse and include the following:

- Repair capacity (Gatland et al, 1997)
- Shutdown strategy (Mathew & Rajendran, 1993)
- Inventory and stores management (Sarker & Haque, 2000; Duffua et al, 2001; El Hayek, 2006)
- Maintenance staffing (Mjema, 2002; Shin, 2004; Chang et al, 2007)

Although there are many different ideas and proposals regarding maintenance and maintenance sub-functional simulation models, the motivation for developing such models is consistent among all authors. The main rationales driving these models are listed below;

- Optimization of maintenance activities,
- Optimization of key maintenance functions,
- Optimization of scheduling and planning,
- Minimization of maintenance associated costs,
- Improved productivity, availability, reliability and throughput.

There are three gaps or opportunities identified as part of the current state of the art. Firstly the majority of models in literature only provide one-off solutions for maintenance strategy issues. As previously mentioned systems are dynamic and the system and its driving parameters are continuously evolving. One-off solutions would not be able to account for this nature
and would become outdated. Secondly the models reviewed in literature only offer a solution to one problem, for example replacement strategies, staffing levels or inventory management. An adaptive asset management model is proposed so that any decision related to a machine or process on the production line can be made. Finally real time and adaptive simulation tools that update with time need to be designed. This means that the most current condition of the assets can be simulated as required and more accurately informed solutions will be available. There is a need for conceptually simple process improvement and asset management methodologies that assist engineers and operators understand how process performance is influenced by critical process variables (van Voorthuysen et al; 2001).

The earlier maintenance simulation models in literature provide solid frameworks for modelling of maintenance activities (see among Sun, 1994; Duffuaa & Andijani, 1999; Duffuaa et al, 2001; Mortensen, 1981; Brown & Powers, 2000; Azadiva & Shu, 1998; Harvey, 1992) and were used successfully to solve maintenance issues and redesign maintenance strategies. However, they do not address the dynamic behaviour of machines and production systems. It is apparent that in more recent literature this issue is considered and as a result models are being designed to account for this behaviour (El Hayek & van Voorthuysen, 2005, 2006; Ali et al, 2008; Yun et al, 2008).

A model for the development of an Intelligent Maintenance System was proposed by Ali et al (2008). Using this model precise downtime schedules, maintenance crew sizes and spares inventory levels can be identified. This model was validated through real life development on an automotive parts production line. As a result of the analysis a day to day maintenance schedule was proposed, which could in turn become more cost intensive due to stoppages for daily maintenance procedures.

Yun et al (2008) recognize that for maintenance to be efficient and cost effective, a series of carefully planned maintenance activities must be accomplished. This lead to the development of a model that was capable of estimating availability, reliability and maintainability of a system. A case study was performed and decisions could be made regarding scheduling of maintenance and the associated costs. Yun et al have carefully considered the various inputs that will drive the model including historic failure data, spares inventory and repairman utilisation and associated costs. The structure of the data-model interface appears to be well designed with data input being fed into the model through a database and the simulation results being fed back into the database for the user to see.

El Hayek and van Voorthuysen (2005, 2006) explored equipment life cycle optimisation and the associated costs and developed three successful models that ultimately lead to an increase in the mean time on wing for an aircraft jet engine by as much as sixteen percent. The models created were to be used by airline engineers to determine maintenance and opportunistic replacement strategies, forecast reliability and equipment ageing for jet engines as well as the level of inventory required and the maintenance capacity of the airline.

It is evident that there is a need for adaptive real time asset management decision tools. Maintenance is only one part of the overall asset management discipline and many of the solutions presented in past literature could be seen as short term. By implementing a targeted process improvement strategy, a company will be able to achieve a far greater ROI from all of its critical production assets throughout their entire life cycle and continue this greater return with new replacement equipment once acquired in the future.

A framework for process improvement using path modelling and simulation was presented by van Voorthuysen (2001). Process and product improvement is important for long term business sustainability and as a result should be ongoing to continuously achieve desired performance and minimise commercial risk. The user of this framework is able to highlight performance and quality issues and identify how interactions between set points and control variables affect production output. The user can then identify a new set of operating variables and simulate their effect on system performance and commercial drivers. By utilising this framework the user can manage the process and control its behaviour.

## 3. THE MODEL

As part of the asset management and process improvement process and ultimately as part of the simulation modelling it is critical to know what data is available, what analysis can be performed using this data, what information is the result of the analysis, what is the knowledge and in turn understanding that follows the information and finally what decisions can be made and the associated level of risk (Figure 1). This process is critical for determining where particular issues in the current system may lie, for example the failure data and derivation of a PDF to forecast future failures. However, this process also works in reverse. In order to achieve a desired result a company can work backwards using this process to learn what understanding and knowledge is required working back to the required data. The reverse process can be used to make decisions about a desired level of performance. The forward and reverse versions of this process can then be tested in the simulation model to test if ideas that are generated are worth pursuing and the best method to reach the preferred outcome.

The framework (Figure 2) to be employed is made of a series of models starting with low level modelling of process behaviour building to a high-level simulation
and process improvement model that will drive high level asset management decisions.

Figure 1: Process for understanding and decision support.

In each instance, a model of the process is established. For reliability this is based on the layout of the process parts (serial and parallel) and critical dependencies. For process improvement this is based on critical process variables and their relationships. Raw process and reliability data is captured and analysed in order to establish and quantify stochastic and dynamic behaviour. For the reliability simulation model, Weibull parameters are established for the layout of the process line. For the process improvement model, the distribution of each critical variables and co-dependencies are quantified. This information can then be utilised to generate knowledge and understanding of present issues that can be recorded in a data base for future reference. In addition once the knowledge and understanding of the problem is achieved potential solutions are then simulated. In the final stage the user will utilise the asset management model to refine the asset management strategy based on commercial and operational drivers.

Figure 2: Asset management simulation hierarchy.

The conceptual decision framework for this model has been developed and is shown in Figure 3. The model is based on the premise that each process can be divided into critical modules and sub-modules which can be “characterised”, statistically or mathematically, in terms of reliability and performance based on historical and current operating data and process signals. The subsequent analysis of this data is used to highlight and determine the origin of poor performance whether it is failure related, capability or capacity related or a process variable, thus forming a foundation for the design of an improvement strategy.

Once the maintenance strategy has been selected by the user (Refer to Figure 4 for the modelling methodology) the appropriate simulation conditions will be applied to the model. Replacements are made and a new set of stochastic failure conditions are generated by the model based on Weibull parameters. The new failure conditions are then applied and either a failure will occur or the part will be replaced. After the conclusion of the next event (failure or planned replacement) the cycle restarts. This modelling technique (Figure 5 shows an overview of the model) was successfully used by El Hayek (2006) to optimise maintenance and replacement strategies for jet engine modules. This methodology allows the user to rapidly test and compare maintenance strategies.

Figure 3: Maintenance strategy development model.

The results of the maintenance strategy simulation will be combined with the results of the process improvement model (Figure 6), also known as the dynamic real time process diagnostics and modelling procedure (Adopted from van Voorthuysen, 2001).

This model assumes that a process is managed on the basis of a set of preferred operating set points and control variables. These operating variables support desired levels of OEE and performance which in turn support commercial goals. The process is characterised on the basis of these variables and process behaviour can therefore be quantified by a set of variables. The resulting process state can be expressed as a transfer function and can be used to predict performance and plan process improvement by inverting the transfer function to estimate a new set of preferred operating set points and control capability. This methodology has been successfully applied to an industrial printing process that at the time was suffering from excessive waste and downtime. The model was able to establish and quantify critical casual relationships between process variables and was used to plan and predict an improvement strategy. As a result of the knowledge and understanding generated by this analysis the company was able to substantially extend the life of the process, thus eliminating premature asset replacement.

The asset management model (Figure 7) provides the user with a highly detailed map for navigating through
the asset management decision process. It accounts for the various aspects of this complex discipline including, financial data and analysis, operational and performance analysis, maintenance management and strategy development. By using the results of the simulation models as input to the asset management model the user will be able to make the critical links between systems and processes, innovation and knowledge and structure as well as links between the assets, the strategy and the skills required to execute.

**Figure 4:** Simulation modelling methodology to be used as the high level simulation model.

**Figure 5:** Overview of the failure and replacement simulation model overview (Adopted from El Hayek; 2006).

5. **CONCLUSION**

Although there are many simulation models that solve maintenance function and sub functional problems, it is clear that asset management simulation models are required by industry to support decisions relating to the whole lifecycle and associated costs. Simulation decision tools now also need to be adaptive to account for the dynamic nature of many complex systems and processes that are currently in use across a wide range of industries. In addition maintenance strategies processes must also be improved to maximise OEE and minimise risk. A philosophy and approach have been presented to be used to develop adaptive, simulation based asset management decision tools with the purpose of achieving the most desirable and robust outcomes whilst minimising commercial risk.

**Figure 6:** Systems representation of a dynamic real time process diagnostics and modelling procedure (van Vooorthuysen et al; 2001)

**REFERENCES**


