REDUCE MAINTENANCE RESOURCES AND INCREASE PLANT AVAILABILITY BY UTILISING WEB-BASED CONDITION MONITORING SYSTEMS AND MARKOVIAN MODELING TECHNIQUES

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ABSTRACT

The purpose of this research is two-fold. Firstly, to decrease maintenance resources and increase plant availability and secondly, to investigate the feasibility of using Web-based condition-monitoring techniques as a preventative maintenance tool. This is achieved by using Markovian modeling and its associated mathematical operations, among other techniques, which in turn leads to the manipulation of the Stochastic Reliability equation to determine the key drivers of poor plant performance. In addition, the findings are elaborated on by applying chaos theory principles and logic.

In this exercise, a Web-based condition monitoring device (Motornostix® Canary) was installed on a critical overhead crane in a pilot plant (ESM) to test the feasibility of the system in the steel production environment. This research also aims to elaborate on the outlook of the current global steel market as well as present the author's views on the topic. To achieve the outcomes of this research, proper methodology and hypotheses were applied to process the information collected and data generated.

The following results of the literature study were amongst the most important:

- The global steel industry is increasingly competitive and the market has changed radically from its previous model[1].
- Traditional "Third-World/Iron Curtain" countries are becoming major players in the global steel industry and the world economic playing field as a whole [2].
- Markovian models are memory-less, discrete and not dependant on the route followed to achieve the current state of the system[3].
- Markovian models are lacking as an application in a chaotic environment as they can only simulate linear systems. Linear systems exist more in theory than in practice. Living systems cannot be equated via linear methods[4].
- The Newtonian paradigm has to be exchanged for a fresh way of approaching maintenance issues[5].

The study has been approached from the perspective that Markovian models do work, if only with a limited degree of predictability over time. However, as has been proven by subsequent findings, Markovian models alone will not suffice in increasing the pilot plant's availability. Intuitive and practical decisions must be applied, in addition, for the outcomes to be both accurate and to impact on business.

It was also noted that failure modes have more than one driver, thus distorting failure and repair rate data into distributions that are not Poison or exponential forms. The inconsistency of the failure rate compounded the difficulty of applying the Markov modeling techniques to this system.

To date, there has been no outside research done on the immediate benefits of implementing Web-based condition monitoring systems. All available papers on the subject have been published by manufacturers of this equipment. Therefore, this research delivers a "third-party" perspective on the effectiveness of these devices as implemented on a pilot plant when used on overhead cranes, whilst quantifying their impact on safety, cost and availability.

The results have proven formidable. Failure rate at the pilot plant was drastically decreased, with no instances of failure (that could have been prevented by this system) occurring during 2006.

Not only was the trial a conclusive success but the application of this technology in other areas of the steel production industry has since begun in earnest.

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2. ACKNOWLEDGEMENTS

The author would like to thank Mittal Steel SA for being permitted to implement the Web-based condition monitoring device on one of their most critical overhead cranes, especially Mr. Sebastien Begue, who helped greatly in this regard.

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To all the superintendents, planners and artisans who shared their extensive knowledge, my sincere gratitude.

3. NOMENCLATURE

CM	Condition Monitoring
EAF	Electric Arc Furnace
ESM	Electric Steel Making
HMI	Human-Machine Interface
HRC	Hot Rolled Coil
IMF	International Monetary Fund
KPI	Key Performance Indicator
MIS	Management Information System
MTBF	Mean Time Between Failure
MTTF	Mean Time To Failure
MTTR	Mean Time To Repair
PLC	Programmable Logic Controller
RCA	Root Cause Analysis
RCM	Reliability Centered Maintenance
SA	South Africa
SecMet	Secondary Metallurgy
VCB	Vacuum Circuit Breaker
WBCM	Web-Based Condition Monitoring

4. OVERVIEW OF RESEARCH

4.1 Background

The global steel industry has undergone rapid metamorphosis in the last twenty years, creating jobs as well as lending security to governments across the world. Now a streamlined profit spinner, the steel industry impresses with its continuous progress.

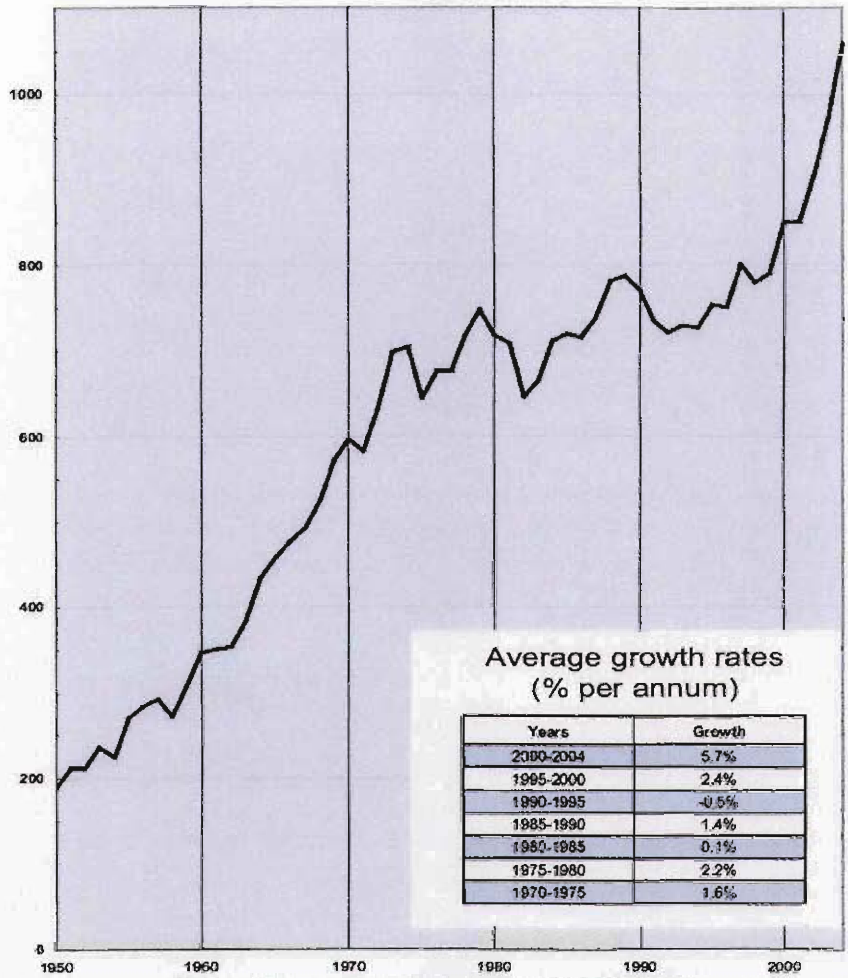
The importance of steel in modern day life cannot be underestimated. *For modern catalytic converters in vehicles to function properly, coiled supports made of special steel foil which is only 0.025mm thick are used. Supplying energy without steel would not even be possible. Steel pipes are used in the production of oil and natural gas in modern power stations. Ten years ago 70% of the steels used in automotive production today did not even exist*[6].

Although composite materials are available on the market they are extremely expensive and difficult to manufacture on the same scale as steel. Steel has been satisfying man's needs for centuries and has the potential to do so for at least the next 50 to 70 years.

In addition to this, steel is now commodity with huge wealth-generating potential. Almost every country in the world, even some of the poorest, has a steel manufacturing plant.

With the global conglomeration of the steel industry which has taken place during the last seven to ten years, the market has changed significantly. The driving force behind these conglomerations has undoubtedly been the purchase of all resources used in the steel production process. A global battle has ensued, in which vast amounts of money are invested in staying ahead of the competition. It can be reasoned that in the fight for monopoly of this insatiable market, players may have lost sight of the fact that steel production is singularly crucial in the development of emerging economies such as India and South America.

The following graph indicates the immense growth in the steel industry which has taken place over the last 55 years[1].



Years	Growth
2000-2004	5.7%
1995-2000	2.4%
1990-1995	-0.5%
1985-1990	1.4%
1980-1985	0.1%
1975-1980	2.2%
1970-1975	1.6%

Figure 1: Annual global steel production ('000 mt)

In December 2005 total global steel production exceeded one billion tons, making history. This figure was unthinkable ten years earlier when the steel industry's growth rate was flat. This resulted in mill closure on a large scale and numerous steel manufacturers joined forces in a bid to survive the downward trend in steel consumption and price[1].

Of the major steel conglomerates formed, the top ten annual crude steel producers are given below[1]:

2004		2003		Comapny
1	46.9	1	42.8	Arcelor
2	42.8	2	35.3	Mittal Steel
3	32.4	3	31.3	Nippon Steel
4	31.6	4	30.2	JPE
5	30.2	5	28.9	POSCO
6	21.4	6	19.9	Shanghai Baosteel
7	20.8	8	17.9	US Steel
8	19	7	19.1	Corus Group
9	17.9	10	15.8	Nucor
10	17.6	9	16.1	ThyssenKrupp

Figure 2: Top 10 global crude steel manufacturers ('000 000t)

With these conglomerates in place, the stage was set for what should still to become a formidable power struggle, not only between steel producers but also between different nations. Most recently the merger of Arcelor and Mittal Steel has resulted in the biggest steel producing company in the world.

What is commonly referred to as the "China Effect" also comes into play. The fact that (see Figure 3[1]) China produces in excess of 270 million metric tons of crude steel per annum is of concern for current steel production giants, as once the Chinese market's demand drops below this capacity it will no doubt seek out alternative markets for export.

	2004		2003	
	Rank	mmt	Rank	mmt
China	1	272.5	1	222.4
Japan	2	112.7	2	110.5
US	3	98.9	3	93.7
Russia	4	65.6	4	61.5
South Korea	5	47.5	5	46.3

Figure 3: Top 5 biggest crude steel producing nations

While China's economy is growing at an astronomical rate (9.9% in 2005)[2], the Chinese government has tried to curb this boom with various measures. The United States has implied that China keeps the value of its currency artificially low in order to boost exports. From a "Cold War perspective" this might seem true. The Chinese government could possibly fear that IMF recommendations to strengthen the currency yet again may destabilise foreign investment. It could be that China is simply experiencing an extreme run of good fortune, or even an economical renaissance of sorts.

Many previously third world countries are experiencing good economic fortune. India's iron and steel industry is likely to double its production in five years[2]. The Indian government has dedicated $15bn towards improving local infrastructure such as roads, bridges, hotels and airports to reposition the country as a global player. With an economic growth rate of 8.1% India also ranks as one of the world's fastest growing economies. The country's demand for steel is growing rapidly; as the strong economic growth has increased the demand for vehicles, household appliances like fridges and building materials[2].

Furthermore, India has the opportunity to export to the lucrative Chinese market which (see Figure 4[1]) is also the largest net importer of steel products. We can also include the Thai and Iranian markets, with which India already has strong economic ties[2].

Rank	Country	Net Imports
1	China	34.7
2	US	13.8
3	Taiwan, China	11.1
4	Thailand	7.6
5	Iran	6.8

Figure 4: Top Five biggest net importers of steel ('000 000t)

Although China is still importing and producing more steel than any country in the world, their local market is now fast approaching a point of saturation. Once this happens, Chinese steel producers will turn to export as a survival tactic. Moving into the mainstream global steel industry will have far-reaching consequences for all players. To date both Chinese and Indian steel manufacturers have been operating in near isolation. The challenges they currently face – dwindling natural resources, skills shortages and access to new technology – will make competing in the global market a formidable challenge.

By opening up their borders for export, which is inevitable at such high growth rates, the Chinese and Indian steel producers open themselves to conglomeration fuelled by the larger global manufacturers. Small producers are unlikely to cope with the global market and, owing to dwindling consumption forecasts, will inevitably sell out; literally and figuratively. Conglomeration of these smaller companies will further strengthen the hold that global steel producers have on potential buyers. A situation is likely to arise were 80% of the world's steel will be manufactured by as few as four major corporations.

Fact: the steel industry is on its way to becoming a billion-Dollar business[1]. As seen from figure 5, the world steel production is an industry valued at almost US $800 million. This figure is increasing year-on-year as producers improve on decades-old processes, something which they manage to do with the lowest possible capital expenditure.

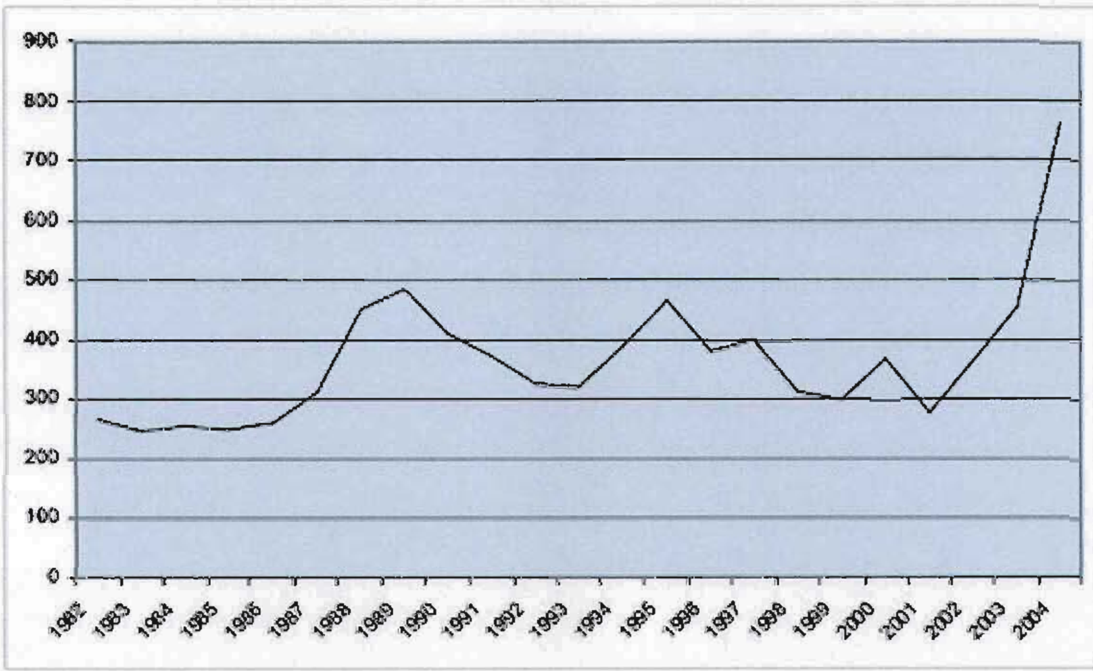


Figure 5: Estimated value of world steel production (US$ billion)

With these cost-cutting initiatives in place, margins and profits climb exponentially as steelmakers become increasingly efficient. It must be questioned whether this surge in profits has a ceiling, or is this potential for profit limitless?

With manpower cut down, efficiencies streamlined and under control, the next "money machine" has been discovered: by exploiting inefficiencies in the maintenance environment, resourceful companies have generated false profits.

Traditionally, the maintenance environment has been perceived by steel producers as something of a bottomless pit into which money has been thrown. It is extremely difficult to manifest throughput with no equipment or hardware resources to support the business. If the maintenance section fails, the business fails.

In their efforts to further increase profits, steel producers have realised that a plant can no longer afford to have cyclical availability trends. Emphasis must be placed on optimising the maintenance environment to promote growth and sustained availability. Large spikes in plant availability influence production yields, efficiencies and throughput. These factors will, in turn, affect the bottom line of the company.

The "Holy Grail" of maintenance management would therefore be to predict impending failures 100% accurately and prevent them.

In order for this obstacle in the way of maximising profits to be scaled, it is imperative that companies expend resources in order to explore all aspects of their maintenance management prerogatives. While there are various means of exploring these options, the most common method is to simply rely on the tried and tested.

Currently management makes decisions concerning the future of their maintenance sections based on what can be termed as educated mistakes i.e. trial and error.

The cutting down and scrapping a spare crane at ESM in the 1980s is a good example of such a mistake. This was based on a decision that a third crane was not a necessity for the company at the time. While breaking down the crane and saving its parts as spares for the two remaining cranes would have been a wiser choice, in retrospect, the cheaper option of lancing the machinery was decided on. Now, 20 years later, charging capacity is one of ESM's greatest bottlenecks. For a minimal cost, and significant risk reduction, the crane gantries, bogies, wheels, motors, etc could have simply been stored neatly away.

While the cost-saving drive inevitably saved ESM from closure, this is a good example of how hasty cost reductions can have a negative affect on future plant performance.

The proper methodology to follow would entail cutting costs, streamlining budgets, pooling resources and working smarter - not harder - through employing various tools, such as emerging technologies.

If done correctly the restructuring undergone by maintenance sections will have far-reaching improvements, not only on the bottom line, but on the company as a whole.

4.2 Problem Statement

The focus of this research is to reduce maintenance resources and increase plant availability. The maintenance strategy currently used is based on Reliability Centered Maintenance (RCM).

Maintenance is both an art and a science. By looking at raw data and making decisions based on proven tools, results can be achieved immediately, with little or no capital expenditure. Unfortunately, few maintenance managers have time to crunch numbers.

For this reason an objective, experienced specialist on the team is crucial for any maintenance manager. This impartial individual is a one who can take action, exploit the data and manage the soft issues. The individual must have the ability to separate emotion from experience when necessary, and put them together when required.

With some capital expenditure it is indeed possible to implement new technologies which will reduce maintenance resources and increase plant availability in general. It is, however, important to constantly track the plant's performance against the desired result. This can prove difficult in the maintenance environment, as most plants only know their availability at the end of the month.

Once data is made available and the previous month's performance tracked, decisions need to be made on the way forward. To execute this, a tool is required to analyse the incoming data and make reliable assumptions based on the outcome - a tool such as the use of Markovian models.

Another focus point will be assessing the efficiency of Web-based condition monitoring devices such as the system supplied by Motornostix. This device reduces the strain on conventional physical condition monitoring resources. By using the Internet as a portal to transfer information, it is possible to have an outside company monitoring the condition of an overhead crane at a distance of more than 1 000km.

4.3 Hypotheses

Reducing resources and increasing availability (as well as utilisation) is a global challenge. Testing the applicability of Markovian models and WBCM in an environment where all the necessary equipment was available posed a challenge. The Electric Arc Furnace melt shop was suggested.

The Electric Arc Furnace melt shop, situated in Vanderbijlpark, had a budgeted tonnage of 990 594 tons for 2005. In 2006 the budgeted tonnage was 1 167 916 tons. In 2007 it will tip the scales at 1 345 000 tons. The pressure to increase production tonnages year-on-year is immediately apparent. The only method for increasing plant capacity is to optimise plant availability - but this implies an equal improvement in utilisation; in this case, the utilisation of funds and manpower available to the maintenance department.

A healthy business should concentrate on analysing and optimising their maintenance workforce. Any decision made in the maintenance environment must be based on sound business principles. The question must be asked: "Does the decision have a *positive financial* impact on the business?"

To disprove the belief that plant availability is directly proportionate to the availibility of the maintenance department's funds and manpower consider, the table below:

YEAR	TONNAGE PRODUCED	ACTUAL EXPENDITURE	HEADCOUNT
2001	996,600	31,840,746.79	431
2002	1,018,733	29,868,071.12	398
2003	478,391	13,912,464.49	370
2004	1,155,782	37,293,927.05	344
2005	1,048,701	45,104,241.21	314
2006	1,167,916	35,452,970.20	237

Figure 6: Actual tonnage vs expenditure and headcount (Expenditure excludes capital expenditure and salaries)

The data depicted above might seem random but a broader looks reveals that market conditions, ad-hoc expenditures and activity are additional factors that play a role in defining cost per ton. These stats need to be analysed and updated regularly to maintain perspective.

A reliable system is needed to identify poor performance drivers. Markovian models have proven useful in the past. Their applicability in the steel making environment will be investigated here.

In summary the aim will be to reduce maintenance costs and resources whilst increasing plant availability by implementing both Markovian models and WBCM at the pilot plant.

4.4 Objectives

The aim with this research is to answer many plant related and maintenance specific questions. In the author's experience the only time a major investigation is launched, is when capital funds are required. Employees no longer launch investigations into their own functions in order to identify inefficiencies. The stresses placed on employees through rapid restructuring and skills shortages have forced them to focus on day-to-day activities. The advantages of raising the bar and focusing on inefficiencies cannot be underestimated.

Using Markovian models, it will be possible to assess various aspects of the ESM maintenance environment. By utilising failure rate, repair rates and defining certain states that the system can be found in it is possible to model and assess poor performance drivers. The parameters that most influence the behavior of the system are modeled and monitored. This will allow the modeler to identify changes and their affect within the system.

The Markovian models will, however, only indicate inefficiencies. They do not offer solutions. It gives an indication of where there are shortcomings and describes them in more detail. How these shortcomings are to be eliminated can only be defined by someone with intimate knowledge of how the business operates. This can only be achieved by an individual with a solid maintenance background, skilled in the production process and knowledgeable of the financial pitfalls along the road.

Most of us have vehicles and appliances that can "think for themselves". They can identify and diagnose early signs of failure, shut off before catastrophic failures occur and even repair themselves relevant to certain inputs and outputs. What isn't realised is that this is applicable to any system.

From a systems perspective, there is no difference between a vehicle and a steel making plant. Yet we have not adequately investigated the extent to which new condition monitoring technology can contribute.

By using Web-based condition monitoring systems it is possible to prove that diagnostic and early-warning systems have their place in heavy industry. Iscor (now Mittal Steel SA) implements a screw limit on overhead cranes. This is a measure taken over and above the final cut-off limit to ensure safety. The only limit prescribed by government safety standards is the final cut-off limit[19]. This research aims to prove that Web-based condition monitoring systems should be a statutory institution on certain safety critical plants.

By incorporating a Web-based system that indicates plant abuse, early failure warnings and preventative measures, it is possible to initiate a preventative maintenance strategy.

This will also be used as a case study for general Web-based condition monitoring, which has not been implemented elsewhere in the steel making environment. Historically speaking the costs associated with such an installation normally deters the client from such an endeavor. This study will attempt to prove the claims made concerning the positive aspects of installing this technology on essential equipment.

The electric steel making plant of Mittal Steel South Africa in Vanderbijlpark was the perfect pilot for such a project. The plant is extremely accommodating, not only on the process side, and also has a flexible maintenance team willing to experiment in order to improve their environment.

5. METHODS AND PROCEDURES

5.1 Traditional methods

A common tool used to investigate methods of identifying the drivers behind plant availability is the Markovian model or chain. This stochastic process was developed by Andrey Andreyevisch Markov (June 14, 1856 - July 20, 1922), a Russian mathematician born in Ryazan, Russia. Markov completed his studies under Chebyshev in 1874 after which he became a member of the St. Petersburg Academy of Science in 1886 [7].

A Markov chain is a stochastic process that possesses the Markov property. A process is Markovian if the probability of future states depends solely upon the current states [7]. In other words, the route followed to arrive at the current state is of no significance to the probability of entering a future state. An example of a Markovian process is a game of Snakes and Ladders. The previous position does not influence the probability of entering a certain new position on the board.

Stochastic modeling in its simplest form is indicative of a prediction of a possible set of outcomes weighted by their likelihoods or probabilities. The model must allow deduction of predictions as well as possible implications of the phenomena at hand [3].

Markov chains are discrete and Markov processes are continuous. A Markov chain is a function of elapsed mission time. It seems evident that to apply the Markov theory to this specific problem it needs to be applied as a Markov process. The Markov process functions as a memory-less system.

The system must be well understood if it is to be modeled. As will be explained in the theory, it is important to assume a constant failure rate. Other important factors to be remembered when modeling a system are the following:

- The sum of the probability of the system going from one state to another must equal unity[8].

- Starting conditions do not govern the probability of going from one state to another. In other words the system is not hypersensitive to initial conditions[8].
- Markov model is only applicable to a system which vary discretely or continuously over time[8].
- The probability of going from one state to another stays constant over time[8].
- Markov chains can only be applied to systems with exponential or Poison failure rate distributions[8].
- The different states must be identifiable[8].

This intriguing modeling process only applies under certain conditions, which are given above. However these conditions raise certain questions.

The Newtonian paradigm is based upon the fact that everything in the natural world can be explained by breaking it down into smaller pieces. This is called reductionism. Reductionism is the common denominator in all modeling techniques. It simplifies modeling a system as well as reducing the degree of calculability.

The Newtonian Paradigm states that the enormous diversity of things can be reduced completely and perfectly to nothing more than the effects of some limited framework of laws. Any future state of a system can be calculated; if the forces acting on the system are known as well as the initial conditions the system starts up under. LaPlace stated that: "*If the underlying quotations were all known, with absolute precision, no behaviors or outcome would be unpredictable*"[5]. Furthermore the Newtonian paradigm states that the natural state of a system is equilibrium[9].

There is more than one type of paradigm concerning the way the natural can be explained. The Complexity paradigm uses systemic enquiry to build fuzzy, multi-level and multi-disciplinary representations of reality. Traditionally science has led us to believe that the natural state of a system is equilibrium. This implies that a system, which is perturbed, will come to rest at some point in time. The second law of thermodynamics states that a system's entropy will not decrease over time.

The concept of chaos theory has existed since the early 60s. Chaos theory, in its essence, describes the following three points:

- Observed randomness may not be randomness at all[5].
- A simple deterministic system may have limited predictability[5].
- A system can move from equilibrium to chaos through not only changing its structure but its parameters as well[5].

Chaos theory has found ways (primarily grounded in topology) to discover deep and complex patterns in random data.

Markovian processes are not applicable to chaotic systems. Yet chaotic systems in themselves are not inherently chaotic. An oxymoron of sorts, chaotic systems will be more attracted to certain points in a state space diagram. These are called strange attractors[9]. Thus there is method in the madness. This will be proved, when analysing delay frequency and duration.

Trying to define chaos theory is like trying to grasp gelatin: "*It is easy to see that there is some substance there; that the substance has some specific form, and it appears solid. When one tries to actually pick it up, however, it quickly becomes a challenge to manage and is transformed into a very different substance than it appeared while sitting in the plate*" (Chamberlain as quoted in McLure, 1998) [4].

Linear systems exist more in theory than in practice. Sensitive dependence on initial conditions is what defines a chaotic system. Lorenz (well known instigator of the "Butterfly Effect") noted that "crisis points" or critical turning points exist in every natural system. In linear systems input is proportional to output. In non-linear systems very little input can generate large amounts of output. All kinds of different scenarios can manifest themselves when different systems start to interact. Formally the focus of chaos theory is on the manner in which simple linear systems give rise to complex unpredictable behavior[10].

Yet this can be eliminated from the Markov process as the regenerative nature of maintenance (i.e. replacement or repair of damaged equipment) inhibits the sensitivity of the system to start-up conditions[17].

Chaos theory simply illustrates the immense complexity of certain systems. Systems can be so difficult to manage that they become almost incomprehensible and uncontrollable. Only by investing significant quantities of resources will it be able to be concretely modeled as the given reality. Thus a certain amount of error is to be expected taking the chaos paradigm into account.

Yet popular literature illustrates the fact that analytical data and simulations deliver equal results when comparing reliability parameters[9]. Thus this research will not attempt to prove that analytical and modeling tools have similar results. It will rather attempt to display the usefulness of the Markovian process in making informed maintenance-related decisions.

There is thus a huge paradigm shift which needs to be made in the way the electric steel making route determines its shutdown frequency. Things need to be done differently, by a huge amount of people before a positive outcome is achieved. This in itself is an admirable feat to achieve. Yet it will be the key factor in determining the success of the maintenance strategy followed in that specific area.

The Markov chain uses and approximation of a system as depicted by the various states that it can be found in. The transitions between these states are depicted by the mean-time-to-failure (MTTF) and the mean-time-to-repair (MTTR) between different states. This is a Newtonian way of thinking and has its drawbacks. The fact that these arc furnaces are run by operators is reason enough to question the Newtonian paradigm. Individual's actions cannot be calculated and estimated. Elements such as vandalism, indifference or error cannot be calculated with pinpoint precision.

Artisans can be especially concerned with these unpredictable elements. They are employed to deliver highly technical precision outputs. Non-conformance should be, within reason, dealt with strictly. Given that an artisan has all the correct tools (i.e. equipment, training and authority) there is no reason why a job cannot be done correctly the first time in keeping with the technical output.

Yes, maintenance management is both a science and an art, but inevitably there will always be unknowns in such a scenario. The reason for this is that the Newtonian paradigm does not, and cannot, take into account the forces acting upon a system with absolute certainty[9]. The notion that a system can be completely described by describing the sum of its parts is ludicrous - especially when the system is a roaring monster capable of spewing forth 150t of molten steel every 126 minutes. Such a system is constantly leaning away from equilibrium and teetering on the edge of chaos. Even a simple system may have limited predictability over time. Minor changes brought about in the system are can be hugely amplified over time. This inadvertently blocks out any meaningful results obtained from such trials.

Human intervention is one of the methods used to force a system back to equilibrium. For example: if left unchecked a plant will run to failure. By following a maintenance procedure or plan it is possible to retain the equilibrium between throughput and availability.

It will be possible to discover the strange attractors for the furnaces by sifting through the delays occurring on a day-to-day basis. The bifurcations brought about in a system may be man-made. These changes can have a profound effect on the system's behavior. One should embrace change and learn from past mistakes, especially recurring ones. Identify the problems that can be eliminated by expending the least capital possible. It is important to listen to the customer.

A statement made by *Ocon: "Production must pay for certain items; not maintenance*[11]" is in this author's opinion not completely viable. This will diffuse costs and make benchmarking between plants extremely difficult.

For the purpose of this dissertation the Markovian modeling method will be used to attempt and model the drivers behind poor performance on the plant.

5.2 State-of-the-art methods

The use of condition monitoring in order to predict failure of certain equipment is by no means a new concept. The incorporation of the Internet into such a project has delivered exciting results. By incorporating the Web as a method of transporting data, companies such as Motornostix® have been doing interesting work in the field of preventive and especially predictive maintenance.

The system is made up of a Motornostix® scanner unit, Canary data acquisition unit, a wireless data link and cabling. The function of the scanner is to collect data from the canary units which are then sent back to the centralised Motornostix® database via the Internet. The Canary units can each monitor nine channels of vibration, three channels of motor current, one tacho channel, four temperature channels and has three uncommitted channels. The Wi-Fi radio link transfers data from the Canary unit to the scanner.

The manufacturers of this equipment claim[12] the following benefits:

- Improved plant availability
- Improved plant reliability
- Improved operator behavior
- Early detection of detail equipment failures, i.e. motor and gearbox failures
- Motor and shaft misalignment
- Loose couplings and mountings
- Bearing failure
- Overload event count

What makes the Motornostix® system so attractive is that the data is crunched by a third party. This implies that no biased recommendations are made. This aids the maintenance manager in determining proper preventative actions that need to be taken on a crane. Maintenance frequencies and plans on a crane can be adjusted using data obtained from that specific piece of equipment, and are not simply based on experiences with "similar" cranes.

According to the supplier the cost of collecting and analysing this data is justified when considering, for instance, the cost of reconditioning one damaged motor that could be prevented using this system. The question, however, is does the performance of the Motornostix™ system really meet the supplier's claims? How accurate is their reporting, and does have the potential to improve plant availability? If it does, is the cost of third-party data crunching showing a return on the service fee charged by the party in question?

In order to test this it will be necessary to install this system on a plant in the steel making environment. We have chosen an essential ESM overhead crane as the pilot plant. At the ESM route there is a hot metal crane which is critical to plant throughput.

Crane 379 is the only crane that can pick up a ladle and place it on the turret of the caster. Without this crane all operations at ESM come to a grinding halt. Therefore there is no place for error when it comes to this specific crane's maintenance.

By comparing the current availability of the crane with its availability before the Motornostix™ installation, one can make various deductions. The bulk of these relate to profitability. If the system can prevent one catastrophic failure, it is possible (taking into account the costs of lost production and equipment damage) that money could have been saved.

For the purposes of this dissertation the Motornostix® system will be used as a state-of-the-art method to establish whether or not WBCM is feasible in the steel making environment.

6 LIMITATIONS OF CHOSEN METHODS AND PROCEDURES

6.1 Traditional methods

The biggest limitation of the Markovian process is the sense of incorrect modeling. According to chaos theory principles as illustrated earlier, a chaotic world cannot be modeled according to Newtonian principles. If the modeling process is to be at all accurate certain criteria have to be present.

The system must not be exponentially dependant on initial conditions. If, after a shutdown, processes start up wrong, they normally stay that way or become worse until the next off day. It is important to remember that if the time between heats is utilised properly the inherent reliability of the furnace can be increased. This changes the scenario significantly.

6.2 State-of-the-art methods

Web-based condition monitoring also has its limitations. It cannot be installed on a charging crane. The flames and excessive heat generated by the charging cranes will damage not only the probes and sensors, but the cabling as well.

However the most limiting factor of such a system is how it is integrated into the rest of the plant. Monitoring cranes will not be successful on its own. This system, or the principle behind it, needs to be integrated into most mechanical equipment. The third party monitoring will be fruitful if monitoring equipment on a 24-hour basis.

Not all equipment can be monitored in this way. The cost of running such a system is astronomical. Only the most critical equipment can therefore be monitored on this basis. This will ensure that the system is still feasible and economically viable to operate. The greatest advantage of WBCM is that it can model a chaotic environment from a real time perspective. This allows the strange attractors, or probable failures to be identified earlier.

7 MARKOVIAN MODEL RESULTS

7.1 Procedure for gathering data

The data utilised in these graphs originates from the MIS (Management Information System), incorporated into the ESM plant during 2002. It is a very powerful tool that helps management track and monitor movement of product through the plant. Moreover it tracks quality, input material and almost any other KPI in a real time mode. Analysis can be drawn from the application and up-to-date decisions made regarding various process variables.

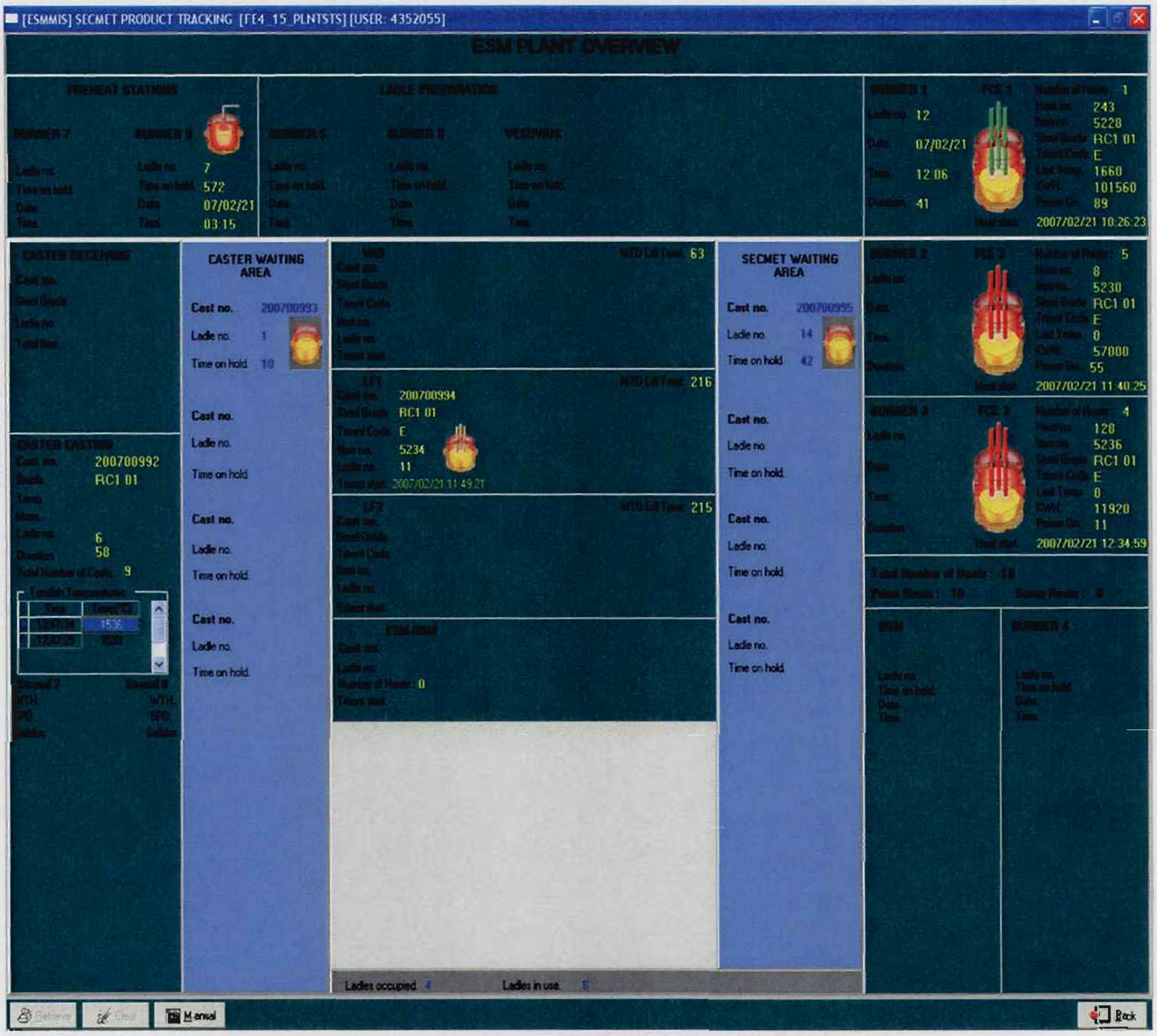
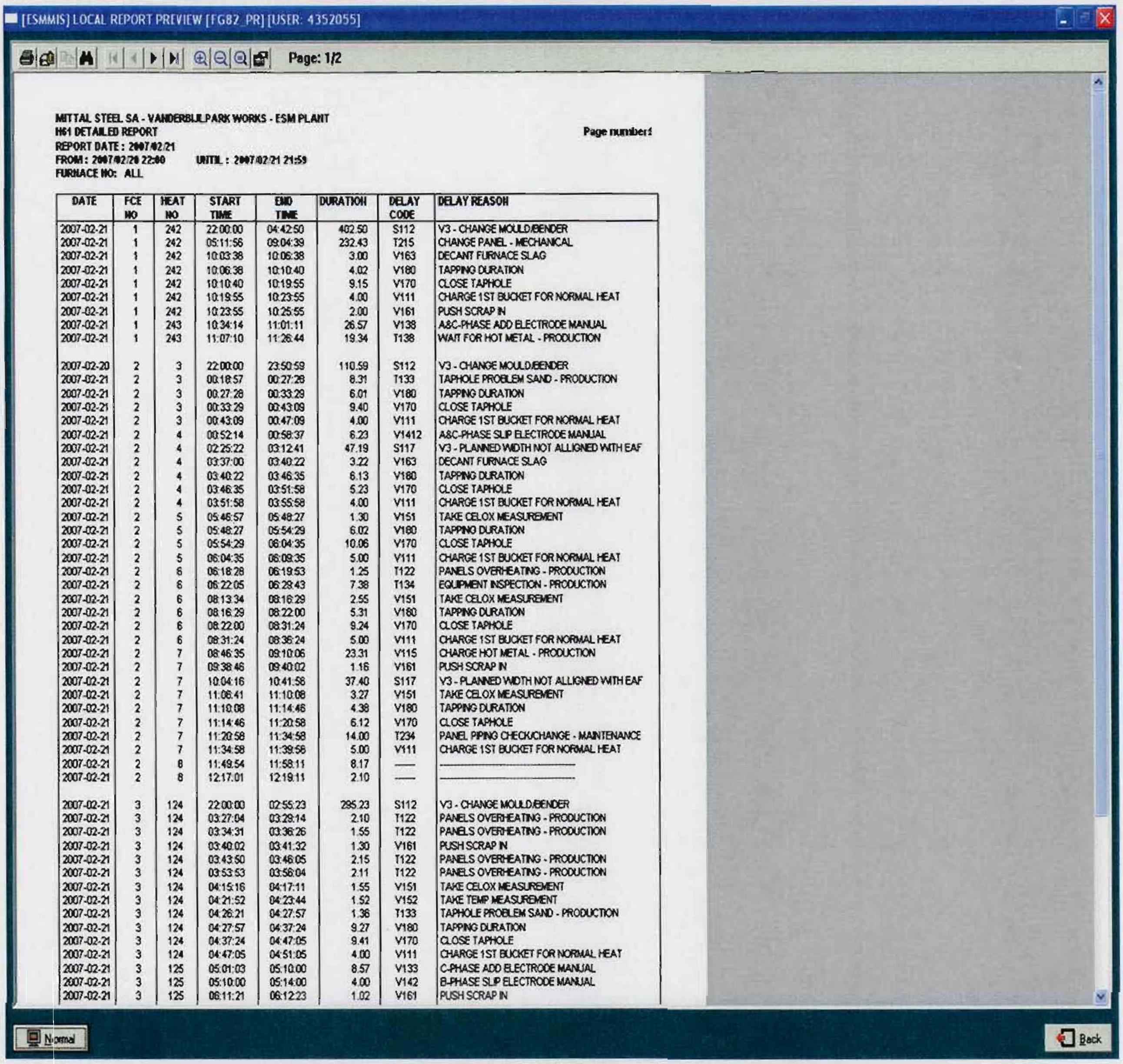


Figure 7: MIS Plant overview screen showing EAF condition (right), SecMet ladle treatment condition (middle) and caster condition (left)

The variables associated with the process of steel making, as well as the maintenance delays, are tracked. Every time the EAF does not have any power in the furnace (with VCB open or closed) the PLC system acknowledges this and a delay pops up on the operator's HMI. A dropdown menu is then initialised. This dropdown allows the operator to choose one of the many explanations why the EAF may be delayed from arcing. The delays are grouped into the following major categories:

- Production delays – tapping, charging, joining electrodes, etc.
- Maintenance delays – panel leaks, off gas problems, etc.
- Refractory delays – gunning, fettling, etc.
- External delays – air products delays, Eskom power dips, etc.

The beauty of the MIS is that it encourages the operator to account for the lost time on the furnace. It is also a very powerful management tool in the sense that it allows critical plant performance parameters to be measured, tracked and assessed in reports that are easily accessible and understandable.



[ESMMIS] LOCAL REPORT PREVIEW [FG82_PR] [USER: 4352055]

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MITTAL STEEL SA - VANDERBIJLPARK WORKS - ESM PLANT
H61 DETAILED REPORT
REPORT DATE : 2007/02/21
FROM : 2007/02/20 22:00 UNTIL : 2007/02/21 21:59
FURNACE NO: ALL

Page number1

DATE	FCE NO	HEAT NO	START TIME	END TIME	DURATION	DELAY CODE	DELAY REASON
2007-02-21	1	242	22:00:00	04:42:50	402.50	S112	V3 - CHANGE MOULD/BENDER
2007-02-21	1	242	05:11:56	09:04:39	232.43	T215	CHANGE PANEL - MECHANICAL
2007-02-21	1	242	10:03:38	10:06:38	3.00	V163	DECANT FURNACE SLAG
2007-02-21	1	242	10:06:38	10:10:40	4.02	V180	TAPPING DURATION
2007-02-21	1	242	10:10:40	10:19:55	9.15	V170	CLOSE TAPHOLE
2007-02-21	1	242	10:19:55	10:23:55	4.00	V111	CHARGE 1ST BUCKET FOR NORMAL HEAT
2007-02-21	1	242	10:23:55	10:25:55	2.00	V161	PUSH SCRAP IN
2007-02-21	1	243	10:34:14	11:01:11	26.57	V138	A&C-PHASE ADD ELECTRODE MANUAL
2007-02-21	1	243	11:07:10	11:26:44	19.34	T138	WAIT FOR HOT METAL - PRODUCTION
2007-02-20	2	3	22:00:00	23:50:59	110.59	S112	V3 - CHANGE MOULD/BENDER
2007-02-21	2	3	00:18:57	00:27:28	8.31	T133	TAPHOLE PROBLEM SAND - PRODUCTION
2007-02-21	2	3	00:27:28	00:33:29	6.01	V180	TAPPING DURATION
2007-02-21	2	3	00:33:29	00:43:09	9.40	V170	CLOSE TAPHOLE
2007-02-21	2	3	00:43:09	00:47:09	4.00	V111	CHARGE 1ST BUCKET FOR NORMAL HEAT
2007-02-21	2	4	00:52:14	00:58:37	6.23	V1412	A&C-PHASE SLIP ELECTRODE MANUAL
2007-02-21	2	4	02:25:22	03:12:41	47.19	S117	V3 - PLANNED WIDTH NOT ALLIGNED WITH EAF
2007-02-21	2	4	03:37:00	03:40:22	3.22	V163	DECANT FURNACE SLAG
2007-02-21	2	4	03:40:22	03:46:35	6.13	V180	TAPPING DURATION
2007-02-21	2	4	03:46:35	03:51:58	5.23	V170	CLOSE TAPHOLE
2007-02-21	2	4	03:51:58	03:55:58	4.00	V111	CHARGE 1ST BUCKET FOR NORMAL HEAT
2007-02-21	2	5	05:46:57	05:48:27	1.30	V151	TAKE CELOX MEASUREMENT
2007-02-21	2	5	05:48:27	05:54:29	6.02	V180	TAPPING DURATION
2007-02-21	2	5	05:54:29	06:04:35	10.06	V170	CLOSE TAPHOLE
2007-02-21	2	5	06:04:35	06:09:35	5.00	V111	CHARGE 1ST BUCKET FOR NORMAL HEAT
2007-02-21	2	6	06:18:28	06:19:53	1.25	T122	PANELS OVERHEATING - PRODUCTION
2007-02-21	2	6	06:22:05	06:29:43	7.38	T134	EQUIPMENT INSPECTION - PRODUCTION
2007-02-21	2	6	08:13:34	08:16:29	2.55	V151	TAKE CELOX MEASUREMENT
2007-02-21	2	6	08:16:29	08:22:00	5.31	V180	TAPPING DURATION
2007-02-21	2	6	08:22:00	08:31:24	9.24	V170	CLOSE TAPHOLE
2007-02-21	2	6	08:31:24	08:36:24	5.00	V111	CHARGE 1ST BUCKET FOR NORMAL HEAT
2007-02-21	2	7	08:46:35	09:10:06	23.31	V115	CHARGE HOT METAL - PRODUCTION
2007-02-21	2	7	09:38:46	09:40:02	1.16	V161	PUSH SCRAP IN
2007-02-21	2	7	10:04:16	10:41:56	37.40	S117	V3 - PLANNED WIDTH NOT ALLIGNED WITH EAF
2007-02-21	2	7	11:06:41	11:10:08	3.27	V151	TAKE CELOX MEASUREMENT
2007-02-21	2	7	11:10:08	11:14:46	4.38	V180	TAPPING DURATION
2007-02-21	2	7	11:14:46	11:20:58	6.12	V170	CLOSE TAPHOLE
2007-02-21	2	7	11:20:58	11:34:58	14.00	T234	PANEL PIPING CHECK/CHANGE - MAINTENANCE
2007-02-21	2	7	11:34:58	11:39:58	5.00	V111	CHARGE 1ST BUCKET FOR NORMAL HEAT
2007-02-21	2	8	11:49:54	11:58:11	8.17	——	——————————
2007-02-21	2	8	12:17:01	12:19:11	2.10	——	——————————
2007-02-21	3	124	22:00:00	02:55:23	295.23	S112	V3 - CHANGE MOULD/BENDER
2007-02-21	3	124	03:27:04	03:29:14	2.10	T122	PANELS OVERHEATING - PRODUCTION
2007-02-21	3	124	03:34:31	03:36:26	1.55	T122	PANELS OVERHEATING - PRODUCTION
2007-02-21	3	124	03:40:02	03:41:32	1.30	V161	PUSH SCRAP IN
2007-02-21	3	124	03:43:50	03:46:05	2.15	T122	PANELS OVERHEATING - PRODUCTION
2007-02-21	3	124	03:53:53	03:56:04	2.11	T122	PANELS OVERHEATING - PRODUCTION
2007-02-21	3	124	04:15:16	04:17:11	1.55	V151	TAKE CELOX MEASUREMENT
2007-02-21	3	124	04:21:52	04:23:44	1.52	V152	TAKE TEMP MEASUREMENT
2007-02-21	3	124	04:26:21	04:27:57	1.36	T133	TAPHOLE PROBLEM SAND - PRODUCTION
2007-02-21	3	124	04:27:57	04:37:24	9.27	V180	TAPPING DURATION
2007-02-21	3	124	04:37:24	04:47:05	9.41	V170	CLOSE TAPHOLE
2007-02-21	3	124	04:47:05	04:51:05	4.00	V111	CHARGE 1ST BUCKET FOR NORMAL HEAT
2007-02-21	3	125	05:01:03	05:10:00	8.57	V133	C-PHASE ADD ELECTRODE MANUAL
2007-02-21	3	125	05:10:00	05:14:00	4.00	V142	B-PHASE SLIP ELECTRODE MANUAL
2007-02-21	3	125	06:11:21	06:12:23	1.02	V161	PUSH SCRAP IN

Normal

Back

Figure 8: MIS report on EAF delays per furnace (Maintenance and Production combined)

The biggest advantage of the MIS is that it allows easy access to all delays on the furnace. On the other side of the scale is the SAP notifications system. Although much more detailed than the MIS system, the SAP system has drawbacks which will be elaborated on later.

The SAP system allows the user to log various data attributed to a specific delay. Equipment function, location, start and end time, long text relating to the incident and RCA (Root Cause Analysis) functionality is some of the information that can be captured in the

M3 Malfunction Report feature available in the SAP system.

The problem is that the M2 (equipment breakdown not associated with delay) and M3 (equipment breakdown associated with a delay) are only completed by the millwright. The flow diagram is as follows:

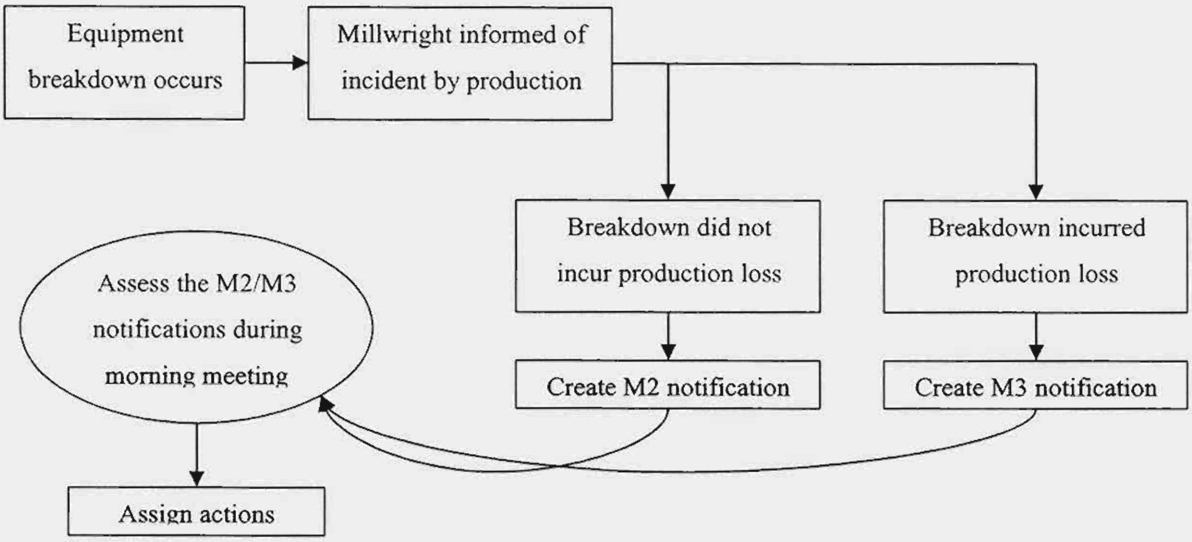

Figure 9: Schematic presentation behind rationale of M2/M3 creation

Thus the millwright is the only individual that creates M2/M3 notifications as their main function is delay management. However, they do not log the following in their shift report:

- Incidents where faulty equipment was rectified by the production employee of which they were not aware.
- Small nagging faults (such as VCB trips or where the operator has a fault reset button) which does not necessitate the help of a millwright.
- Faults that go unreported.

This is the reason why it was decided that the MIS delays would be used for the purpose of this exercise. They are a real-time indication of what is happening at the furnace. The other advantage is that the data is more accessible as it is extracted in a Microsoft Excel spreadsheet. The SAP notifications cannot be drawn into an Excel spreadsheet directly from SAP and need various manipulations to get the data in an acceptable format.

The data was extracted from the MIS and subsequently analysed.

7.2 Data Analysis

The data stored in the MIS can be extracted to Excel by calling up and dumping a tag. The period for which the data can be extracted is determined by the user. For the purpose of this study, a year was chosen as an exemplary set of data. The reason being that:

- Sampling size is adequate (2 470 incidents)
- Time between first and nth sample is sufficient to eliminate any unwanted noise in the data (one year)
- Three similar furnaces are modeled collectively and individually

The biggest challenge when manipulating this data was the tag does not dump the date and time into a single cell. Thus all date differences and durations between two times had to be calculated. After consulting the Internet[13] an easy solution was found. By subtracting days and multiplying the difference with 1 440 minutes, the amount of minutes could be calculated. When finding the difference between the two times that the events occurred (i.e. duration) it becomes more complicated.

This was overcome by manipulating the data and using formulas to depict the data in a way that was easily readable.

The descriptive statistics were derived from the data and can be reported as follows:

MTTR	*EAF1*	*EAF2*	*EAF3*
Mean	28.91	37.38	33.35
Median	10.15	16.34	13.00
Standard Deviation	57.06	68.16	81.28
Range	483.49	1110.24	1394.02
Sum	29290.74	30280.51	23443.86
Count	1013.00	810.00	703.00

Figure 10: MTTR descriptive statistics

MTBF	EAF1	EAF2	EAF3
Mean	282.26	375.19	409.19
Median	128.00	199.00	237.50
Standard Deviation	354.21	409.83	428.60
Range	1439.00	1438.00	1436.00
Sum	281692.00	296402.00	279065.00
Count	998.00	790.00	682.00

Figure 11: MTBF descriptive statistics

The following graphs were generated to depict the frequency at which MTTRs and MTBFs of a certain magnitude are represented in the data per EAF. The MTTR and MTBF were calculated according to the following guidelines:

- The first incident recorded for the year has a MTTR but no MTBF.
- The MTBF for incident one cannot be calculated as it is the 1st data point in a series of *n* data points. With *n* data points one will only have *n – 1* MTBFs.
- For this set of data there are refractory rebuilds built into the EAF campaign. Thus the first incident after a rebuild will have a MTTR but not a MTBF as it is the first incident.

The graphs were recorded as follows:

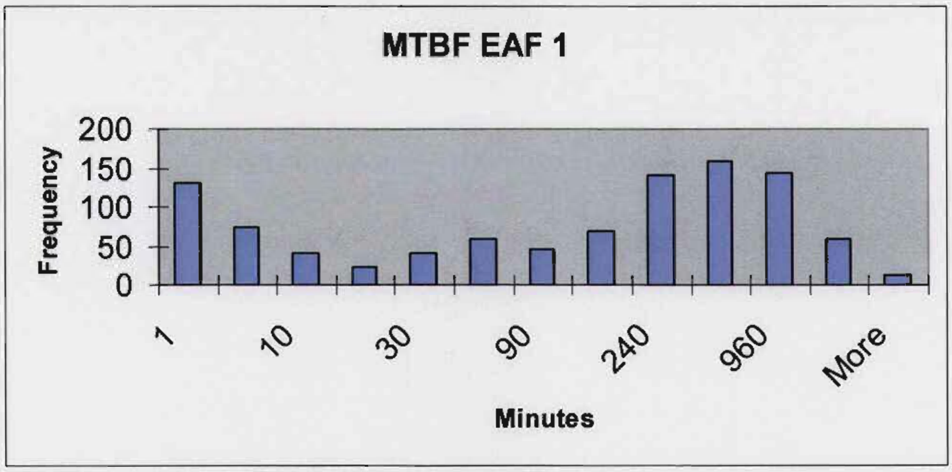

Figure 12: MTBF Histogram EAF1

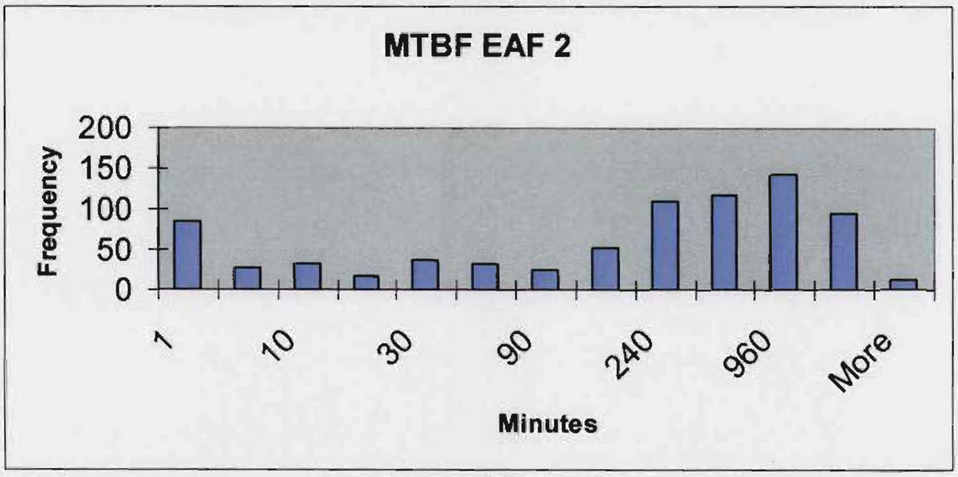

Figure 13: MTBF Histogram EAF2

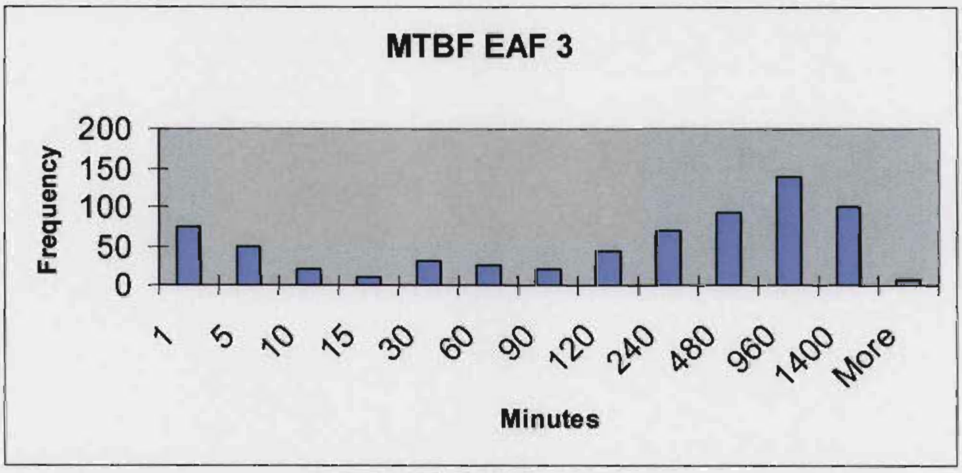

Figure 14: MTBF Histogram EAF3

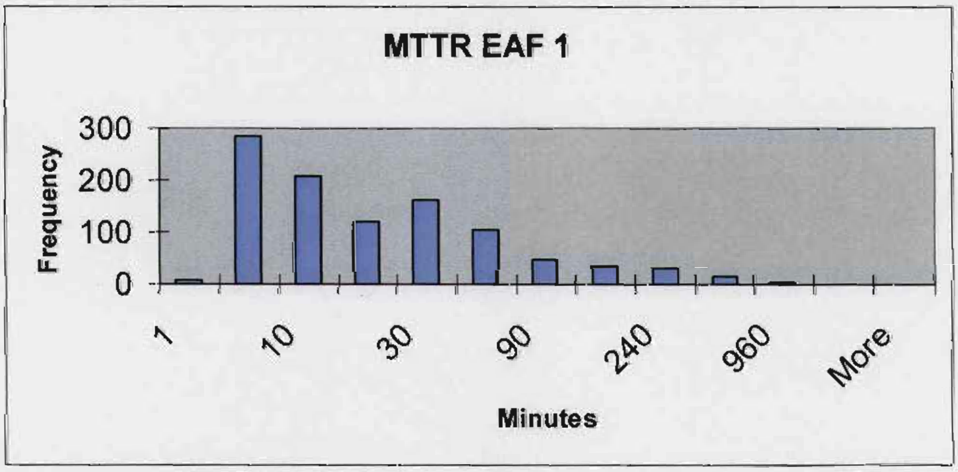

Figure 15: MTTR histogram EAF1

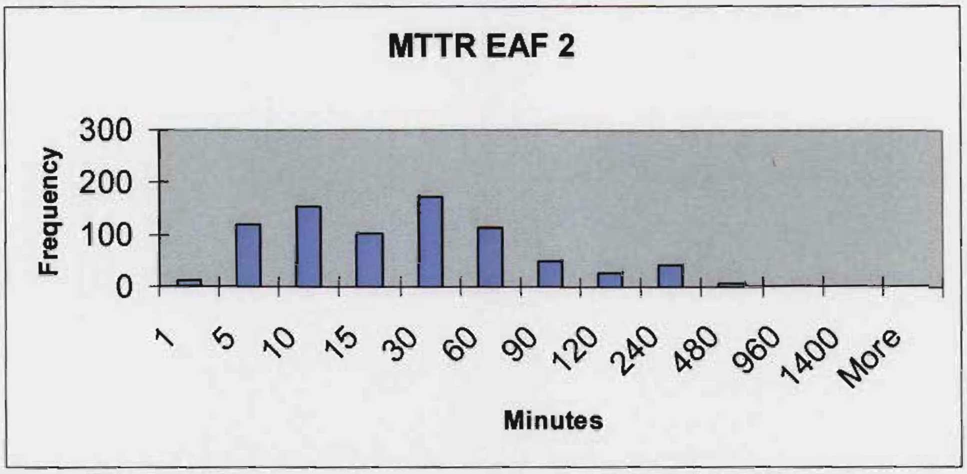

Figure 16: MTTR histogram EAF2

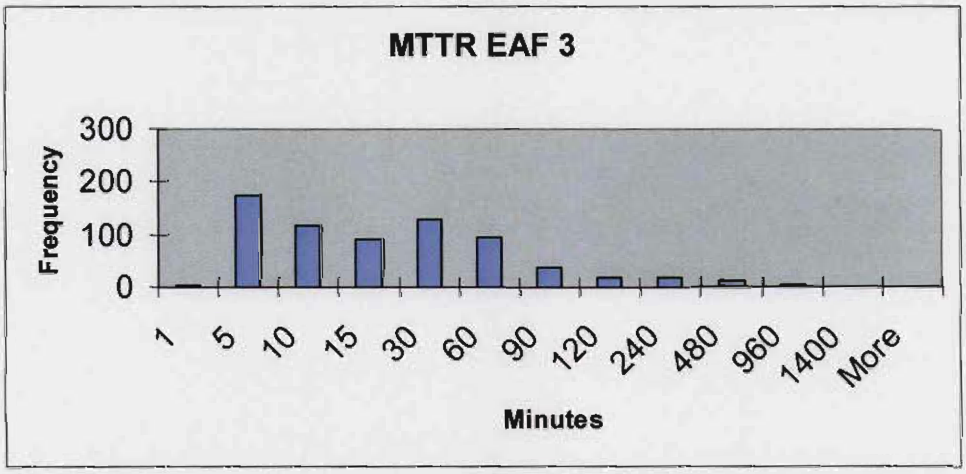

Figure 17: MTTR histogram EAF3

Inherent availability (A_i) can be described as the probability that a system will perform satisfactorily at any point in time[14] and can be given by:

$$A = \frac{MTBF}{MTBF + MTTR}$$

Equation 1

Utilising equation 1 in conjunction with the data listed in figure 10 and 11 the following results were obtained:

Parameter	MTBF	MTTR	Availability
A(i1)	282.26	28.91	0.91
A(i2)	375.19	37.38	0.91
A(i3)	409.19	33.35	0.92
A(iAvg)	355.55	33.22	0.91

Figure 18: Inherent availability per EAF

To study the impact of the delays on availability and to model the EAF scenario according to Markovian principles it was important to establish the average MTBF and MTTR for all three furnaces, as well as their averages per delay type. This was done by grouping delays per type and then calculating MTBF and MTTR between specific incidents.

In the MIS system each delay is booked as a specific incident: i.e *Roof slew o.o.o., Waste gas mechanical* etc. Thus by using these delay codes it was possible to group the delays according to code. By using the time interval between delays of the same type a MTBF could be established. Similarly by using the delay duration a MTTR could be established.

The graphs were recorded as follows:

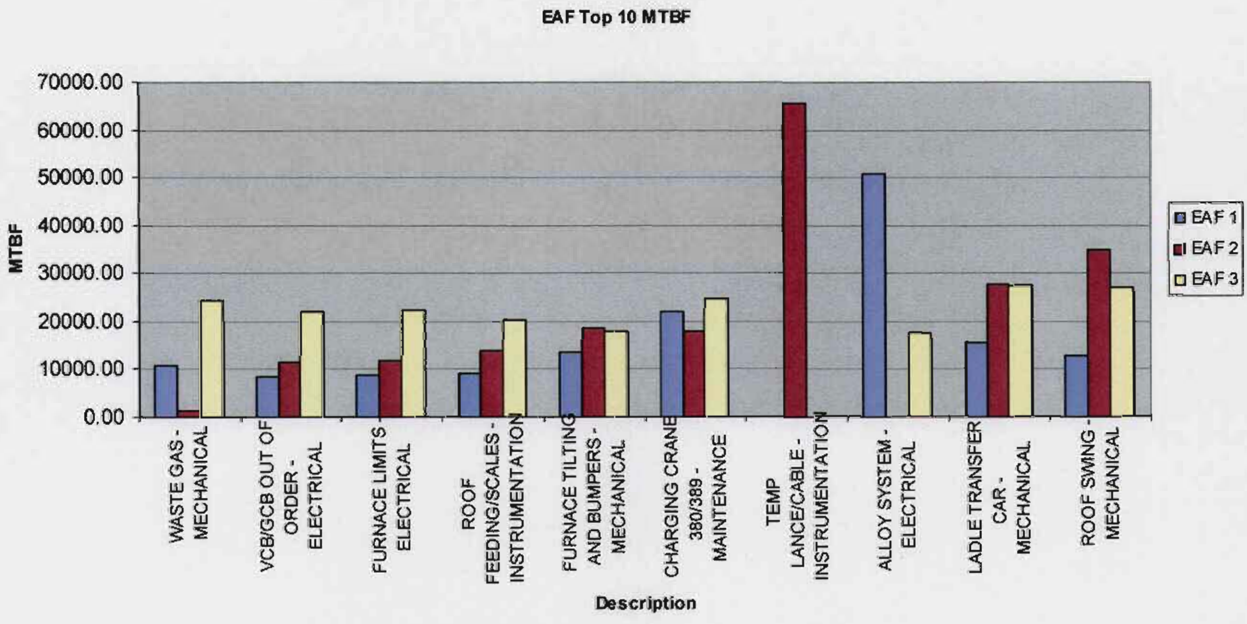

Figure 19: Top 10 MTBF per delay description per EAF

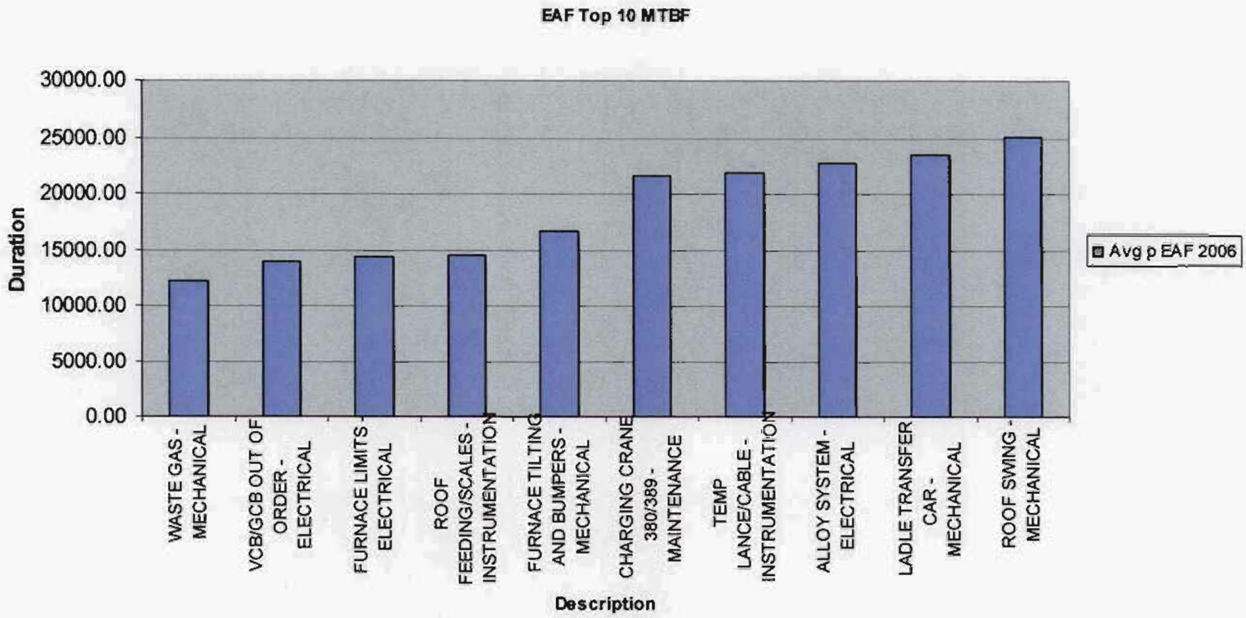

Figure 20: Top 10 MTBF average per delay description

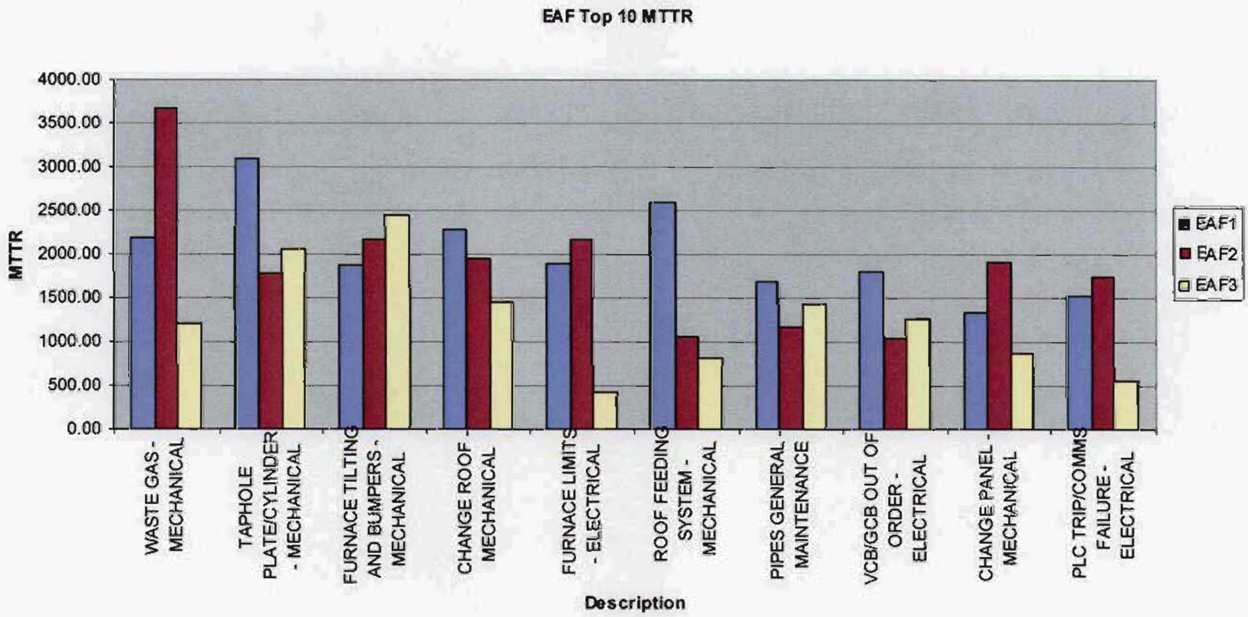

Figure 21: Top 10 MTTR per delay description per EAF

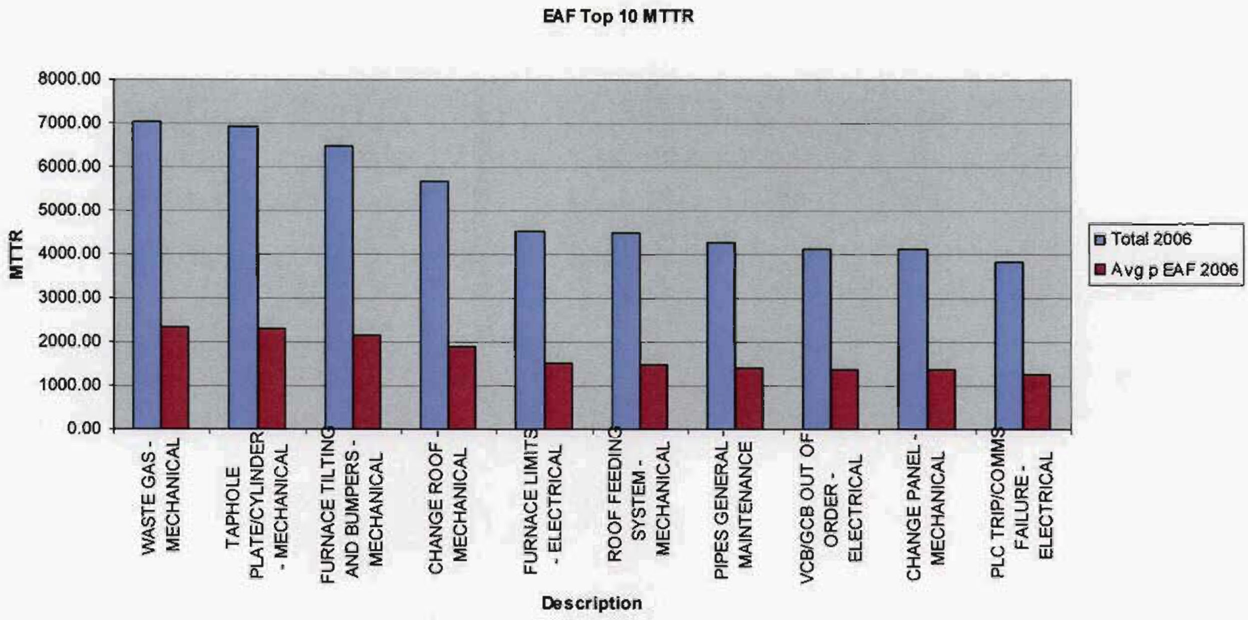

Figure 22: Top 10 MTTR average per delay description

It was then decided to utilise the top five delays (from a MTTR perspective) and an average MTBF and MTTR of all other states to calculate availability according to Markovian principles.

By identifying MTTR as the main driver the results were as follows (using equation 2 and 3):

MTTR Scenario Markov states												
State#	Description (MTTR)	MTTRF1	MTTRF2	MTTRF3	Total	Avg	MTBFF1	MTBFF2	MTBFF3	Avg	μ = repair rate	λ = failure rate
1	Furnace running	-	-	-	-	-	-	-	-	-	-	-
2	WASTE GAS - MECHANICAL	2178.46	3667.59	1203.51	7049.56	2349.85	10919.12	1218.57	24225.92	12121.20	0.00042556	0.00008250
3	TAPHOLE PLATE/CYLINDER - MECHANICAL	3089.62	1778.08	2055.23	6922.93	2307.64	17962.55	223888.92	18026.89	86626.12	0.00043334	0.00001154
4	FURNACE TILTING AND BUMPERS - MECHANICAL	1865.94	2166.42	2450.16	6482.52	2160.84	13388.66	18766.00	17945.17	16699.94	0.00046278	0.00005988
5	CHANGE ROOF - MECHANICAL	2275.27	1945.57	1450.25	5671.09	1890.36	26934.32	30924.22	41622.20	33160.25	0.00052900	0.00003016
6	FURNACE LIMITS - ELECTRICAL	1897.26	2170.27	432.59	4500.12	1500.04	8764.50	11981.01	22185.91	14310.47	0.00066665	0.00006988
7	ROOF FEEDING SYSTEM - MECHANICAL	2589.06	1057.52	822.93	4469.51	1489.84	20751.63	35806.03	22257.87	26271.84	0.00067121	0.00003806
8	PIPES GENERAL - MAINTENANCE	1691.26	1158.75	1421.30	4271.31	1423.77	31553.14	24826.31	20274.61	25551.35	0.00070236	0.00003914
9	VCB/GCB OUT OF ORDER - ELECTRICAL	1801.50	1041.48	1264.75	4107.73	1369.24	8452.99	11401.04	22015.29	13956.44	0.00073033	0.00007165
10	CHANGE PANEL - MECHANICAL	1324.18	1908.64	868.28	4101.10	1367.03	39993.18	34659.97	42146.53	38933.23	0.00073151	0.00002568
11	PLC TRIP/COMMS FAILURE - ELECTRICAL	1527.15	1737.57	557.61	3822.33	1274.11	21593.99	24111.61	53303.00	33002.86	0.00078486	0.00003030
12	PANEL PIPING CHECK/CHANGE - MAINTENANCE	1120.53	1381.76	877.66	3379.95	1126.65	31092.39	55432.89	43277.15	43267.47	0.00088759	0.00002311
13	SCRAP CRANE 383/384 - MAINTENANCE	1236.16	988.42	904.37	3128.95	1042.98	25659.54	42802.35	37392.65	35284.85	0.00095879	0.00002834
14	ROOF SWING - MECHANICAL	1250.15	992.91	535.05	2778.11	926.04	12995.76	34951.21	27081.07	25009.35	0.00107987	0.00003999
15	CHARGING CRANE 380/389 - MAINTENANCE	778.50	949.78	637.97	2366.25	788.75	22091.40	18089.53	24601.73	21594.22	0.00126783	0.00004631
16	LADLE TRANSFER CAR - MECHANICAL	630.16	1010.48	326.06	1966.70	655.57	15472.90	27657.98	27439.45	23523.44	0.00152540	0.00004251
17	COMPUTER DELAY GENERAL	150.33	785.94	936.19	1872.46	624.15	46242.85	45484.14	65230.54	52319.18	0.00160217	0.00001911
18	ELECTRODE CONTROL - ELECTRICAL	135.00	346.97	1195.69	1677.66	559.22	36655.38	70794.53	15671.46	41040.46	0.00178820	0.00002437
19	FLASH OVER - ELECTRICAL	100.09	666.66	675.11	1441.86	480.62	0.00	16375.45	73441.56	29939.00	0.00208065	0.00003340
20	ROOF FEEDING/SCALES - INSTRUMENTATION	449.45	496.80	482.88	1429.13	476.38	9191.43	14007.68	20264.24	14487.78	0.00209918	0.00006902
21	ELECTODE REGULATION - SYSTEMS	265.67	844.90	71.46	1182.03	394.01	13411.19	38085.22	45031.76	32176.06	0.00253801	0.00003108
22	SLAGDOOR PIPES - MAINTENANCE	347.04	350.83	58.89	756.76	252.25	34952.08	16851.32	114572.22	55458.54	0.00396427	0.00001803
23	ELECTRODE COOLING SPRAYER - MAINTENANCE	183.59	192.32	129.37	505.28	168.43	30961.72	1920.55	55245.60	29375.96	0.00593730	0.00003404
24	LADLE TRANSFER CAR - ELECTRICAL	121.76	27.55	238.67	387.98	129.33	77911.42	21146.82	75875.83	58311.36	0.00773236	0.00001715
25	ROOF FEEDING SYSTEM - ELECTRICAL	92.57	148.63	142.12	383.32	127.77	17296.47	23270.54	51314.35	30627.12	0.00782636	0.00003265
26	FURNACE TRANSFORMER - MAINTENANCE	0.00	71.59	182.52	254.11	84.70	0.00	0.00	184052.99	61351.00	0.01180591	0.00001630
27	PICARDI - SYSTEMS	35.36	92.60	51.28	179.24	59.75	63137.98	87008.10	47566.23	65904.10	0.01673734	0.00001517
28	ALLOY FEEDING/SCALES - INSTRUMENTATION	125.18	7.29	44.26	176.73	58.91	90993.71	0	97712.63	62902.12	0.01697505	0.00001590
29	TEEMING CRANES 381/382 - MAINTENANCE	11.04	0.00	156.04	167.08	55.69	0.00	0.00	76845.99	25615.33	0.01795547	0.00003904
30	TRANSFOMER TAP ADJUSTMENT	35.13	4.44	91.91	131.48	43.83	24166.64	28791.03	33105.79	28687.82	0.02281716	0.00003486
31	ALLOY SYSTEM - ELECTRICAL	46.33	0.00	69.58	115.91	38.64	50599.56	0	17690.53	22763.36	0.02588215	0.00004393

Figure 25: Repair rate and failure rate for state conditions

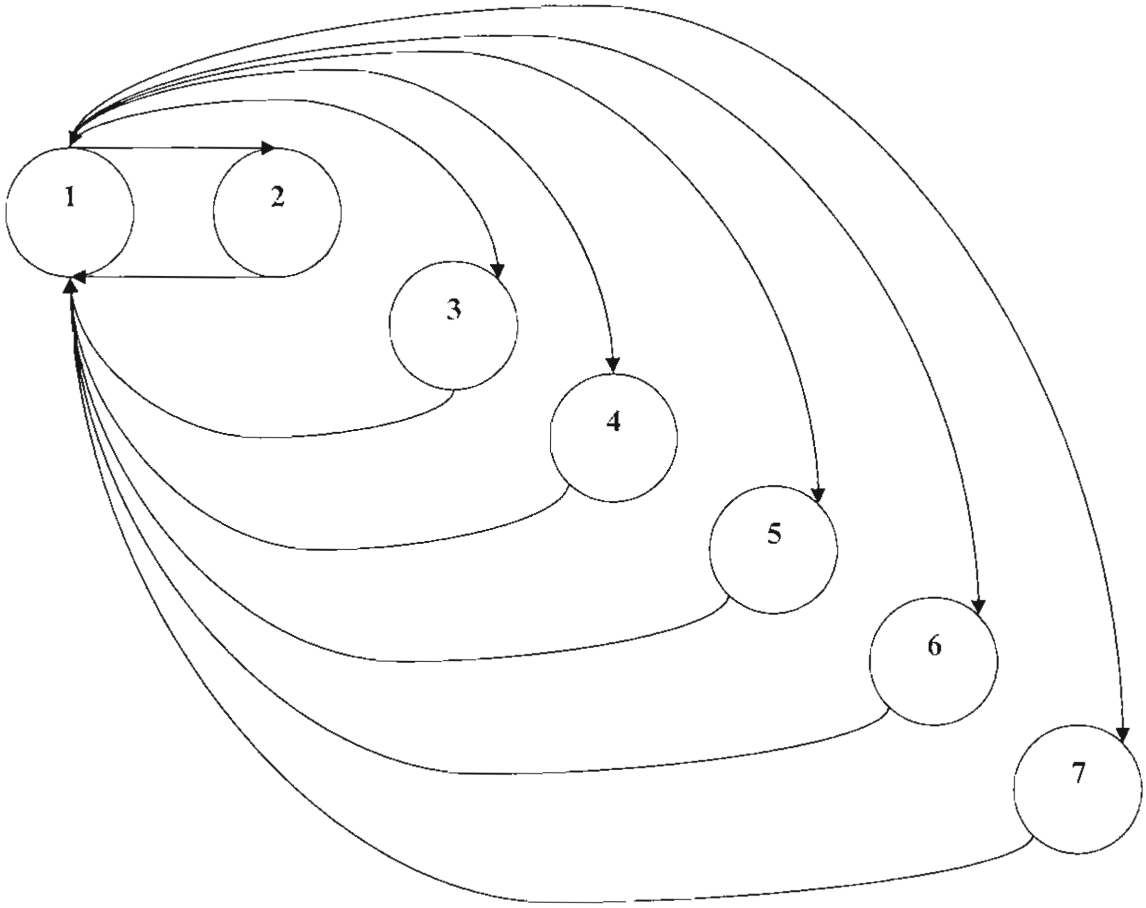

Figure 25: State-Space diagram with MTTR as main driver

According to R. Billinton[8] the following holds true for exponential distributions:

$$MTBF = \frac{1}{\lambda}$$

Equation 2

$$MTTR = \frac{1}{\upsilon}$$

Equation 3

Thus by manipulating equation 2 and 3 we find that:

$$P_0(\infty) = \frac{\lambda}{\lambda + \upsilon}$$

Equation 4: Probability of being found in the operating state even if the operating state is defined as a "down state" for the system

$$P_f(\infty) = \frac{\upsilon}{\lambda + \upsilon}$$

Equation 5: Probability of being found in the failed state

The stochastic probability matrix (***P***) can be given as

$$P_{ij} = \begin{matrix} P_{11} & P_{12} & P_{13} & \dots \\ P_{21} & \dots & \dots & \dots \\ P_{31} & \dots & \dots & \dots \\ P_{n1} & P_{n2} & P_{n3} & P_{nn} \end{matrix}$$

Equation 5: Stochastic probability for i, j = 1, 2,3 .... n

It also holds true that for the limiting state:

$$P(n) = P(0)P^n$$

Equation 6: Were *P(0)* is described as the Initial probability vector

Therefore with MTTR as the main driver and using equation 6 while assuming the plant starts in the running condition and that the system cannot go from one failure mode into another without entering the run state, the matrix was simplified as follows:

$$P(n) = \begin{bmatrix} 1-\lambda_2-\lambda_3-\lambda_4-\lambda_5-\lambda_6-\lambda_7 & \lambda_2 & \lambda_3 & \lambda_4 & \lambda_5 & \lambda_6 & \lambda_7 \\ \upsilon_2 & 0 & 0 & 0 & 0 & 0 & 0 \\ \upsilon_3 & 0 & 0 & 0 & 0 & 0 & 0 \\ \upsilon_4 & 0 & 0 & 0 & 0 & 0 & 0 \\ \upsilon_5 & 0 & 0 & 0 & 0 & 0 & 0 \\ \upsilon_6 & 0 & 0 & 0 & 0 & 0 & 0 \\ \mu_7 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Equation 7: Stochastic probability transitional matrix

But because the following holds true[15]:

$$[P] = [P_1][P_2][P_3][P_4][P_5][P_6]$$

Equation 8

And

$$P_1 + P_2 + P_3 + P_4 + P_5 + P_6 = 1$$

Equation 9

Equation 7 can be re-written as follows:

$$\begin{aligned} &P_1 + P_2 + P_3 + P_4 + P_5 + P_6 = 1 \\ &\mu_2 P_1 = 0 \\ &\mu_3 P_1 = 0 \\ &\mu_4 P_1 = 0 \\ &\mu_5 P_1 = 0 \\ &\mu_6 P = 0 \end{aligned}$$

Equation 10

In matrix form, this can be represented as follows:

$$\begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ \mu_2 & 0 & 0 & 0 & 0 & 0 \\ \mu_3 & 0 & 0 & 0 & 0 & 0 \\ \mu_4 & 0 & 0 & 0 & 0 & 0 \\ \mu_5 & 0 & 0 & 0 & 0 & 0 \\ \mu_6 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} P_1 \\ P_2 \\ P_3 \\ P_4 \\ P_5 \\ P_6 \end{bmatrix} = \begin{matrix} 1 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{matrix}$$

Equation 11

The unavailability equation for this matrix can be given as:

$$U = -\frac{1}{1 + \left[\dfrac{\dfrac{1}{(MTTR)}}{(MTBF)} \right]} = \frac{1}{1 + \left[\dfrac{1}{\dfrac{(MTTR)}{1} \dfrac{1}{MTTBF}} \right]}$$

Equation 12

Using equation 2 and 3, it is possible to rewrite equation 11 as:

$$U = \frac{1}{1+\left[\frac{1}{\frac{\lambda}{\mu}}\right]} = \frac{1}{1+\left[\frac{1}{\frac{\lambda_1}{\mu_1}+\frac{\lambda_2}{\mu_2}+\ldots\ldots+\frac{\lambda_n}{\mu_n}}\right]}$$

Equation 13

Thus by using the state space diagram illustrated in figure 25 and equation 13 it is possible to calculate the availability of the EAFs. It is important to remember that state 7 is an averaged failure rate and repair rate for the remaining states:

The following results were obtained from the unavailability model given in equation 13 and for states grouped as per example in figure 25:

States calculated	**Unavailability**
State 2 – 6	15.24%
State 2 – 16	14.44%
State 2- 31	13.1%

Figure 26: Comparative total EAF unavailability using state repair and failure rate

It is evident that the more failure states are added the closer the unavailability converges to a precise value. By calculating the various states' unavailabilities it was found that the more states added to the calculation, irrespective of sequence, the closer the value converged to 13.1%. This proves that the more data is used in equation 13 the closer the final answer comes to representing reality.

The results in this chapter will be discussed further in the text.

8 WEB-BASED CONDITION MONITORING SYSTEM RESULTS

The EAF has a complimentary plant which casts the steel produced at the furnaces. The plant consists of a fixed bow caster, casting widths of 900mm to 1 900mm at a thickness of 245mm. The crane that is used to pick the ladle up to the turret is named Crane 379[16].

Crane 379 is the most critical crane at ESM as it is the only crane in that specific bay. If this crane breaks down the 250t ladle cannot be taken up to the caster and the entire casting process is brought to a halt. The furnaces will also inevitably be delayed because there is no other location to cast the steel.

Crane 379 major delays			
Notification number	*Date*	*Duration (h)*	*Description*
620150244	2003.03.02	5.97	Sheave wheel collapsed (Vibration)
620150319	2003.03.17	2.72	Main hoist motor burned (Currents)
620196618	2003.12.01	4.08	Guardian shaft broke (Vibration)
620247132	2004.09.23	6.65	Gearbox motion broke (Vibration)
620255665	2004.11.13	3	Motor earthed (Currents)
620256328	2004.11.17	1.92	Base bolts loose + coupling worn (Vibration)
620268852	2005.01.27	1.35	Brake worn (Temperature)
620270135	2005.02.11	33.4	Malmedi coupling broke (Vibration)
620277962	2005.03.20	30.97	Guardian shaft broke (Vibration)
-	-	12.3	Various (Vibration + Temperature)

Figure 27: Crane 379 delays that could have been prevented using Web-base condition monitoring

It can be seen in figure 27 that there have been two major incidents on the crane prior to the installation of the Web-based condition monitoring system. Both of these involved full hot metal ladles and could have been catastrophic.

The combined net loss of the delays captured in figure 27 (at an average margin for the period 2003 to end 2005) is in excess of R14 million*. This was calculated using an average casting rate of 120 tons per hour.

* The estimation of these costs is based on sensitive information regarding the company's profit margin. Failure of equipment is based on historical information.

Early in 2006 Motornostix™ was contacted in order to do a trial on Crane 379 to determine the feasibility of Web-based condition monitoring systems at ESM. The system was installed by Motornostix™ on days that the crane was offline. Due to the critical nature of this crane the team from Motornostix™ only had a very small window to install the equipment.

From the interviews (see Appendix A) held with various employees at different levels of the organisation the following was evident:

- All employees could explain the basic principles according to which the Web-based condition monitoring system works.
- All employees see the monthly reports produced by Motornostix™.
- All employees feel that the system contributes positively towards the availability of Crane 379.
- All employees feel that there are other areas where the Motornostix™ system can be applied successfully.

One example of an incident that was prevented occurred on 28th April 2006. The technicians in Cape Town realised that the south-east motor on the main hoist assembly of the crane had breeched its levels with regards to vibration.

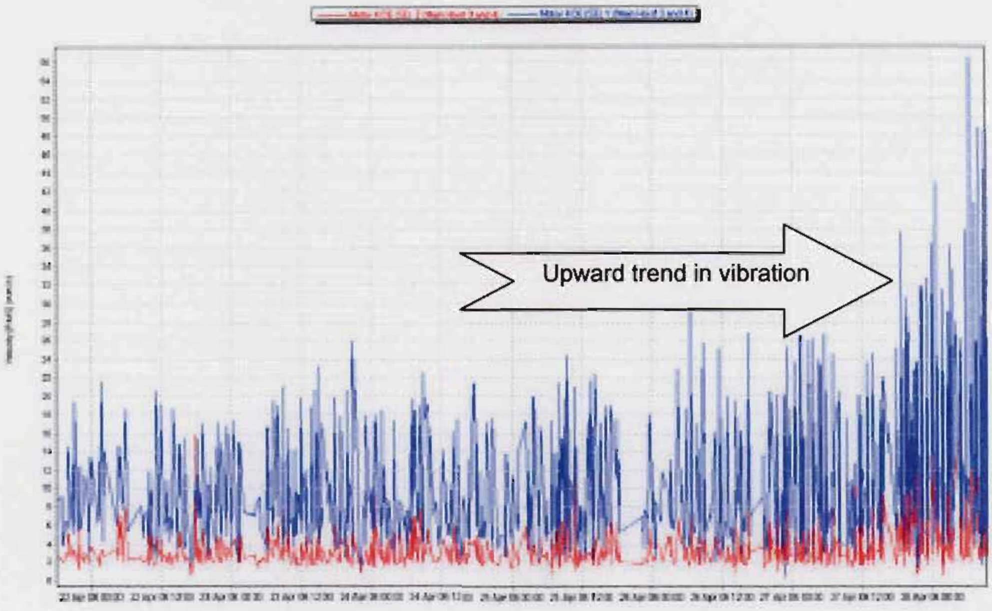

Figure 28: Upward trend in south east motor vibration on Crane 379 main hoist

Mr. Niekie Peters (System Specialist: ESM) was contacted at 9:30 that morning. Together with a team of maintenance employees they inspected the crane visually to determine the cause of the vibration. They found that the base bolts on the motor were loose and this was the most likely cause of the vibration.

After tightening the base bolts and putting the crane back into operation the results were favourable.

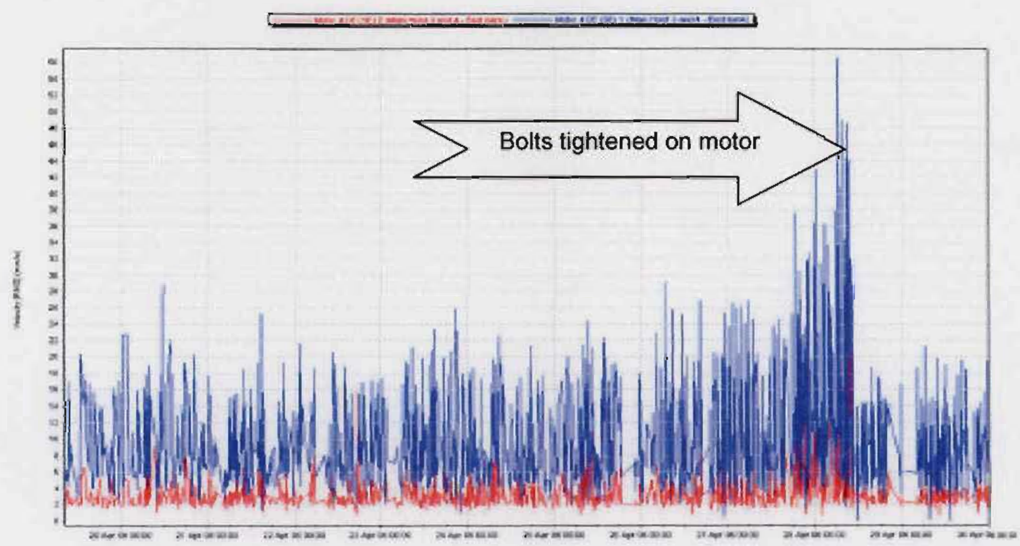

Figure 29: South East motor vibration after putting crane back in operation

9 INTERPRETATION OF RESULTS OBTAINED FROM MARKOV MODEL

The results obtained from the Markov models were surprising. It is quite evident that the EAFs **do not** follow a Markov process and cannot be modeled as such.

The reasoning behind this statement is that after the probabilities were empirically determined and the stochastic probability matrix conceived, it was tested. It was evident that the sum of the probabilities of the system going from one state to another **does not** equal unity.

This can be attributed to the fact that data averaging was done to establish λ and μ per failure mode (state) and then again for all three furnaces as an average.

It is also important to note that the failure modes (states) do not have a constant failure mode. This implies that

$$\lambda(T) = \frac{f(T)}{R(T)} = \frac{\lambda e^{-\lambda(T)}}{e^{-\lambda(T)}} = \lambda$$

Equation 14: Exponential failure rate function

Equation 14 does not hold true and is not a constant. It is rather a variable with a large standard deviation between incidents. This standard deviation becomes even larger and more unpredictable when looking at the same failure mode on different furnaces.

It is evident to see from figures 30 and 31 that there **are no constant failure rates** even amongst similar failure modes. This is proof that equation 14 does not hold true. The large difference in MTBF (the inverse of failure rate) standard deviation also indicates that the failure rate will not be constant at all. This implies that for a specific failure mode the data set of failures are not distributed over fixed intervals (failure rates).

Figure 30 also clearly states that the MTBF of taphole delays (and 94% of the other failure modes) do not follow an exponential or Poison distribution.

Descriptive stats taphole plate/cylinder - mechanical

EAF1

Mean	17962.55
Standard Deviation	25548.21
Count	50

EAF2

Mean	16851.32
Standard Deviation	24815.55
Count	55

EAF3

Mean	18026.89
Standard Deviation	28154.97
Count	50

Figure 30: Difference in standard deviation between the same failure modes on different furnaces

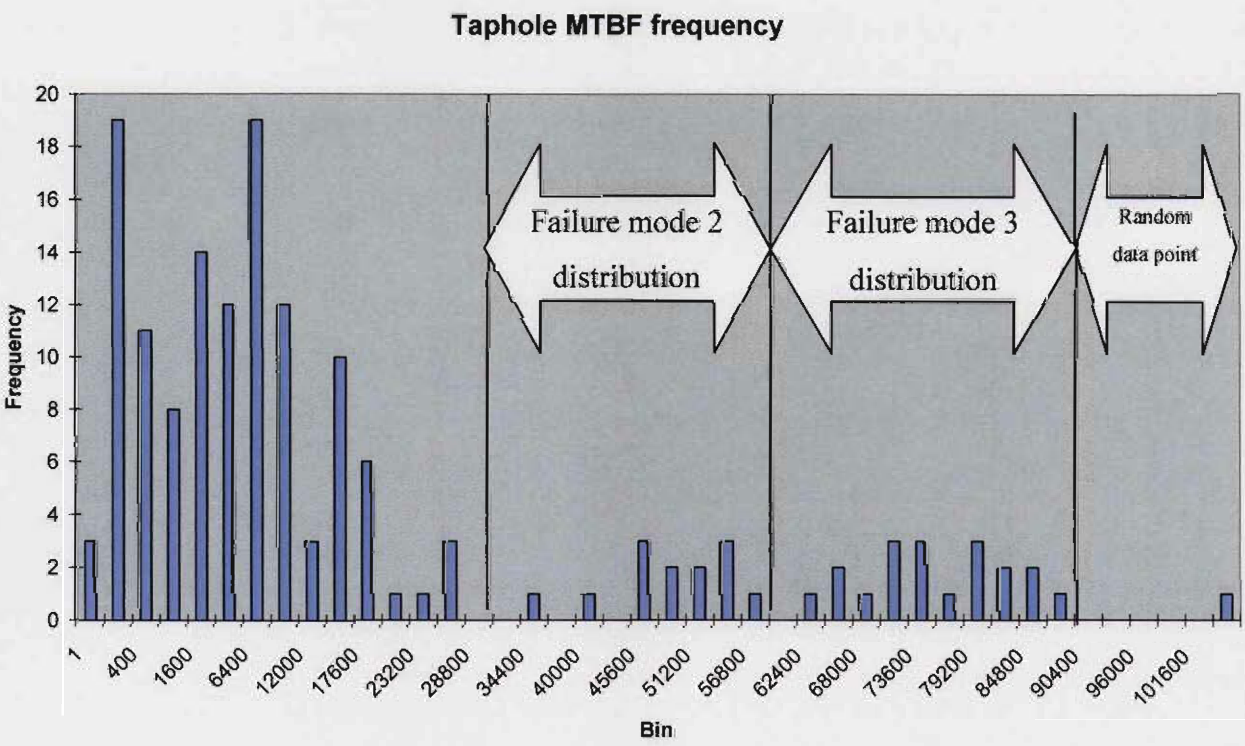

Figure 31: Histogram of MTBF for taphole delays using all three furnaces data

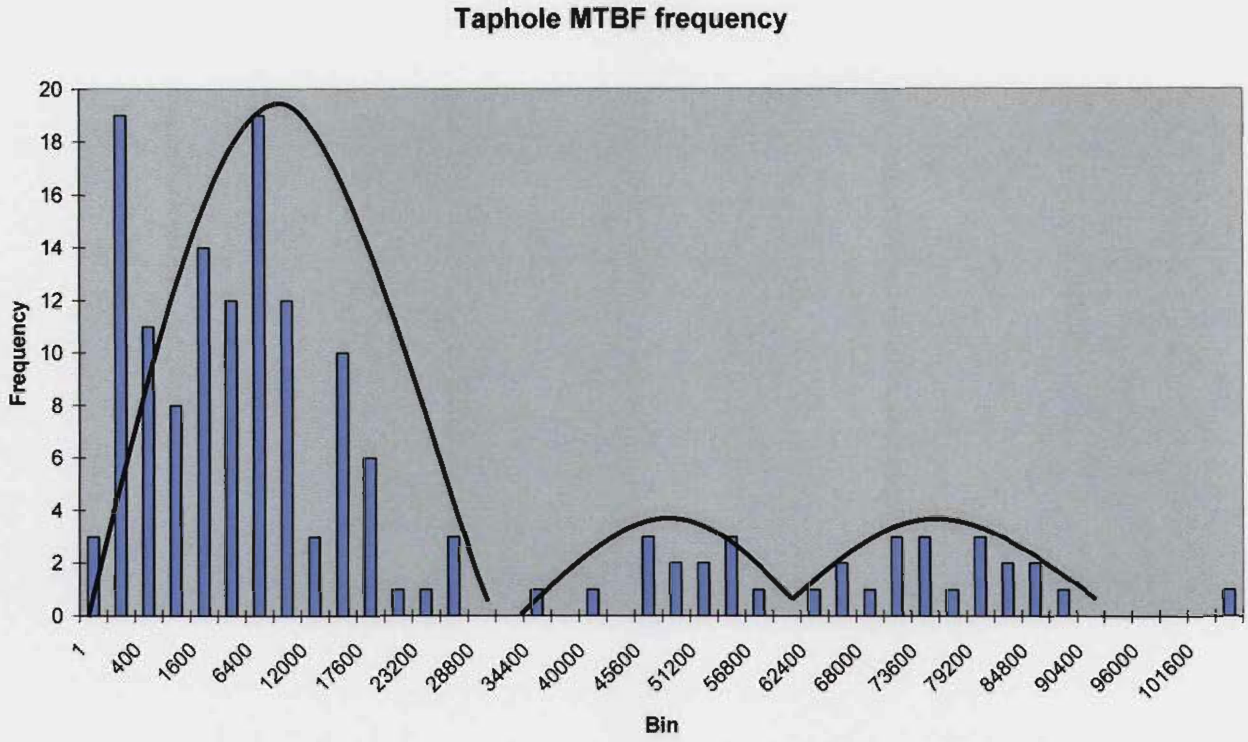

Figure 32: Histogram of MTBF fit with normal distribution representation

From the histogram given above (as with 94% of the other states or failure modes) it is evident that there are two or more drivers which determine failure rate.

For MTBFs between 1 and 23 200 minutes there is a definite Poison distribution of the data. Between 45 800 and 62 400 minutes there is also such a distribution of data and between 62 400 and 90 400 minutes another such distribution appears.

The taphole plate on an EAF is the plate coupled to a hydraulic cylinder that keeps the taphole of the furnace closed. When the cylinder is closed (i.e. taphole closed) the plate is positioned by a lip on the opposite side of the cylinder. There is taphole sand between the plate and the molten steel in the furnace. Upon opening the cylinder, the sand falls out and molten steel is tapped into the ladle.

When analysing the data it is clear that there are three main drivers determining taphole plate MTBF. These are:

- Normal plate adjustment (1 – 28 800 minutes)
- Plate change and/or replacement of lip (34 400 – 56 800 minutes)
- Plate and frame change (62 400 – 90 400 minutes)

Thus by interpreting these three drivers of taphole plate MTBF as a grouped failure mode, it brought about a distribution which was not Poison-like in any manner. In doing this the Markov process stochastic transition could not be applied. The state failure rate and repair rate (commonly associated with the Markov process and derived for this process) could be applied to equation 13 to determine the unavailability of the three EAF systems.

The different methods weighed up against one another as follows:

Unavailability	Probability
ESM 2005 reported unavailability	0.123
Inherent unavailability	0.086
State 2 - 6	0.152
State 2 - 16	0.144
State 2 - 31	0.131

Figure 33: Results from different methods used

The inherent unavailability is much lower than that of any other measured or calculated unavailability. The reason for this being that the inherent availability was calculated using the sum of the three furnaces average MTBF and MTTR. This dampened the effect of some of the failure modes and gave a more promising view of reality.

It was interesting to note that the more states were included in the calculation the faster it converged to a value which was indicative of the current reality.

The unavailability reported for the period 2005 was better than the calculated 31 state unavailability. It can be given as 88.7%[18]. This can attributed to the human factor. Many of the delays booked against the maintenance section on the MIS by the operator could be production delays. They will then not be tallied for the calculation the maintenance unavailability.

The true unavailability for the year 2005 can be estimated at between 12.3% - 13.1%. This gives a maximum deviation of 0.8%. Even though this may not be attributed as great loss it equates to 2.92 days and if fully utilised could amount to increased profits of R12 million*.

* The estimation of these costs is based on sensitive information regarding the company's profit margin. Failure of equipment is based on historical information.

10 INTERPRETATION OF RESULTS FROM WEB-BASED CONDITION MONITORING SYSTEM

It was interesting to establish that the general workforce had such an intricate knowledge of the workings and goings on coupled with the Motornostix™ installation and its performance. This could be attributed to the fact that all parties were involved with the inception of this project, and subsequently took an interest in its success.

Although the initial installation was done for a minimal fee, the service fee seemed substantial at the time. The once-off installation fee of R20 000 was offset by the R90 000 per annum fee for equipment hire and Web-based condition monitoring of the crane.

It is estimated that pre-empting the loose base bolts alone spared a delay costing in excess of R235 000 of potential income. This is indicative of a payback in less than five months. It is, however, important to note that condition monitoring devices are more often than not deemed an unnecessary cost - until an expensive failure occurs, something which this research proved was prevented time and again over recent months.

It was evident that the modes which deliver the highest degree of value are vibration followed by current measurement.

The amount of detail elaborated on in the report is also helpful. Knowledge of the vibration tendencies and history is now also known for this specific crane. The use of this tool as a condition based preventative maintenance tool cannot be emphasised enough. Failures associated with vibration were quickly identified and prevented. This was aided by the open communication channels between the supplier and Mittal, allowing for effective communication made timeously to the correct people.

While the base bolt incident was prevented there were no other incidents to report. This does not, however, diminish the positive impact of the Motornostix® system in the steel making environment.

It is also evident that Motornostix™ believes the trial to have been successful, as per their statement attached as Annexure B. Discussions with Johan Grobler (General Manager: Motornostix™) confirmed this.

11 CONCLUSIONS AND RECOMMENDATIONS

From the Markovian process applied above solid deductions could be made. While the Markovian process could not be applied in full, formerly unknown data pertaining to failure modes was revealed. Initially, the reason why the Markov model could not be applied was thought to be the chaotic nature of the system.

Upon further investigation it was found that the problem was related to multiple drivers (strange attractors) grouping the data into distributions which were seemingly random. Upon investigation of this phenomenon it was found that the grouping could be explained by multiple drivers (sub-failure modes) acting on the system. The Newtonian paradigm held true from the perspective that the sum of the drivers equals the failure mode effect as a whole.

It is now known that 94% of all failure modes have more than one driver behind each failure. Although not 100% successful, the Markovian models have proved useful in identifying the poor performance drivers behind failures on the pilot plant. The traditional method was useful if only to bring the sub-failure modes to light. Once these sub-failure modes have been analysed, the Markovian process will be successfully applied to this system.

The prerequisite of breaking the system up into states and defining each by using attributes such as failure and repair rate has confirmed many theories while disproving common perceptions. It is now concretely proven that the delays experienced at ESM can be sub divided into sub-failure modes.

Although of a good standard there is still room for improvement in the methods operators use to book delays on the MIS system. Not all the delays are booked under the correct description, yet a big advantage off this system is that **every** minute that is lost is accounted for. The importance of discipline in this regard cannot be overstated. The statement that I, as a maintenance manager, and many of my colleagues have made regarding the sanity and accuracy of the delays booked on the production system is false.

Looking at the data it is evident that there is a 1.8% deviation between the availability reported by the maintenance section and the production section. This is within an acceptable level taking into account that both systems rely heavily upon human inputs.

The MIS does not have only a multitude of useful, accurate data; but from a Newtonian perspective it is an excellent keeper of time lost. Not only has the usefulness of the MIS and the data captured within been substantiated, additional notable information was also gathered.

Although of a world standard, there are certain critical features missing in the ESM maintenance system. Long-term (more than five years) needs are not addressed. In figure 25 it can be seen that the waste gas system on the EAF attributed for 7 049 minutes worth of delays. This equates to roughly R1 000 000 loss in profit*. The situation was however identified in 2004 and ran through to August 2006.

The reason the waste gas system deteriorated to such an extent is questionable. The water cooled ductings had never been replaced in 15 years since the upgrading of the furnaces. Thus there was no replacement strategy or planned action to justify their removal and replacement. Thus, after learning a very hard lesson, planned maintenance cards have been placed in the system. These cards will alert ESM employees in 2019 to begin the application process for CAPEX funds to replace the ductings on a planned basis.

It has also become evident that the EAFs do have problems with electrical limits. These are being addressed and have been under constant CI for the last 15 years. The EAF is a harsh, unforgiving environment where the charging of hot metal (through the roof) or a reaction might prove the end of a limit's life. The planned cradle changes of 2005, 2007 and 2008 have granted the opportunity of changing many of the limits currently in use. The affordability and ease of maintenance of internally rod mounted cylinders has made this a viable option from 2005 onwards. Doing away with the striker type limit and incorporating this design will ensure increased availability and reliability of limits throughout their lifespan.

Housekeeping is also an area of great concern. The delays caused by furnace tilting and bumpers (see figure 21) indicates that it is the third biggest delay on the system. Delays are caused by loose pieces of scrap falling into the bumper room. These pieces fall in between the limit and effect tilting conditions dangerously. This delay could be halved by employing proper housekeeping principles.

Due to process requirements a lot of process scrap is lying around the plant. Due to the constant drive to decrease costs, process scrap generated in the mills (in the form of de-coiled HRC) is charged in quantities of up to 17%. The un-coiling of these have left them distributed everywhere on the plant, especially in the bumper rooms. Due to this study highlighting the influence of this on the ESM operation, all HRC is coiled before leaving the mills.

The overwhelming success of the Web-based condition monitoring installation on Crane 379 has opened the doors for further improvement on the EAF maintenance strategy. It is a rock solid case for further expansion into these “uncharted waters”.

The reduction in maintenance resources have not been realised as yet. There was an extensive restructuring executed at ESM in 2005. This has already cut the maintenance resources by 21.3%[18]. The new organisation structure and reduced manpower has placed significant strain on the maintenance section. A significant number of knowledgeable employees have been lost due to restructuring, which aggravated the situation.

Maintenance cost was significantly reduced, as was the cost of plant stoppages. *It is estimated that the savings on Crane 379, which can be attributed to production loss, are in the region of R30 million. The cost attributed to equipment failure, which could not be repaired preventatively had the WBCM not been in place, is estimated to be R800 000*.*

This research has proven beyond reasonable doubt that there is scope for applying Web-based condition monitoring to other sections of the plant. The return received from the trial conducted during this research is proof to management that this technology works.

* The estimation of these costs is based on sensitive information regarding the company's profit margin. Failure of equipment is based on historical information.

Quotes have already been received to monitor EAF off-gas fan motors, Crane 379 auxiliary hoist and EAF scrap crane condition using Web-based condition monitoring. This will not only address one of ESMs greatest shortcomings (sensitivity to charging capacity) but also monitor critical equipment.

Upon completion of these installations the compressors and main pump station pumps will be addressed. When comparing the cost of such an installation to the advantages seen from using it, this technology makes economical sense. The fact that Motornostix™ makes this technology available in the form of a rental agreement makes the option even more attractive.

Dealings with the company have shown that they believe in their product and know what the benefits are for the user. They expect a premium to be paid for their equipment. From a business perspective this is fair.

It is recommended that the system be installed as a mandatory device on all hot metal cranes within the Mittal SA group. Although not by any means statutory by law, the system does have certain benefits in preventing a catastrophic incident.

Although the main drivers of poor performance have been noted in the section given above, during the course of this research many negative drivers have already been addressed. Most have been addressed from a short term perspective and various from a long term point of view.

However, there is still place for improvement. The ever increasing pressures placed on resources have necessitated the introduction of Web-based condition monitoring techniques. Owing to the tremendous success of this technology application in this research, it is clear that the ESM maintenance strategy can be complimented by it. In identifying certain critical equipment that can be monitored by WBCM, it can take significant strain off crucial maintenance resources.

The availability of the pilot plant (overhead crane) has improved by 3.1% in 12 months. This can be directly attributed to the implementation of the WBCM technology on the pilot plant.

The unavailability drivers identified by the Markovian modeling techniques have formed the basis of a blueprint for future improvement.

The reduction of maintenance resources and increasing of plant availability by utilising WBCM systems and Markovian modeling techniques thus proved to be valid. It has also opened doors for further research and investigations.

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Appendix A: Interviews held with employees involved with crane maintenance

1. Please state for the record your name and function within the ESM organisation.
My name is Nico van Vuuren. I'm a Senior Millwright at the Crane Maintenance section.
2. What do you understand about the Motornostix™ equipment fitted on Crane 379 and how it operates?
It senses vibration from the gearboxes, props and the motors as well as measuring certain currents on the crane. It's connected to a cell phone and signals from Crane 379 are sent to their station in Cape Town.
3. Have you seen the monthly reports published by Motornostix™ concerning the results of the data measured on Crane 379? If you have, what is your perception of them?
I've seen the monthly Motornostix™ reports and believe they are good for the cranes.
4. Do you feel that the system has prevented any major failures on the crane?
Yes I do. For example, there was a motor on the south-west side main hoist; the base bolts came loose and they picked it up through those vibrations.
5. What do you think would have been the extent of the damage, had this early warning system not been in place?
The motor would have come loose, and could have turned and broke the coupling. This would have caused serious damage.
5 a) How long do you think the crane would have stood if that happened?
If we had to replace the motor, and depending on the damage on the coupling, easily four hours plus.
6. In your opinion, has this system been successful as a trial?
We've had the Motornostix™ system on the crane for a year and have only had success so far.
6 a) Do you think we can use the system on other critical cranes at Mittal?
Yes.
7. Do you think there are other applications in addition to that of the cranes for the Motornostix™ system?
Yes, I believe so.
7 a) What do you think we could implement it elsewhere?
Any place where there are a lot of vibrations, motors, conveyors and so on.

1. Please state for the record your name and function within the ESM organisation.
Johan Geldenhuys, Superintendent: Maintenance.
1 a) I believe you were previously in the crane section?
Yes, worked on the cranes for about nine years.
2. What do you understand about the Motornostix™ equipment fitted on Crane 379 and how it operates?
We started using it, to our benefit, to give us piece of mind. I have personally been in the unfortunate position where that crane dropped its load to the ground four times. Vibration monitoring on the cranes has been a big relief for me.
2 a) Do you know how the system operates?
From what I understand, we installed various different measuring points that are transmitted to the head base in Cape Town for databases analysis. When they see anything wrong, they let us know.
3. Have you seen the monthly reports published by Motornostix™ concerning the results of the data measured on Crane 379? If so, what is your how perception of them?
I've seen the reports and think they are good. We discuss the reports on the Crane Forum that is currently in the works.
4. Do you feel that the system has prevented any major failures on the crane?
Yes, there was vibration on the crane and they alerted us. There was a fault with one of the motors and we changed the motor and the base bolts that were also loose.
5. In your opinion has this system has been successful as a trial?
Yes. I will suggest installing it on one or two other busy cranes as well; Crane 720 perhaps as we experience a lot of incidents of vibration on that crane as well.
6. Do you think there are other applications in addition to that of the cranes for the Motornostix™ system?
The motors in pump stations.

1. Please state for the record your name and function within the ESM organisation.
Niekie Peters, Electrical Technician: Heavy Current, V3 Concast, Mittal Steel, VDBP
2. What do you understand about the Motornostix™ equipment fitted on Crane 379 and how it operates?
About two years ago, Mr Gerhard Wernecke started a project on Motornostix™ and he incorporated me on the electrical side of the project. First the Motornostix™ team came out and inspected the crane and how it operates. They gave us a tour of the equipment that they use and then we began installing Motornostix™. They call it the "Canaries". The system works like a drive chain. There is a board that can bring digital and analog inputs and that works through a 104 PC. The data is captured via a cell phone. They contact the call centre and there analyse the entire system and provide us with a report.
3. Have you seen the monthly reports published by Motornostix™ concerning the results of the data measured on Crane 379? If so, what is your perception of them?
Yes, each month analysers send me an email with the entire report which stresses any problems. Six months ago they phoned me in the middle of a weekend and to inform me of a problem on one of the drive chains on the north-east south motor. I came out to the plant and called the fitters. We saw that one of the base bolts were loose. It was the only incident reported to us and it is a good system. Cranes like 379 where we installed the system are critical. The money was well spent.
4. What do you think would have been the extent of the damage, had this early warning system not been in place?
If we didn't pick it up earlier, we would have lost the base bolts on one of our cranes, leaving it to slip with 250 tons of hot metal. That would have been disastrous.
5. In you opinion has this system has been successful as a trial?
Yes, this was more than a trial. I think it is a critical to a crane like 379 and we can ensure that the crane is operating as it should at all times.
6. Do you think we can use the system on other critical cranes at Mittal?
Yes, we can really benefit from that.
7. Do you think there are other applications in addition to that of the cranes for the Motornostix™ system?
Yes, monitoring bag house fans motors where you can pick up delays on your furnace. I think

it will be worthwhile to put in the system there.

Appendix B: Motornostix statement letter

Motornostix®
Critical Machine Vibration Monitoring
Website: www.motornostix.com

Motornostix (Pty) Limited
(Reg. No 2000/024321/07)

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Our Ref: MXSA-MITTAL190307

19 March 2007

Mr. Gerhard Wernecke
Maintenance Manager - ESM
Mittal Steel SA - Vanderbijlpark
PO Box 2
Vanderbijlpark
1900

MOTORNOSTIX MONITORING SERVICE ON CRANE 379 MAIN HOIST

Dear Gerhard

The Motornostix vibration monitoring system was installed on crane 379 in early 2006 and has since proved to be of good value to Mittal. The introduction of the Motornostix machine health monitoring service on crane 379 introduced a new dimension to the knowledge of the main hoist's equipment health. Vibration and supporting monitoring information that was previously not accessible and unknown, was brought right to the desk of maintenance personnel. The early detection of failure conditions leads to a reduction of production down time and improves the safe operation of the crane. The MX monitoring service includes the analysis of the clients data; relieving client resources to concentrate on the steel production processes.

A good example of such an early detection during a Motornostix data analysis inspection was on 28 April 2006 when the vibration trends from the drive end of the South East motor revealed that the motor's none drive end mounting bolts were moderately loose. Motornostix notified the Mittal maintenance department after which these bolts were tightened. Vibration levels remained stable at this lower level thereafter which eliminated a possible failure. Such a failure could have resulted in downtime if it was not attended to early enough.

The vibration level trend development and correction can be seen in the graph presented in Figure 1.

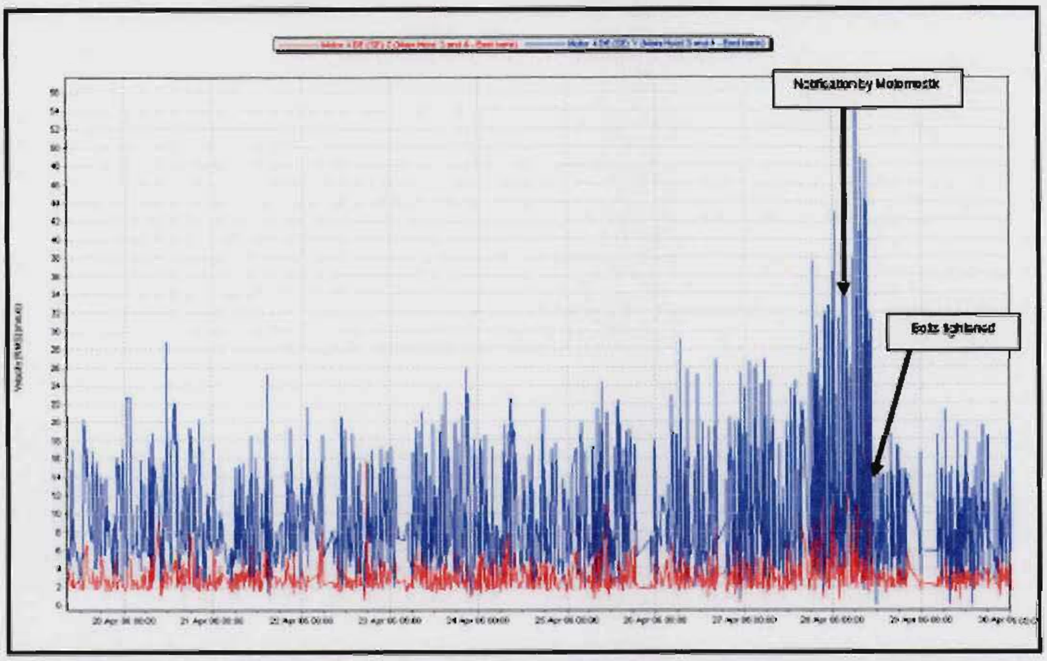

Figure 1: Motor 4 vibration trends for April 2006

Motornostix Monitoring Service improves the safe operation and availability of critical equipment, like crane 379, by providing:

- An automated data gathering method that is safe to use under operational conditions
- A continuous record of condition monitoring measurements
- Interpretation by trained specialists
- Notification of fault conditions by SMS, e-mails and telephone
- Periodic machine health reports

For any queries or information please feel free to contact us or visit our website at www.motornostix.com.

Kind regards

Johan Grobler
General Manager