USING TECHNOLOGY IN MOBILE EQUIPMENT MAINTENANCE AT TECK COAL TO CREATE A COMPETITIVE ADVANTAGE

by

Donald Sander
B.Sc. In Mechanical Engineering,
Registered Professional Engineer

PROJECT SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF BUSINESS ADMINISTRATION

In the MBA Program
of the
Faculty
of
Business Administration

SIMON FRASER UNIVERSITY

Spring 2011

Approval

Name: **Donald Sander**

Degree: **Master of Business Administration**

Title of Project: **Using Technology in Mobile Equipment Maintenance at Teck Coal to Create a Competitive Advantage**

Supervisory Committee:

Dr. Ian P. McCarthy
First Reader
Professor and Canada Research Chair in Technology & Operations Management
Faculty of Business Administration

Dr. Mark Selman
Second Reader
Special Advisor to the Dean
Faculty of Business Administration

Date Approved:

Abstract

Teck Resources Limited's coal division, Teck Coal, is the second largest global producer of metallurgical coking coal, which is a fundamental requirement in the production of steel. One of the largest operating costs for Teck Coal is associated to mobile equipment maintenance. The experience of the author in three of the six Teck Coal maintenance departments is used in demonstrating why a shift to a more proactive maintenance paradigm is necessary to be competitive. This paper focuses on the opportunity to improve the organization's ability to effectively identify its equipment health conditions in a timely manner. This can be successfully accomplished through the implementation of new technology to monitor, analyse and trend equipment conditions. The results would include the identification and correction of equipment problems in advance of failures, which will ultimately reduce the maintenance workload. This paper will also demonstrate why minimizing work is vital to the organization due to the scarcity of tradespeople and imminent retirements, and how technology in the form of expert systems must be leveraged to provide knowledge for the less experienced tradespeople remaining in the organization. The ability to exploit technology to allow Teck Coal to work smarter with fewer tradespeople will be a strategic advantage and will provide operational benefits. Essential to the success of the maintenance paradigm shift, is an effective change management process that engages the employees and ensures the change is sustainable. The process for ensuring the success of the changes proposed is also presented in the paper.

Dedication

I wish to thank my family, for their patience, understanding and support throughout this process, in particular, a big thank-you to my wife, Janie, for her continuous support along the way.

Acknowledgements

I wish to thank all the professors at SFU for their guidance and support over the past several years. It was my pleasure to participate in MBA program with you.

In addition, I wish to thank my Teck cohort for their teamwork and friendship in making the past several years enjoyable. I wish each of you the best in your future career, wherever this may take you.

Table of Contents

List of Figures

List of Tables

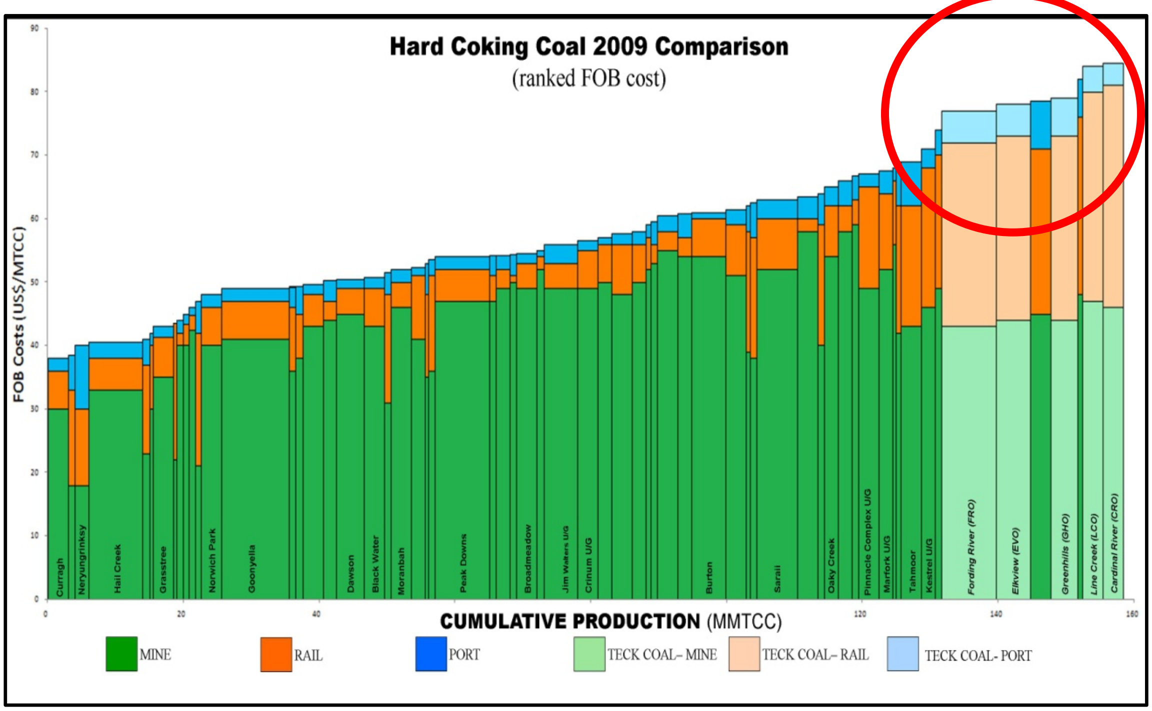
1.0 Introduction

This chapter will provide a brief overview of Teck Coal, its business and one of many strategies employed at the operating sites to maintain its operational efficiency. It is important to understand that Teck Coal has to be a leader in operational efficiency because its distribution costs are higher than those of its competitors. A project overview is also included to provide the reader with a summary of the analysis and arguments presented in the various chapters in this paper.

1.1 Teck Coal Overview

Teck Coal is comprised of five operations in British Columbia and one in Alberta (Teck, 2009). It competes on the global high quality, hard coking coal (HCC) seaborne market. Its main competitors have the advantages of lower transportation and port costs, which allow the competition to operate at lower cost quartiles in comparison to Teck Coal, which is illustrated in Figure 1, *Hard Coking Coal Cost Comparison*. The 1100km distance that coal must be railed from the operating sites to the ports results in higher total operating costs and places Teck Coal in the fourth quartile in the HCC global supply market. See the illustration below.

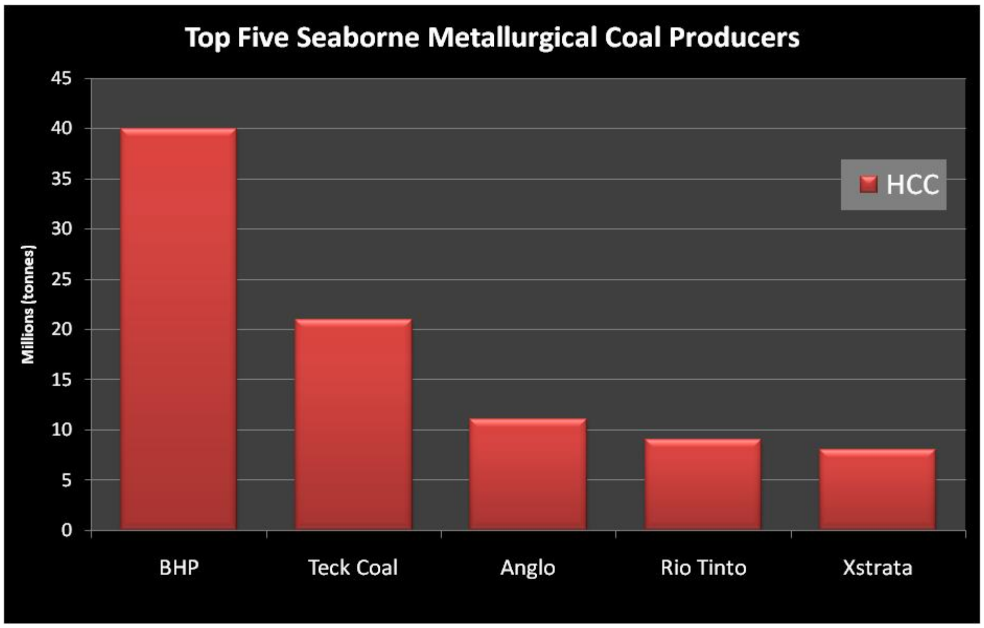
Figure 1- Hard Coking Coal Cost Comparison



Source- Drawn by Author, Data from Wood Mackenzie, 2009

The top two producers represent 39% of the high quality metallurgical coal supply. The top four Australian producers represent 51% of this HCC supply. Each producers sell similar, but slightly differentiated products, which can increase market power for the higher quality firms. Below is a chart shown as Figure 2 - *Teck Coal Market Supply*, which illustrates that approximately 57% of the market is supplied by the top 5 producers. In a balanced market, suppliers of seaborne HCC

Figure 2- Teck Coal Market Supply



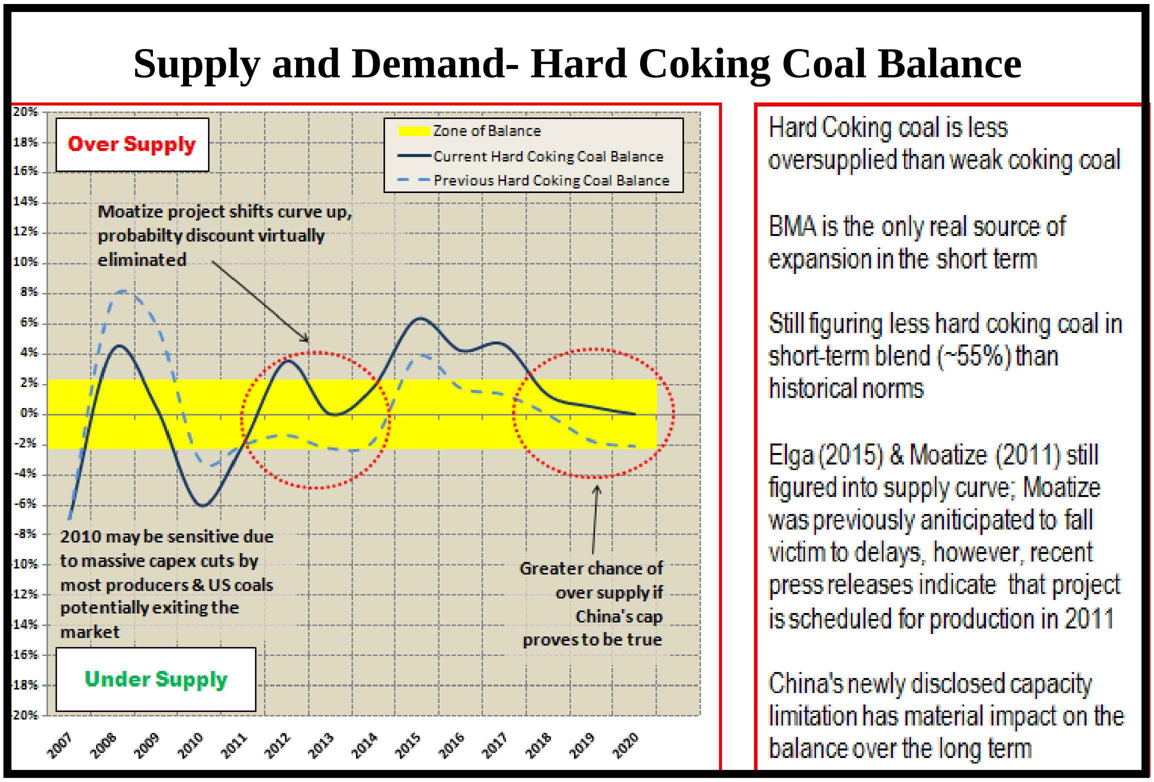
Source- Drawn by Author, Provided from Internal Document

of equal quality, compete on a price basis as buyers attempt to negotiate by putting downward pressure on the input prices of their raw materials.

In recent times, the HCC industry realized both an unprecedented volatility in demand and high prices for this raw material. This is attributed to an increased demand for steel in developing countries, primarily led by China's growth (Teck, 2009).

With an increase in demand, mining companies are expanding production, from existing operations to Greenfield projects (Teck, 2009). Specifically, new metallurgical coal Greenfield projects are being developed in Russia (Elga Project) and in Mozambique (Moatize Project). This increase in supply will have a material effect on supply and demand. Figure 3, *Supply and Demand for Hard Coking Coal*, taken from a Teck Coal internal presentation, represents a projection for the supply and demand balance of HCC and illustrates the current shortage of supply could transition to a balanced or oversupply situation. Only those organizations that can be cost effective will be competitive in an oversupply situation.

Figure 3- Teck Coal Supply and Demand



Source- Drawn by Author, Data from Teck Resources Limited, 2009- Quarterly Operators Meeting

Teck Coal utilizes some of the largest and most state of the art mining equipment in the world. This operational strategy aims to produce highly efficient operations such that site operating costs are minimized to offset the relatively higher distribution costs. To stay competitive, Teck Coal operates fewer pieces of equipment as these larger units are significantly more productive. Only a few years ago, Teck Coal's largest haultruck in operation had a 240-ton capacity and the largest shovel had an 85-ton capacity. Presently, haultrucks range in size up to a 400-ton capacity and most shovels in operation are the 120-ton payload class. These larger key assets must be consistently reliable and available for the operating group to support and maximize their efficiencies.

1.2 Project Overview

With the operation of large and complex mining equipment, Teck Coal requires an effective and efficient maintenance strategy to support its investment in mining equipment while meeting its operational needs. Teck Coal must transition to a more proactive maintenance strategy not only to support the operational requirements, but also to have equipment available at the lowest possible cost. Unplanned repairs as a result of breakdowns must be reduced. One of the driving factors that contributes to this problem is the need for Teck Coal to improve its ability to effectively identify equipment health conditions in a timely manner so problems can be addressed on a proactive basis thus reducing equipment failures. Technology can provide this insight.

This paper focuses on identifying areas where technology can be leveraged to provide opportunities to improve the mobile equipment maintenance strategy, which will positively contribute to Teck Coal's competitiveness in the world metallurgical coal supply chain. To be a competitive organization and gain a strategic advantage over its rivals, newer technology must be applied within the organization to significantly enhance its maintenance efforts, shifting Teck Coal towards a new paradigm focused on a proactive maintenance strategy. Part of this new paradigm includes improving its health monitoring of the equipment condition to minimize premature failures and to improve the productive capacity of the operation.

Advances in technology have been driven by organizational demands for the improvement of equipment performance. These include: improved knowledge of failure mechanisms, component health predictability, advancements in monitoring and sensing devices, advances in the form of diagnostic, trend related, and knowledge based software and developments in computer networking capabilities. Exploiting these opportunities provides differentiation, potential for first mover benefits and ultimately a competitive advantage.

In addition, a more proactive maintenance strategy incorporating an improved use of technology will help resolve an imminent shortage of skilled tradespeople such that this limited resource can be leveraged to complement its strategic advantage in maintenance. This requires the transition from expert fire-fighters to resolve breakdown problems to those roles within the organization that are value added activities, such as the execution of planned work.

Technology provides the tools for advancing processes towards a new paradigm of proactive maintenance. With an organizational transformation, leadership is critical in the change management process. The required cultural change within the organization in order to garner the full benefits of technological advancements and drive the appropriate behaviors required to support this, is equally important. A reminder by Alan Friedman that change management goes far beyond merely introducing technology, *"No program can succeed if it is not well conceived. If done correctly, a predictive maintenance program should change the culture, philosophy and* *workflow of the maintenance department. It's not just the addition of a new technology or tool, but a different approach or strategy towards maintaining one's assets."* (Friedman, 2009, 35).

The author has direct knowledge of the current and historical maintenance practices within Teck Coal from numerous years of experience associated with three of the Operation's mobile equipment maintenance departments. This experience allows the author to provide knowledge on where opportunities for improvement currently exist in maintenance. In addition, investigations on world-class maintenance strategies used in industry were conducted using the information available on the internet and by reviewing various reports, periodicals and whitepapers associated with this subject. The author also attended an internal best practice maintenance reliability seminar and held discussions with consultants and other knowledgeable personnel within Teck Coal in determining recommended changes required to move the organization to a world-class level.

Chapter 2 of this paper provides an industry analysis that describes general trends in the mining industry as well as trends in progressive maintenance strategies. It is vital to understand the general trends within high-capital intensive industries and the mining industry to create an awareness of what operational or maintenance strategies are being employed to improve efficiencies and lower costs and which of those maybe applicable to Teck Coal. Following this, Chapter 3 presents an examination of the current Teck Coal maintenance paradigm along with some initiatives currently underway. This provides some background information on previous maintenance strategies as well as an update on maintenance initiatives underway that are directly related to the focus of this paper.

From the Internal Analysis, Chapter 4 focuses on problematic areas within the current maintenance practices. The main problem analyzed is Teck Coal's inability to effectively identify equipment problems in a timely manner, which results in too much breakdown maintenance. The current time-based maintenance strategies employed are ineffective in providing this information. Reactive maintenance, or fire-fighting, is both inefficient and ineffective as it requires more maintenance effort than do properly planned and scheduled repairs. Also aggravating the lack of knowledge of equipment condition are the problems associated with subjective equipment inspections. Some diagnostic tools for assessing equipment condition that are currently in use are highlighted in this chapter, but the application of these technologies within Teck Coal will be shown to be very limited. Lastly, Chapter 4 will illustrate the large number of trade retirements the organization will be faced with. The loss of trades expertise and capacity exposes Teck Coal to an internal weakness based on its inability to maintain the equipment fleet availability to a level necessary to meet operational needs unless the current paradigm changes.

In Chapter 5 of this paper, opportunities to incorporate technology into the maintenance strategy are presented which will aid in the transition to a proactive paradigm. Specific technology aimed at implementing real-time condition based monitoring of the equipment is reviewed along with the capabilities of this software technology, including the opportunity to develop and utilize an expert system, which is a feature of this software. The transition to quantitative inspections that provide the ability to trend data and predict the state of equipment components is also presented. This chapter proposes solutions to substantially improve the effectiveness and efficiency of the scarce trades resource by transitioning from breakdowns to proactive work. Not only will the right work at the right time be the outcome, but the amount of required repair work will be minimized. The estimated financial benefits of implementing the solution are presented in the final section of this chapter to present what is believed to be the minimum opportunity available.

The implementation phase associated with the introduction of the technological solutions into the maintenance departments at Teck Coal is presented in Chapter 6 of this paper. In particular, Kotter's principles for leading change are used to demonstrate the change management process required to successfully create a new maintenance paradigm within the organization. Chapter 7 includes a brief summary of the aspects presented in this paper and concludes with recommendations for Teck Coal based on the analysis of this report.

2.0 Industry Analysis

This chapter focuses on trends in open pit mining companies as well as the maintenance trends in the industrial sector. With the advancements in high-speed wireless communication, the application of technologies used successfully in fixed plants can be effectively employed in mobile equipment maintenance. In conducting the analysis for this paper, it is apparent organizations recognize the opportunities for both cost and productive capacity gains which can be achieved simply by improving their internal maintenance strategies. When done effectively, this can maximize asset value and drive higher profits.

2.1 Mining Company Trends

Mining companies are in a capital-intensive sector and they invest significantly on the acquisition of mobile equipment such as large haulage trucks, loaders, electric shovels and drills. In addition, there are considerable operating costs associated with this equipment. In recent times, strategic decisions are being made by numerous mining companies to invest in fewer but in larger mining equipment. In recognition of this, Original Equipment Manufacturers (OEM's) of mining equipment are designing increasingly larger equipment. Electric shovels have increased in size from a maximum bucket payload of 56-tons to 120-ton capacity. Figure 4, *Evolution of Haultrucks*, illustrated below shows the growth in size of the Caterpillar haulage trucks capable of carrying payloads from a 50-ton unit to the newer 400-ton units. This new equipment is not only larger; it is also faster, adding to operational efficiencies.

Figure 4- Evolution of Truck Sizes

Source- Caterpillar, 2008- Understanding Mining Truck Drive Systems. Reprinted with permission

Simultaneously, this strategy also minimizes the number of people an organization needs for production, thus reducing costs. Combining the large-scale projects underway in the oil sands area with the shortage of labour in that area, the need to use some of the largest equipment in the world is nowhere more apparent (Wells, 2007). This trend in transitioning to larger equipment is similar to what Teck Coal's main competitors are also doing. Research conducted on an electrical shovel manufacturer shows a significant increase in large shovel sales, supporting the higher demand for these products.

2.2 Maintenance Trends

Industry in general has recognized opportunities to achieve higher production levels and lower costs through effective maintenance strategies. The positive economic impact on increasing overall equipment effectiveness (OEE) is a major incentive for organizations to develop an overall strategy that supports this and is driven by the business goals. This aligns the respective objectives of both maintenance and production through effective asset management.

Processes including Six Sigma, 5S, Kaizen and others are being used in capital-intensive industries to maximize asset performance through the support of reliability practices and technologies to eliminate failures. These processes also focus on the elimination of waste, teamwork between operations and maintenance, and a continuous improvement cycle. This supports the drive to improve maintenance performance and also reinforces the notion that maintenance is much more than a cost centre, it generates productive capacity.

In mining, all maintenance downtime associated with larger equipment now represents a higher percentage of operational capacity loss. Accordingly, this equipment downtime has a negative effect on a mining company's ability to meet its production targets and its ability to generate revenues, in particular when the mining equipment is the operation's bottleneck.

Having reliable mobile equipment that performs as intended and operates at the lowest possible cost, is essential to the success of an operating mine. The ability to achieve these results in a consistent manner will provide an operating mine with a competitive advantage. The maintenance of this mobile equipment represents a significant aspect of asset management and an organization's bottom line. Effective maintenance is a vital aspect in providing a competitive advantage in the global market.

Based on research conducted on leading asset management strategies, best in-class maintenance trends include real-time condition monitoring , thermography, vibration analysis, and laser alignment devices to support the processes mentioned above. In addition to this, significant effort is being placed on improving the effectiveness and efficiency of maintenance planning, scheduling and work execution. Implementing reliability practices and strategies are also critical in order to succeed in achieving world-class maintenance.

Process and oil and gas sectors are amongst the leaders in the implementation of proactive maintenance strategies and in the integration of new technologies within their processes. Dofasco Steel is renowned for having effective world-class maintenance processes and have won the maintenance excellence award for being the best managed maintenance facility. They are an industry leader in proactive maintenance and reliability strategies (Ivara, 2005). The technologies employed in these organizations were considered when proposing solutions in this paper.

With major advancements made in high-speed wireless technologies, the same proactive strategies used in fixed plant applications, can now be effectively used on mining equipment. Essentially, similar initiatives that have been successful for the non-mining industry are now making their way into the mining sector. An example of this is Ivara Corporation has applied the similar processes and initiatives used in fixed plants on a mobile equipment fleet at an iron ore company (Ivara, 2000). These technologies provide opportunities in mobile equipment and first movers will have a competitive advantage.

3.0 Internal Analysis

This chapter will provide an assessment of the current maintenance paradigm at Teck Coal along with initiatives underway to reduce costs, improve productive capacity and to improve the competitiveness of the organization. Teck Coal realizes improvements in mobile equipment maintenance is necessary to be competitive and has created a vision to support this. Information about changes underway in maintenance are presented, which will resolve maintenance processes issues. Despite the changes underway, there is still a gap in the overall maintenance strategy that exists, which is truly understanding the equipment condition. This information is critical in making the maintenance processes effective as it is this knowledge that is necessary to feed the processes. Until this is resolved, unnecessary equipment breakdowns will continue. In addition, some of the effects of equipment breakdowns are also highlighted in this chapter.

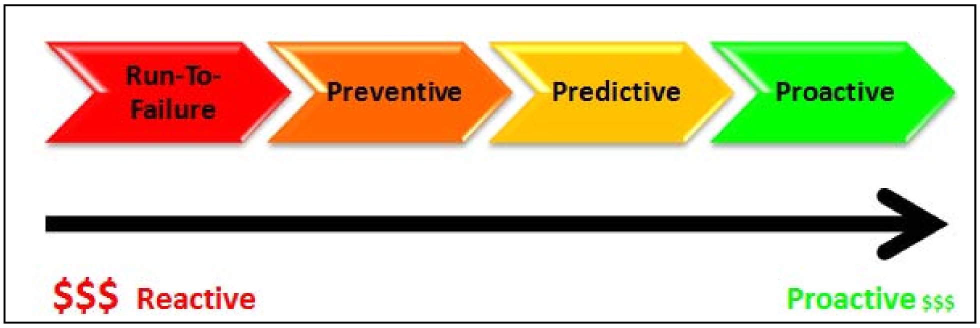
3.1 Current Maintenance Paradigm

Teck Coal is currently utilizing some proactive maintenance and predictive strategies but generally utilizes a time-based maintenance strategy thus operations suffer with equipment breakdowns. This results in reactive work. In 2006, Ivara Corporation completed a reliability assessment at Fording River Operations; Teck Coal's largest operating mine. At the time of the assessment, it was concluded that 35% of the maintenance work being completed on mobile equipment was reactive in nature (Ivara, 2006A). This is representative of all sites as similar practices are used.

The study was completed a few years ago, and though enhancements have been made to improve maintenance processes and reliability, the amount of breakdown work has not changed materially within Teck Coal. A substantial number of maintenance activities are stuck in a time-based maintenance paradigm that has been around for numerous years. There are still too many surprises related to equipment health. As a result of this reactive environment, a significant portion of a tradesperson's time is spent acting as fire-fighter, repairing a breakdown as quickly as possible so the equipment can return to operation. Considerable effort is being applied on expediting breakdowns repairs as opposed to eliminating the breakdowns. By nature of current practices, the cultural change could be difficult for some tradespeople because of deep-seated beliefs and historical practices. Furthermore, repairing breakdowns in a quick manner is a behaviour that is often rewarded. This unfortunately positively reinforces a reactive culture for some.

All Teck Coal operations conduct maintenance in a similar manner so a tremendous opportunity exists to improve on the overall maintenance strategy. The organization must transition from reactive to proactive as shown on Figure 5, *Transformational Change in Maintenance Strategy.* This will result in both lower repair costs and an increased production opportunity (Ivara, 2006A)

Figure 5- Transformational Change in Maintenance Strategy

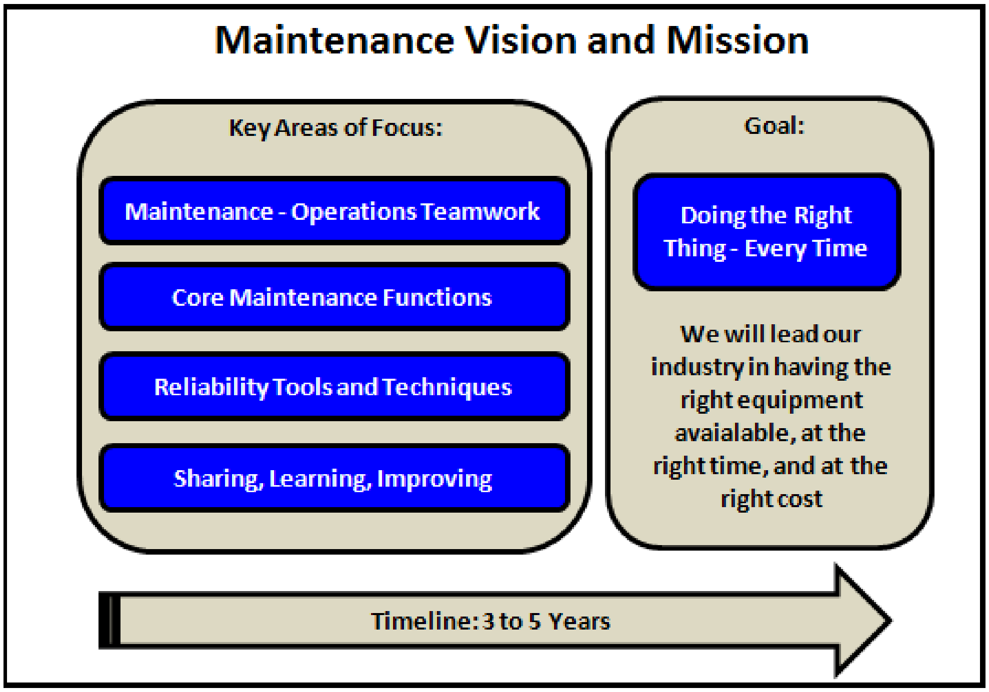


Source- Drawn by Author

3.2 New Teck Resources Maintenance Vision

Teck Resources Limited introduced an initiative in 2009 focused on improving its overall maintenance performance. This was primarily driven by an opportunity to reduce its annual maintenance spending of $700M. The organizational goal for maintenance is *Doing the Right Work at the Right Time*. Doing too much work too soon or too little work too late are both ineffective in achieving world-class maintenance standards and results in a poor utilization of manpower. Teck Resource Limited's annual operating costs on mobile equipment maintenance were $500M in 2009. This represented approximately 12.5% ($4,012M operating expenses in 2009) of its annual operating expense (Teck, 2009). The key areas of focus for the maintenance initiative are illustrated in Figure 6, *Teck Resources Maintenance Vision and Focus Area,* on the following page.

Figure 6- Teck Resources Maintenance Vision and Focus Areas



Source- Drawn by Author, Teck Resource Limited, 2010 - Maintenance Vision and Mission Presentation

Specifically in Teck Coal, the cost of mobile equipment maintenance is $325M and represents 28% of the total operating expense as the mining activities contribute to a higher proportion of the overall site costs. This information was provided by Shehzad Bharmal, Director of Business Improvement for Teck Resources Limited. This cost presents a significant opportunity for cost savings if improvements in maintenance are realized. Aligned with the organizational goals, one of Teck Coal's business goals is as follows:

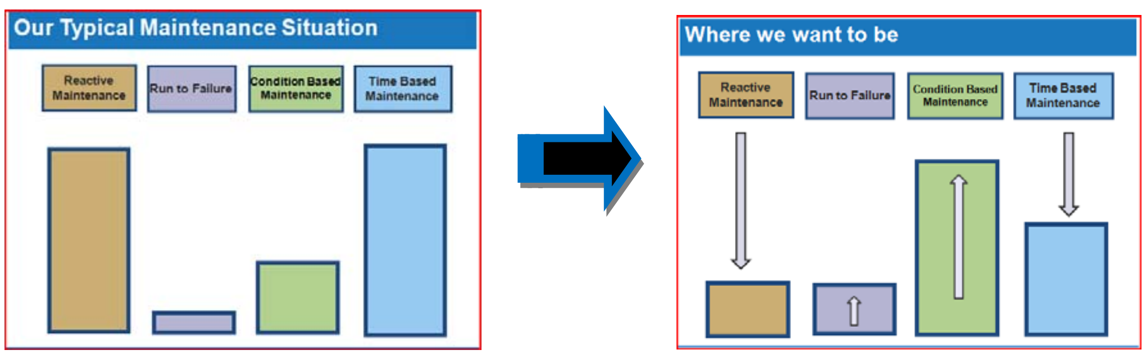
> *"We will become "best-in-class", measured against a comparable global standard. We will operate with a disciplined, planning-based management culture, maintaining adherence to plan while allowing for changing conditions and improved knowledge. While promoting safety and the environment as core operating values, we will ensure that our mine sites remain positioned in the lower half of the cost curve and that we achieve product quality within targets for key parameters identified as important by our customers.*
>
> (Payne, 2008, 37)

This reinforces why a new paradigm in maintenance is required.

3.3 Core Maintenance Process Initiative

Recently, *Celerant Consulting* was engaged by Teck Coal to develop effective maintenance processes within the operations. In particular, these processes included work identification, scheduling, planning and work execution. At the onset of the project, Celerant completed an initial assessment to establish baseline performances. Key Performance Indicators (KPI's) were established at this time to measure the project progress and various successes. The overall goal was to assist the organization in its transition from time-based and reactive work to more condition based as illustrated below in Figure 7, *Maintenance Transition*:

Figure 7- Maintenance Transition



Source- Celerant Consulting, 2010- Presentation Submitted to Line Creek. Reprinted with permission

A fundamental principle Celerant engrained in the maintenance staff was to execute the planned work and manage breakdowns such that these would not negatively affect either the execution of planned work or operational performance. One of the Celerant principles states that fewer breakdowns will result if more planned work is executed. Celerant also introduced important process changes within the maintenance departments including redefining the planning and scheduling roles. Their process ensured a high priority was maintained on completing scheduled work because this is the most efficient and effective form of work execution. As part of their process enhancements, all non-scheduled work had to be prioritized using a risk matrix to determine the timing for the repairs based on both operational and maintenance requirements. A structured approach to facilitating effective meetings along with the necessary coaching required to make this sustainable was conducted. Improved accountability and delivering on established commitments was reinforced with the maintenance staff. Meetings became focused on reviewing barriers that prevented schedule compliances. In addition, opportunities to improve the identification and correction of process failures were reviewed. Celerant Consulting assisted in initiating reliability practices in maintenance in conjunction with the process improvements.

To make the processes of this initiative effective, which will help the organization move to a more proactive strategy, it is vital that the right work be identified. One of the challenges associated with improving core maintenance processes is the requirement to understand the current state of the equipment health. In absence of this knowledge, the overall effectiveness of maintenance is less than desired as the right work is not always understood. This is supported by Christer Idhammer who stated, "*Furthermore, a high level of planning and scheduling cannot be reached without the support of all other elements of good maintenance, including maintenance prevention, preventive maintenance, storeroom support, root-cause problem elimination, etc."*(Idhammer, 2010, 19)

3.4 Overtime and Contractor Usage

Teck Coal is using more overtime and contractors than ever. These strategies are required primarily as a result of a shortage of experienced tradespeople. Both result in higher costs but are required to ensure the operating productive capacity of Teck Coal is maintained. Contractors are often required to provide expertise as the mining equipment manufacturers have local service branches to support the equipment. Traditionally, overtime has been used to assist with breakdown repairs, however, there is more reliance on contractors to assist with this work simply due to the shortage of tradespeople.

3.5 Contractor Response to Manage Inventory

OEM suppliers have also been under cost pressures and have responded by reducing local spare parts inventory in favour of larger, more centralized warehouses. This increases the need for accurate maintenance plans and breakdown avoidance to minimize disruptions caused by the difficulty in sourcing parts locally. Non-planned events, or breakdowns, dramatically increase production losses as the equipment is out of operation for extended periods and costs increase due to parts expediting.

4.0 Problems Associated with the Current Maintenance Strategy

Teck Coal's annual cost associated with the maintenance of the mobile equipment is $325M. This represents 28% of the total operating expenses (Teck, 2009). One of the main problems associated with the current maintenance paradigm is Teck Coal's inability to effectively identify equipment health problems in a timely manner. In this chapter, this issue and the contributing factors to this problem are identified and analysed. Collectively, these contribute to additional costs, operational disruption and additional work.

The author has many years of experience in maintenance at Teck Coal, including managing two of the maintenance departments. As well, the author has served on an internal maintenance best practice committee and is currently involved with some of the maintenance initiatives. Consequently, the author has direct knowledge of the current maintenance paradigm, which is used for the purpose of this chapter.

4.1 Identification of the Problem

Based on the industry analysis and the internal analysis chapters, current maintenance practices do not provide the ability to effectively identify equipment conditions in a timely manner, which results in excessive breakdowns and creates more work than necessary. This problem must be resolved to provide either a competitive advantage or at a minimum, avoid a competitive disadvantage. Four issues associated with the problem, some of which contribute to the problem, will be analyzed to demonstrate opportunities for improvement. These include the following:

- A lack of knowledge of equipment health condition and managing an inordinate amount of data
- Too much subjectivity associated with maintenance inspections
- A lack of application of diagnostic tools and devices
- There will soon be a scarcity of tradespeople and experience which is relied on to complete the repair work

Using the details provided in Chapter 5, section 6 (Financial Benefits of Solutions), it is estimated that a 15% cost savings and a 2.6% productive capacity increase would be realized by transitioning from a time-based paradigm to a strategic proactive paradigm. For the purpose of this analysis, it is recognized that the improvements to processes currently underway will also contribute to the overall benefit so this is taken into account. The ability to effectively identify equipment problems in a timely manner dovetails with the process improvements underway, and is required to obtain the full financial benefits of proactive maintenance. This ensures the right work is completed at the right time. It is estimated by the author that ensuring the right work is being completed will contribute 40% of the benefit and from this benefit, 55% is directly related to having knowledge of equipment health to avoid breakdowns. Overall, this represents a 3.3% maintenance savings and a 0.58% productive capacity increase or an opportunity to improve profits by an estimated minimum of $11.5M per year, after start-up costs are incurred. Figure 21, *Breakdown of Opportunities- Cost and Availability,* on page 52 illustrates the benefits identified above.

The following sections provide an analysis of areas in maintenance that were identified and require improvement in order to achieve a more proactive maintenance paradigm.

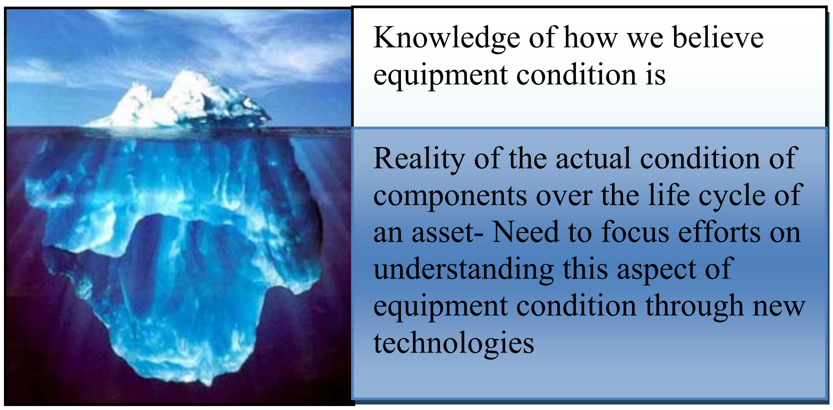
4.2 Lack of Knowledge of Equipment Health Condition and Managing an Inordinate Amount of Data

The most significant problem contributing to excessive reactionary work and breakdowns is Teck Coal's lack of knowledge associated with its mobile equipment health condition. The primary activities associated with maintenance at Teck Coal, which have been in use for numerous years, are typically time-based strategies. Equipment is routinely scheduled for time interval work where condition assessments or planned jobs are completed. Examples include: replacing an engine at 15,000 operating hours, or taking oil samples every 500 operating hours, conducting thermography on powerlines quarterly or downloading VIMs data every 4 months.

Understanding what is the right work that should be carried out on mobile equipment is a large problem for organizations. It is common to find that 50% of the work completed by organizations that are even employing proactive maintenance strategies, is the wrong work (Ivara, 2006A). This is primarily because maintenance does not fully understand the condition of its equipment, nor does it fully understand what is causing or preventing the failures. The problem is exacerbated when a time-based or planning maintenance strategy only reveals a portion of the equipment health. This is illustrated with the concept of an Iceberg shown as Figure 8 on the following page.

This lack of knowledge causes equipment to operate in undesirable conditions and results in breakdowns. The associated unplanned repairs are costly, inefficient, and negatively affect production demands. In the future, breakdowns will inevitability result in equipment sitting idle for longer durations as the manpower available to complete the repairs will be limited. Figure 8, *Maintenance Knowledge Iceberg,* represents the condition an asset is believed to be in, as compared to its actual condition.

Figure 8- Maintenance Knowledge Iceberg

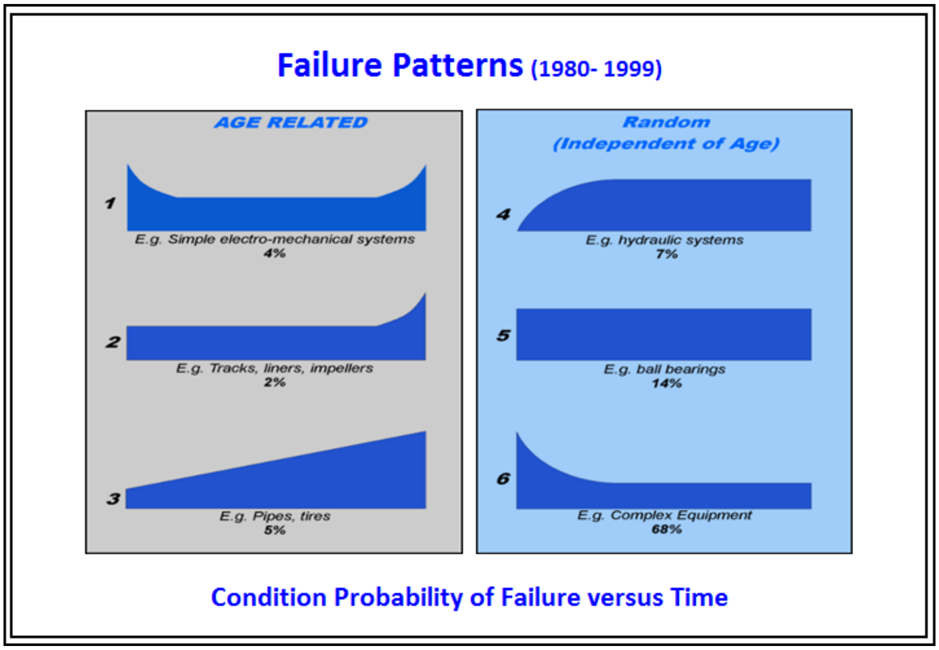


Source - Iceberg taken from Teck Resource Limited, 2009- Courageous Safety Leadership Presentation

The statement that *65% of equipment failures occur between services* (Conkright, 2010) exemplifies why time-based maintenance strategies are ineffective because using this strategy, the actual equipment health condition is largely a mystery. These failures between services result in poor equipment reliability and lower availability. Eliminating, or minimizing these breakdowns, is the primary motivation for why a change from current practices is needed. A sense of urgency in understanding equipment health condition is required. At the time of its assessment at Fording River, Ivara Corporation also stated that, "*although the majority of most industries PM program is time based, it is widely accepted that <20% of all failures can be addressed by applying time based maintenance. In order to address the >80% of the failures that conform to a random failure pattern it is essential to establish a structured on-condition program...*" (Ivara, 2006B, 47).

The time-based maintenance or a planning paradigm presumes there is always a direct relationship between operating life and equipment failure probability. Studies have shown there are six well-defined modes of equipment failure probability. These are illustrated on the following page as Figure 9, *Failure Patterns versus Time*. Though the failure probability curves shown are associated with the aircraft industry, the failure modes are applicable to most mechanical and electrical assets. The more complex equipment becomes, the more the failures are representative of the patterns shown as 5 and 6, which have a tendency to be more random in nature.

Figure 9- Failure Patterns versus Time



Source- Drawn by Author, From Teck Coal, 2010 - Best Practice Meeting

New maintenance strategies must be developed to assume that failures can occur at any point in time, or randomly, in the absence of effective condition monitoring. This is a significant shift from the existing belief that failure probability increases after some fixed-time interval. The change management aspect of modifying the deep seated beliefs would be a problem as it seems to be contrary to what is viewed as common sense; (i.e. –older components are more likely to fail unexpectedly).

Modern equipment is equipped with numerous and sophisticated health monitoring sensors; however, Teck Coal maintenance processes have not been developed to capture this information effectively and efficiently such that this data can be converted to timely knowledge of the condition of equipment. Often early warning signs are unknown to those who need to make decisions until there is an eventual failure. There is an inordinate amount of data available from each on-board data logger that records numerous condition events, operating behaviours and health status information, such as VIMs on Caterpillar equipment. Unfortunately, this information is only used on occasion as there is too much data and information to manage manually. Unless there is a critical fault, the information is often ignored because the amount of data is simply unmanageable. An opportunity to use this information to trend health condition or identify issues before equipment breaks down is lost.

Time-based interval maintenance results in lost opportunities in understanding equipment condition and contributes significantly to breakdowns and unreliable equipment.

4.3 Too Much Subjectivity in the Inspection Processes

The current process for the equipment maintenance inspections involves the completion of a set of instructions and assessments by the tradesperson. The results of the inspection are collected and recorded on paper sheets. This process has been around for numerous years. The dynamic and static inspections are used to assess the equipment health and determine what repairs are needed. The nature of the inspection instructions and accordingly, the responses to the various tasks, are too subjective. Problems arise as tradespeople typically respond to an inspection with a check mark (√) which indicates a favourable result, and that the machine health is satisfactory. Though the conditions are still within an acceptable standard, there is seldom any quantifiable data provided, which would add much more value to the inspection process. Often, an (X) and a comment are used when the condition requires attention. Inspection sheet instructions provide limited usability guidelines and acceptable wear limits. When used, these serve as "go or no-go" decisions by the tradesperson to decide whether a corrective action is required. Most of the inspection instructions are viewed as black and white, either it needs a repair or adjustment, or it is acceptable. It is typical that only the problem areas are being identified. The paper inspection sheets lack the necessary details and instructions to make them an effective tool for both the tradesperson and those interpreting the results. The subjectivity of the process is aggravated by the fact that when a measurement is requested, the accuracy and variability of the measurement is left up to the tradesperson. As an example, one tradesperson may be measuring to the closest 10mm, while others may be measuring to the closest 15mm, which can be a significant difference if this information was used for trending purposes.

Deficiencies identified during the inspection process become an unplanned repair and the inefficiencies associated with these types of repairs occur. This also results in an unexpected delay in returning the equipment back to the operating group.

Once completed, the inspection sheets are forwarded to the maintenance planning group. These are reviewed by reading any notes provided by the tradespeople and by checking the recorded measurements. If the measurements are below the thresholds, the paper inspections are filed. The same process generally continues until at some point, a repair becomes necessary.

The problem with the current inspection process is the subjective information does not lend itself to analytical assessments that could in turn be used to predict the future health state of the equipment. An opportunity to gain valuable insight into the present and future condition is lost due to the subjectivity and lack of instructions on the paper inspection sheets that are used by the tradesperson. Figure 10, *Subjective Maintenance Inspection Sheets*, shown below is an example of generic inspection instructions currently employed and illustrates why they add very little value in effectively identify future problems.

Figure 10- Subjective Maintenance Inspection Sheet

Current Haultruck PM Inspection Process

	1000 HOUR Initial
GROUND CHECKS:	
- DO "SHAKE" TEST	________
- CHECK STEERING LINKAGE FOR LOOSE OR WORN HARDWARE	________
- CHECK HOIST CYLINDER FOR LEAKS, DAMAGE, WORN PINS, KEEPERS AND BEARINGS **(pull bottom hoist cyl cap inspect hoist pin & bearings and make sure retaining bolt is tight)**	________
- CHECK BOX HINGE PIN AREAS FOR WEAR OR DAMAGE	________
- CHECK SWAY BAR FOR WEAR AND TIGHTNESS	________
- SPOT CHECK TORQUE ON BRAKE HOUSING BOLTS	________
- TIGHTEN TRANSMISSION MOUNTS	________
- CHECK MAINFRAME AND SIDE FRAMES FOR CRACKS	________
- CHECK A-FRAME FOR DAMAGE & EXCESSIVE WEAR	________
- CHECK TORQUE, DIFF MTG BOLTS SHOULD BE 110 FT/LB	________
- ADJUST DIFFERENTIAL THRUST STOP	________

Source- Figure by Author

4.4 Lack of Application of Diagnostic Tools and Devices

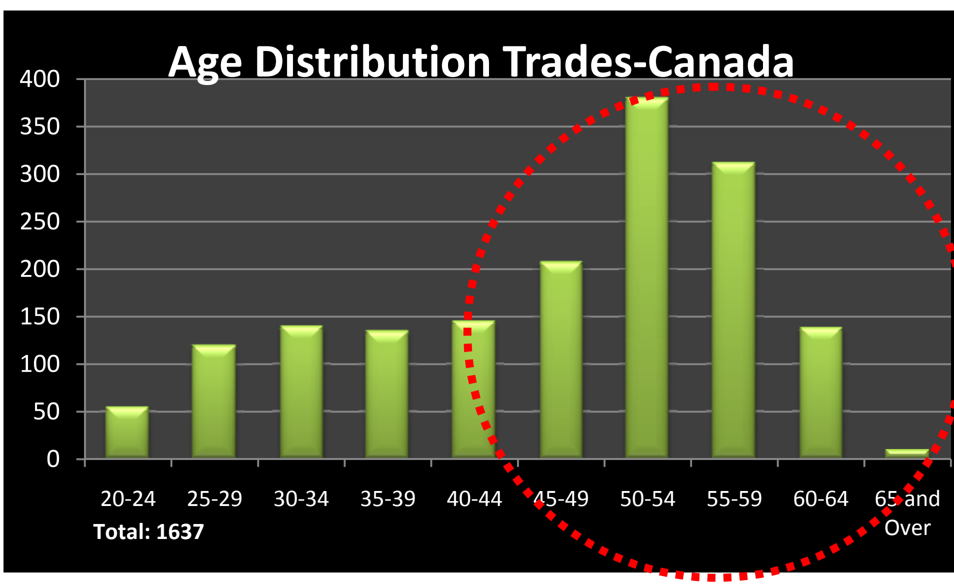
Methods of assessing equipment condition routinely employed at Teck Coal include visual observations, manual measurements, pressure checks and temperature sensing. Further to this, each site has established a Non Destructive Testing (NDT) group, typically made up of one or two individuals. The NDT groups use maintenance diagnostic testing equipment such as ultrasonic equipment, thermography cameras, vibration analyzers, and alignment tools. In the past, these diagnostic tools were significantly more complex to use. Historical problems included difficulties in setting up the devices and often interpreting what to do to resolve the problem was challenging. The individuals originally selected to use these diagnostic tools required a significant investment in training and, for some of the test equipment, several years of practical experience before developing competency in their applications. As such, this became a very specialized group within Teck Coal and limited in size. In turn, this has restricted the applications these devices are used to assess mobile equipment health, which is problematic as these tools and devices provide some of the most important early warning signs associated with the mobile equipment health condition. It also represents a very under-utilized health monitoring strategy for mobile equipment within Teck Coal.

Another problem that exists with the application of maintenance diagnostic testing is the frequency in which testing is conducted. In order to use the current diagnostic tools, the equipment must be taken out of operation. As such, to minimize the disruptions to operating group, this type of monitoring occurs infrequently, such as on a maintenance service. As most failures tend to occur randomly, the effectiveness of these periodic diagnostic checks is limited.

4.5 Scarcity of Tradespeople and Experience

The current demographics of tradespeople highlights the organization will face numerous retirements in the near future. This presents a weakness within Teck Coal. This problem will negatively affect the organizations ability to maintain the mobile equipment fleets. With the amount of breakdown repairs currently required, there will be an insufficient amount of tradespeople to complete repairs and maintain the equipment. This group's demographics within Teck Resources are shown below in Figure 11, *Age Distribution of Trades in Canada*, and are

Figure 11- Age Distribution of Trades in Canada



Source- Drawn by Author, Data taken from Teck Coal, 2010 - Presentation by Ivan Moser taken from a presentation prepared by Ivan Moser, Human Resource Manager, Teck Coal, and illustrates the number of retirements the organization will be facing in the ensuing years. This is also representative of trade's demographics for Teck Coal, as per Dean Winsor, General Manager of Human Resources for Teck Coal. These retirements will create two major problems. First, there will be a tremendous amount of experience, or intellectual capital, leaving the operations. This will result in a maintenance brain drain and poses a critical risk to the operations. Secondly, there is a lack of tradespeople available in industry so securing replacements will be a challenge. In fact, this is already the current situation. There is a modern day cultural bias against a trades type career choice, in favour of those careers offering higher incomes such as professional careers (Currie, 2006). As such, the access to tradespeople, especially those with experience, is extremely limited. Current practices underway to mitigate the problem include maximizing the number of trade apprentices. However, the experience level and competency of the maintenance departments is deteriorating as these apprentices are an increasing proportion of the trades group. This results in longer repair times and more frequent misdiagnosing of problems associated with mobile equipment.

Further aggravating this problem is Teck Coal's mining equipment is getting larger and the demands on its availability are higher than ever. This new equipment is also getting more complex and sophisticated. The skills necessary to maintain these assets has increased and the availability of this resource is diminishing. Fewer and fewer competent tradespeople to carry out effective maintenance work will be available. This resource will be relied on to work safer, faster and handle a new level of maintenance technical complexity (Currie, 2006). Tradespeople can no longer be replaced on a one-to one basis; therefore, maintenance departments within Teck Coal will be relied on to maintain equipment fleets with fewer tradespeople.

The current maintenance paradigm often results in breakdown or reactionary work, which is the most ineffective use of manpower. Too much fire-fighting repair work is completed. All sources of inefficiency for this valuable resource must be eliminated as this problem poses a serious risk for Teck Coal. World-class wrench-time is 65% and studies in Teck Coal indicate the operations are near the industry average of 40% (Ivara, 2006A). A large opportunity exists to improve the efficiency of tradespeople.

5.0 Strategic Response- Applying New or Advanced Technologies

Solutions to the main problem previously identified are discussed here in Chapter 5. These solutions will help shape a new proactive maintenance paradigm. The contributing issues to this problem will also be addressed in this chapter. The solutions proposed are based on internet research, maintenance magazines, reliability and asset management whitepapers and discussions with consultants and subject matter experts in various maintenance fields as previous described.

After conducting research and analyzing industry trends, it is apparent that there are technological solutions available to assist in resolving each of the problems identified. The focus of this chapter is to present these solutions and demonstrate how they address the problems identified, see Figure 12, *Matrix of Solutions to Problems Identified.* These are explored in depth in the chapter. Finally in the last section of this chapter, the minimum estimated financial benefit of implementing the solutions proposed is presented.

A brief overview of a strategic approach to implementing technology is provided in the following section.

Figure 12- Matrix of Solutions to Problems Identified

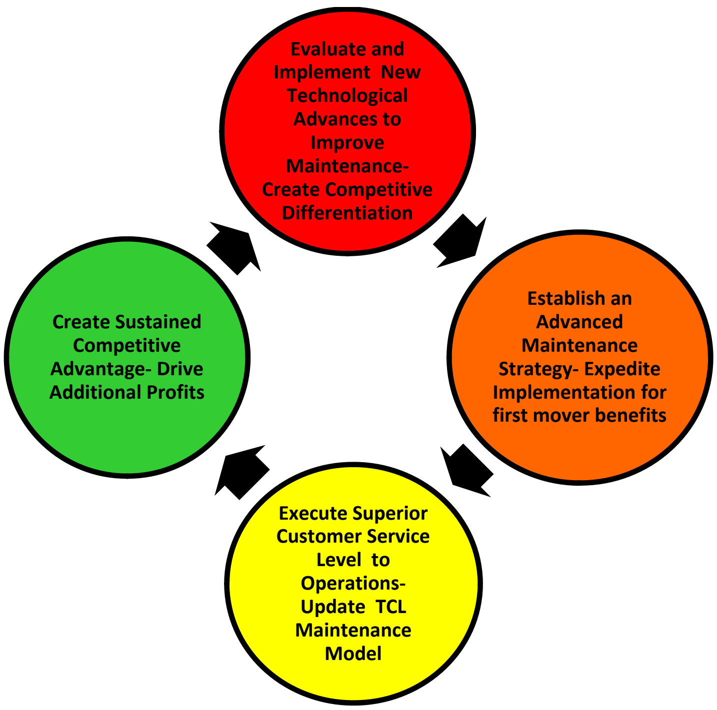
	Problems Identified			
Solutions Resolve Which Problem Identifed	Lack of Knowledge of Equipment Health and Managing Data	Too Much Subjectivity in the Inspection Process	Lack of Application of Diagnostic Tools/Devices	Scarcity of Tradespeople- Loss of Experience and Less Tradespeople to do the Work
Real-Time Condition Monitoring with Data Management and an Expert System	✓			✓
Quantify the Inpection Process- Objective Inspections with a PDA Capable of Trending	✓	✓		✓
Increase Application of Diagnostic Tools and Devices- Use Predictive Tools, some Constant Monitoring	✓		✓	✓
Knowledge Capture Used to Expedite Troubleshooting and Repair Times				✓

Source- Drawn by Author

5.1 Technology- A Strategic Approach

The application of newer technologies is required to drive a paradigm shift which will result in a superior maintenance strategy. Consider Figure 13- *Continuous Improvement Cycle Using Technological Improvements- New Maintenance Paradigm*. The implementation of technological advances to improve maintenance will not only resolve the problems identified, these can create a competitive differentiation. Emerging technology, or disruptive technologies, utilized within Teck Coal's maintenance strategy can provide first mover benefits and the potential opportunity to participate in the development stage of some of this technology. With effective new strategies in place, the organization will transition to a more proactive maintenance approach through the application of new technology to increase value added work. An improved internal customer service level is provided to the mine operations group as they have the productive capacity required to meet the operational needs. This new paradigm complements the operational strategy of being dependant on operating fewer and larger pieces of equipment. The continuous evaluation of new technologies and the implementation of those aligned with the maintenance vision must be undertaken to promote a competitive differentiation. A continuous improvement cycle must be established as a critical process in the new paradigm.

Figure 13- Continuous Improvement Cycle Using Technological Improvements- New Maintenance Paradigm



Source- Drawn by Author

5.2 A New Approach to Condition Monitoring To Gain Knowledge of Equipment Health and Data Management

The largest opportunity to fundamentally change the way maintenance is conducted in Teck Coal is in implementing an effective real-time condition monitoring strategy. This solution addresses the problem previously identified as the lack of knowledge of equipment health and will also be shown to mitigate the problem of the scarcity of both tradespeople and experience as tradespeople retire. This change will have the greatest effect on reducing unexpected breakdowns which are very disruptive to the mining operation and is an inefficient use of tradespeople. This technology facilitates a critical aspect of a strategic maintenance program: identification of the right work needed at the right time. The sophistication of today's technology can also be utilized to reduce troubleshooting requirements, which offsets some of the loss of experience. This is supported in a whitepaper by SmartSignal, "*In order to obtain the timeliest understanding of equipment health for all key resources in a large plant or fleet, engineers increasingly turn to real time, model based solutions*" (Gandhi, Herzog, Nieman, 2010, 3).

Large mining equipment, which is critical to a business's success, must operate at high levels of reliability and availability. In order to facilitate this, constant attention is required to eliminate surprise events. This level of attention requires equipment health condition to be frequently and accurately measured to avoid unscheduled breakdowns and costly repairs (Currie, 2006). Constant or real-time monitoring provides the timely understanding of equipment health. Real-time, model based solutions, provide the capability of providing executable knowledge from the inordinate amount of data being collected and analyzed. The sophistication of current technology provides the opportunity for the analysis of the reams of data available, both current and historical, and to use this to statistically make predictions about future events. Technology has the ability to turn a massive amount of data into exception based intelligence. The benefit of this condition monitoring is, it automatically detects and diagnosis anomalies early enough to shift what would have been an unplanned breakdown, to a planned and scheduled repair. This will increase the effectiveness of the trades resources available and will improve productive capacity. The manual management of this inordinate data is almost impossible. The benefits of condition monitoring are emphasized by Michael Currie, "*Condition Monitoring frees people's time to do the things that really matter in managing assets. It imposes discipline. CM is at the core of programs designed to identify conditions leading to equipment failure, avoiding those situations in the future, and extending the life of assets that otherwise would be repaired before it was necessary. Tradesmen's time is much better spent engaged in planned, preventative and* *predictive tasks and in feeding information back to reliability engineers in order to gain continuous improvement."* (Currie, 2006, 1).

Predictive analysis technology and real-time condition monitoring typically require basic processes. These include:

- A representative mathematical model
- Produces an estimate of normal equipment operating conditions based on its healthy state
- Acquires actual sampling of current state
- Compares the representative model estimates of expected operating conditions against actual to detect deviations
- Assesses the magnitude of deviations to categorize as normal or significant.

There are limited options available for real-time condition monitoring systems available as this technology is relatively new to mobile equipment. Condition monitoring software applications developed on empirical methods include both parametric and non-parametric.

An accurate understanding of what problem is trying to be solved is a critical factor as is the understanding of the advantages of the analytical tools. Models of analytic solutions should be considered on key technical elements, such as; algorithm accuracy, robustness and speed, the simplicity of design and results and model adaptation, and the ability to provide appropriate visualization and a clear communication of results (Gandhi, Herzog, Neiman, 2010).

Also some consideration must be made regarding how the software is aligned with business processes and provides practical results for Teck Coal. These factors include its ease of use, training and maintenance and the flexibility, as well as its adaptability and growth potential across equipment fleets (Gandhi, et al., 2010).

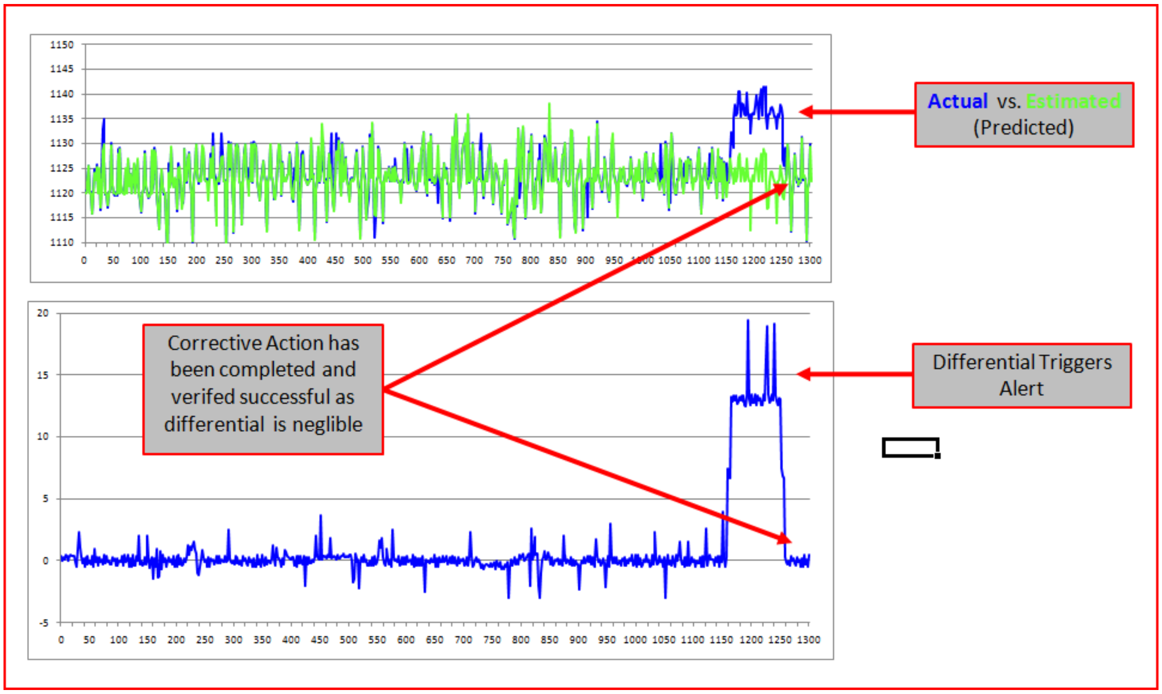
Similarity based modeling (SBM), a non-parametric model, used as a predictive model for mobile equipment, has been shown that its technology surpasses others in detecting faults (Gandhi, et al., 2010). It makes fewer assumptions and its applicability has a much wider range than parametric methods. It can be used in conditions where there is less known about the application being analyzed. As there are fewer assumptions, non-parametric models are not only more robust, they are simpler.

Parametric modelling is well suited for stationary, steady state conditions. Non-parametric modelling excels in situations where conditions are highly transient, as is the situation with mobile equipment fleets. The conditions associated with mobile equipment are continuously changing. For instance, a haultruck could be operating loaded or empty, it could be travelling uphill, downhill or it could be operating on flat ground. In addition, throttle position, temperature, speed and payload also vary significantly and can be highly irregular. The complexity in modelling these changing conditions is a very difficult challenge; however, non-parametric modelling excels in analyzing the multitude of varying conditions associated with mobile equipment. SmartSignal technology is a powerful real-time condition monitoring system that employs non-parametric modelling (Gandhi, et al., 2010). From a large amount of data collected of the equipment operating conditions, it is able to predict future performance. Its models are built by reconstructing patterns associated with historical data equipment operating conditions taken from the equipment while in a normal healthy state. As an example, SmartSignal uses information from a data logger such as Caterpillar's Vital Information Monitoring System (VIMS) on the equipment to build its models. It incorporates in its model, the numerous behaviours of each sensor under a multitude of operating conditions. It develops a matrix like structure that constantly monitors how each parameter or sensor is behaving based on numerous varying operating conditions to generate its models.

Another advantage of the non-parametric models is they can be created quickly. Critically important of this modelling technique is its ability for model adaptation when conditions alter, such as the changing conditions associated with an aging engine. When these situations occur, SmartSignal will flag this as an abnormal behavior and/or behavior that is new to the model. At this point, confirmation that this behavior change is not due to any probable failure is required. Once this is ruled out, a small sample of new data, representative of the new conditions is collected and presented to the model so it can learn or adapt to these changes.

Every piece of mobile equipment is unique in how it performs as small subtle behavioral differences exist in each individual asset. In recognition of this important factor, SmartSignal is used to build a unique model for each asset. Having unique models for specific equipment provides a competitive advantage. Data loggers, such as VIMS, are now available on the majority of mining equipment, regardless of the equipment manufacturer. To construct the models, data loggers are used to record an inordinate amount of data on mobile equipment while in its health state. The data collected is validated and cleansed and only used to construct the model after the equipment is verified to be in a healthy state. The models generated through SmartSignal are then used to project normal operational conditions in real-time and flag abnormal behaviors. The illustration shown as Figure 14, *Example of Model and Actual Behavior- Exhaust Temperature*, on the following page, is a graphic representation of the modelled performance of a sensor in a state of normal or health operating behavior (shown as green) and compares this to the actual behavior (shown in blue). The difference between the two behaviors is illustrated as the residual. When the residual exceeds a specified variation, the software captures the anomaly which can then be used to predict both the type and immediacy of a failure.

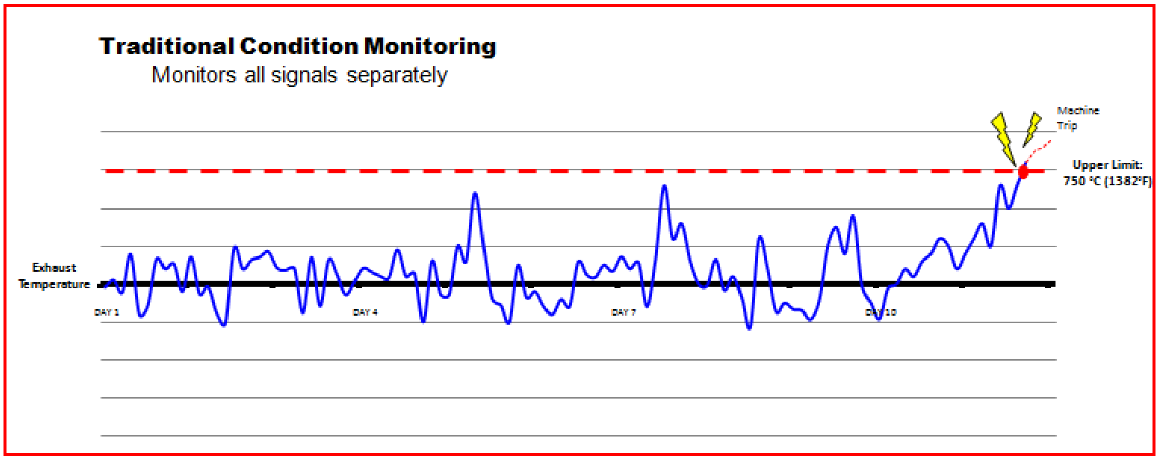
Figure 14- Example of Model and Actual Behaviours- Exhaust Temperature



Source- Drawn by Author, Data from SmartSignal Corporation, (n.d.), Success Stories Examples pdf

Traditional real-time condition monitoring methods, using parametric modeling, simply draw on sensor thresholds that are applied to all operating conditions. As a result, wider bandwidths must be used to reduce the triggering of false alarms due to the highly transient conditions. Accordingly, alarms are only triggered when thresholds for each unique sensor are met. This limits the effectiveness of this modelling as the deviations from normal behaviors are ignored until the equipment trips an alarm when either exceeding an upper or lower limit in the software. Thresholds can be modified to specific levels depending on the needs of the customer but remains a fixed level. Figure 15, *Example of Traditional Monitoring- Exhaust Temperature*, on the following page illustrates traditional condition monitoring.

Figure 15- Example of Traditional Monitoring- Exhaust Temperature



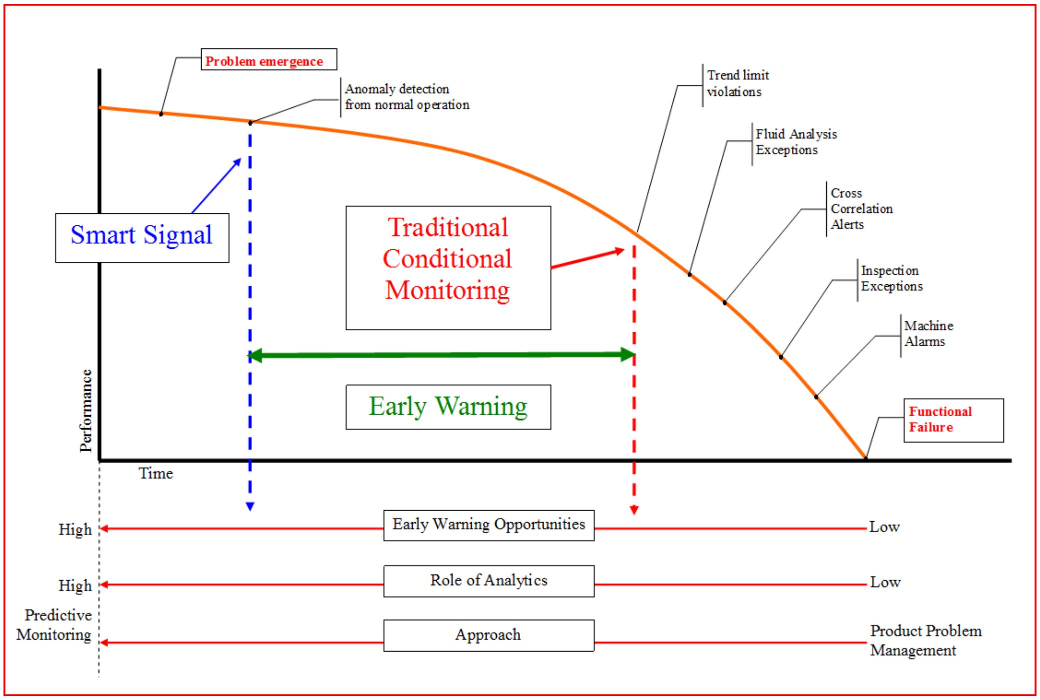
Source-Drawn by Author, Data from SmartSignal Corporation, (n.d.) Technology, Simple Explanation pdf,

The advantage of SmartSignal technology is its ability to distinguish anomalies from the normal healthy operating behaviors. There are situations where the operating behaviors are within the established threshold limits but the equipment is not operating as normal. SmartSignal recognizes this kind of anomaly and triggers an alert and the equipment condition is assessed.

In real time, SmartSignal creates a dynamic band of normal operating performance by comparing it to other sensor values in the model producing an earlier warning as compared to traditional monitoring. An additional advantage of this technology is developing problems are often being captured or recognized by more than just one sensor. This technology pieces numerous variances from the dynamic bands together and by analyzing the relationship between these sensors, it is able to detect problems much sooner than traditional monitoring. It provides a crystal ball for mobile equipment maintenance and greatly assists in defining the right work in a timely manner, regardless of the manufacturer, as stated by SmartSignal, *"Works on all types of critical rotating, non-rotating, and processing equipment- any model of any equipment from any OEM- across all major industries"* (SmartSignal, 2010, 8).

There are two categories of failures associated with this software. One is a slow developing failure which can be monitored over a longer period of time such as over several days. The second is a rapidly developing failure which can occur in a matter of hours. Though this is considered to be real-time monitoring, SmartSignal only checks the data approximately 4 to 6 times per day. This is sufficient to monitor slow developing failures but is ineffective for rapidly developing failures. In cases where failures tend to be quick, such as a fuel pump failure, SmartSignal can be embedded in the data logger itself, to specifically monitor these parameters to provide a timely warning to a problem. SmartSignal can detect faults 5-10 days before traditional condition based monitoring, as shown in Figure 16, *Illustration of a P-F Curve*, below and is claimed to be superior technology, *"Several Studies have shown that SBM technology outperforms other candidate technologies in detecting faults"* (Gandhi, et al., 2010, 9).

Figure 16- Illustration of a P-F Curve



Source- Drawn by Author

The simplicity of interpreting the model results by equipment experts provides another advantage of this software. This expertise can also be used to develop expert rules and logic to differentiate between normal and abnormal behaviors. SmartSignal uses additional software known as "Shield" to develop an expert rules system. The software uses knowledge capture in developing its rules by inputting the corrective repair information back into Shield so it is now associated with the details of the pattern change. It attempts to match the signature to what caused this. Shield also has the ability to look at the microscopic pattern change of the abnormal signal to relate a specific deviation pattern, such as smooth, choppy or step change and associate this to a specific failure. Over time, inputting data into Shield expands the software knowledge and the uncertainty on the corrective action required to resolve the issue becomes less and less. An example of how this works can be seen in an abnormal increase in exhaust temperature. Assume this could be caused by an injector issue (step change in deviation pattern) or possibly by a problem with a cam lobe (choppy deviation pattern). After the repair is completed and it is determined the appropriate corrective action to resolve the problem was related to an injector, the specific repair description is inputted into the Shield software. The repair success is confirmed by verifying the actual (blue line) and model (green line) have come back together and the residual is negligible. In the future, Shield will match the same microscopic pattern change to what it now understands previously resolved the problem. It will match the increase in exhaust temperature which had a step change deviation pattern to an injector issue.

In addition to inputting the history into SmartSignal's Shield software based on the remedial work, there is also the ability to input knowledge from subject matter experts that can identify what corrective action is required to repair a prevailing failure pattern. This helps to mitigate the expertise loss previously identified as a problem due to the loss of tradespeople. The software can also be used as a tool to expedite the skill development of the inexperienced tradespeople, especially in regard to the troubleshooting process. This is a critical teaching aid for less experienced tradesperson and increases the efficiency of this scarce resource. The expedited repair also allows the equipment to return to operation in what will be, significantly less time, improving productive capacity. SmartSignal promotes the simplicity of their modelling and ability to develop expert systems which supports the tradespeople in troubleshooting, "*The overall simplicity of SBM models facilitates development and usage of automated expert rules to distinguish between normal operating conditions and a faulted condition. It can be used to identify a new operating condition, facilitating automated adaptation models. Expert rules logic also can be extended to provide fault diagnostics in important cases, like complex plant systems, where 'fingerprints' of failure modes are known from development of subject-matter expertise and knowledge capture*" (Gandhi, et al., 2010, 11).

The application of this real-time condition monitoring system can be accomplished in two ways. First, SmartSignal can be installed locally in the operation where it is used for both the continuous monitoring of equipment and alerting abnormal behaviors and then, in-house expertise and knowledge are incorporated back into the Shield software after the repair has resolved the abnormal behavior. This is heavily reliant on site expertise and detailed knowledge of the equipment, which could present a challenge. This has the potential to be expanded to a common Teck Coal monitoring center.

An alternative manner to implement this real-time monitoring strategy is to use established centers of excellence, or performance monitoring centers. This is a centralized approach and allows the OEM's to continuously monitor equipment anywhere in the world.

Caterpillar is looking at developing this approach. Some of the benefits this methodology includes; the use of common practices, consistent approaches and access to the OEM equipment expertise. The centralized approach also allows the OEM's to provide experience and results based on their world-wide network of experience. This pooled knowledge will benefit users and builds the capacity of the corrective action library for specific fault patterns much quicker. Another benefit of the centralized OEM approach is early warning systems require a higher level of expertise to diagnose problems and the access to this expertise provides a competitive opportunity. This strategy is believed to be aligned with Teck Coal due to the shortage of skilled tradespeople. Operations need their trades to be maximizing "wrench time"; therefore an effective strategy would be to allow the OEM experts analyze the data to provide action generated tasks for the site tradespeople to complete.

This type of technology is a form of disruptive technology as it requires a change in the normal condition monitoring approach to maximize its true benefit. The technology will detect faults early into the failure. If it is repeatedly ignored until the problem becomes considerably larger in scale, the advantages and benefits of this early detection system are lost. Using this new technology as a leading indicator or as the earliest possibly anomaly detection system combined with other predictive condition monitoring, such as oil sampling or thermography, will allow Teck Coal to find and correct smaller problems as early as they are detectible and before these develop into higher cost and longer duration repairs.

The implementation of this predictive condition monitoring system is the most significant opportunity Teck Coal has to create a new maintenance paradigm for mobile equipment based on a more proactive approach. With larger and more productive equipment, productive capacity must be maintained to ensure revenues are not affected by unnecessary capacity loss. With the imminent trades shortage, unplanned breakdowns caused by unknown equipment conditions can no longer continue. This is reinforced with a statement made by Michael Currie in a whitepaper claiming, *"Today, critical labour shortages in trades and technical roles have increased downtime risk to such a level that there is a new urgency to leverage CM to increase labour productivity and avoid lost production. Condition Monitoring is no longer considered just an engineering tactic; it is valuable management strategy for coping with changing economic circumstances"* (Currie, 2006, 3). First mover benefits of effectively implementing such a strategy will provide a competitive advantage.

By combining the new technology with other predictive approaches, the power of this disruptive technology can be leveraged as a competitive strength and advantage.

5.3 Quantify the Inspection Process- Objective Inspections

The majority of paper preventive maintenance inspections involve the subjective assessments of equipment condition. This creates a barrier in achieving the full effectiveness of this process. To be effective, inspections must provide objective information, or measurements, so trends can be established and used to predict the future state of the equipment health and consequently, repairs can be completed at opportune times, such as with a scheduled service. This improves the usefulness of the inspection process.

There is a tremendous opportunity to create a competitive advantage by transforming paper inspections into inspections completed with the use of an electronic data logger, or personal digital assistant (PDA) as used in other industries. This makes certain, consistent data is collected so the equipment condition can be substantially better analyzed (Liptrot, Palarchio, Thomas, 2000). Using a PDA as an inspection tool provides the opportunity to configure the reporting choices such that inspections transition from subjection and inconsistent comments to a quantifiable measurement that can be used to trend and predict equipment health. An example of transitioning from subjective to objective checks that are value added and can be used to trend machinery health conditions is shown in Figure 17, *Objective and Quantifiable Inspection*. These inspections would be developed for a PDA application. In addition, specific choices to an inspection could be used such that the tradesperson is obligated to select the best matching statement.

Figure 17- Objective and Quantifiable Inspection

Current Haultruck PM Inspection Process	1000 HOUR Initial	Proposed Haultruck PM Inspection Process- Quantifiable Metrics (Examples Which are Used for Trending)	
GROUND CHECKS-			
- DO "SHAKE" TEST	____		
- CHECK STEERING LINKAGE FOR LOOSE OR WORN	____	Record steering linkage clearance LH	1/8 1/4 3/8 1/2 5/8 3/4 7/8 1
HARDWARE	____	Record steering linkage clearance RH	1/8 1/4 3/8 1/2 5/8 3/4 7/8 1
- CHECK HOIST CYLINDER FOR LEAKS, DAMAGE, WORN	____	Check hoist cylinder for drips/10 seconds- LH	0 1 2 3 4 5 6 7 8 9 10
PINS, KEEPERS AND BEARINGS		Check hoist cylinder for drips/10 seconds- RH	0 1 2 3 4 5 6 7 8 9 10
(pull bottom hoist cyl cap inspect hoist pin & bearings and		Check bottom hoist cylinder pin to eye clearance- LH	1/8 1/4 3/8 1/2 5/8 3/4 7/8 1
make sure retaining bolt is tight)		Check top hoist cylinder pin to eye clearance- LH	1/8 1/4 3/8 1/2 5/8 3/4 7/8 1
- CHECK BOX HINGE PIN AREAS FOR WEAR OR DAMAGE	____	Check bottom hoist cylinder pin to eye clearance- RH	1/8 1/4 3/8 1/2 5/8 3/4 7/8 1
- CHECK SWAY BAR FOR WEAR AND TIGHTNESS	____	Check top hoist cylinder pin to eye clearance- RH	1/8 1/4 3/8 1/2 5/8 3/4 7/8 1
- SPOT CHECK TORQUE ON BRAKE HOUSING BOLTS	____	Ensure retaining bolts for hoist cylinder are tight- LH	OK Tightened
- TIGHTEN TRANSMISSION MOUNTS	____	Ensure retaining bolts for hoist cylinder are tight- RH	OK Tightened
- CHECK MAINFRAME AND SIDE FRAMES FOR CRACKS	____	Measure box hinge pin to ear clearence- LH	1/8 1/4 3/8 1/2 5/8 3/4 7/8 1
- CHECK A-FRAME FOR DAMAGE & EXCESSIVE WEAR	____	Measure box hinge pin to ear clearence- RH	1/8 1/4 3/8 1/2 5/8 3/4 7/8 1
- CHECK TORQUE, DIFF MTG BOLTS SHOULD BE 110 FT/LB	____	Measure sway bar tightness- Front	1/8 1/4 3/8 1/2 5/8 3/4 7/8 1
- ADJUST DIFFERENTIAL THRUST STOP		Measure sway bar tightness- Rear	1/8 1/4 3/8 1/2 5/8 3/4 7/8 1

Source- Drawn by Author

The PDA's have the capability of being wirelessly connected to a server acting as a data manager. As the inspection information is recorded into the PDA, the information could be sent to the data manger. Its algorithm would assess the data against a threshold to determine if this has been exceeded. In addition, the algorithm could predict whether the particular future trend, based on data for that inspection point, would result in its condition exceeding a defined threshold prior to the subsequent inspection. If either situation is met, an alert could be triggered to the tradesperson through the PDA, providing immediate feedback that the area inspected requires urgent attention. The PDA could also request the tradesperson to re-verify a measurement if there was a significant abnormality from the expected trend. The benefit of this knowledge and predictability is to complete a repair or adjustment on the asset before it is released to operations preventing a breakdown. This knowledge allows maintenance to make informed decisions as to when the repair should be completed. Michael Currie, from a whitepaper describing the need for technology to support tradespeople, states, "*In the words of Li Ka Shing, 'information technology…unlocks the value of time'. It allows people to do what they are best suited to, to add the most value. In the case of a plant that has a limited number of highly skilled workers; technology should provide those people with reliable information to support decision-making. It should automate tasks that are repetitive and mundane, reduce errors, and perform complex calculations that would otherwise be difficult and time consuming. It should form a part of, rather than drive, a CM program."*(Currie, 2006, 2).

With technology, emails, and/or text messaging can be automatically generated by SmartSignal such that key personnel making decisions are informed of the abnormal equipment condition instantaneously. In addition, automatic work orders and parts lists could be generated once the work request is approved, saving the tradespeople and maintenance staff considerable time through the automation of this process.

The most important benefit of this strategy is the value of the maintenance inspections would be significantly enhanced. Quantifiable data, or objective checks, collected using a PDA could now be utilized much more effectively in the analysis of various component conditions. Each piece of equipment would require a tag to identify the source to ensure the information correctly populates the database.

The automatic trending of inspection data allows maintenance to prioritize its work to avoid breakdowns and the inefficiencies associated with reactive work. Using quantifiable data to predict component condition through automatic trending would significantly enhance the effectiveness of maintenance. The results of implementing these innovative practices and technologies would create a competitive advantage.

This particular proposed solution helps to resolve a few of the problems identified. First, the objective inspection process would resolve the problem described as having too much subjectivity in the equipment inspection process. Secondly, the PDA and the predictability capability of the system would help to mitigate the poor knowledge of equipment health problems previously described. Lastly, this solution would result in fewer breakdowns as timely maintenance would be completed. This improves the effectiveness of tradespeople and ultimately results in less work which helps mitigate the trade scarcity problem identified.

5.4 Increase Use of Other Diagnostic Tools and Devices– Use Predictive Technologies

This section will highlight some of best diagnostic tools available for mobile equipment maintenance. These devices are much simpler to use and some have built-in intelligence to guide the user through the inspection process. The implementation of the solution proposed primarily addresses the problem regarding the low application of diagnostic tools and devices but also mitigates other problems identified. This solution provides additional equipment knowledge and reduces breakdowns which will in turn, reduces the amount of work required by tradespeople.

5.4.1 Thermography

Thermography is one of the easiest diagnostic tools to use for maintenance inspections, yet its utilization is limited within Teck Coal. Increases in temperature or higher relative temperatures are typically early indicators of equipment problems. This predictive technology allows for the determination of anomalies of critical components without the need for any direct contact. New technology includes real-time continuous thermographic monitoring to detect problems on equipment without affecting the operation. Applications include checks on electrical cabinets, transformers, and in mechanical areas where temperature sensors cannot be utilized. Thermography provides the ability for maintenance to recognize potential problems early on and, depending on the seriousness, the corrective action can be either completed immediately or it can be planned and scheduled for a more convenient time, possibly when it is less disruptive to the operation. This technology reduces breakdowns and costs as David Doerhoff states, *"Manufacturers are seeing favorable ROI with infrared thermography programs as technology* *enables them to take corrective action before problems occur- thereby saving money and resources."*(Doerhoff, 2010, 24).

Thermography has been used at Teck Coal predominately in electrical systems on equipment and for power distribution systems. It has also seen some use in mechanical systems; however, this technology is significantly under-utilized relative to its potential. As illustrated in Figure 18, *Applications for Thermography*, the use of thermography is vast and can assist in inspecting numerous electrical and mechanical systems.

Figure 18- Applications for Thermography

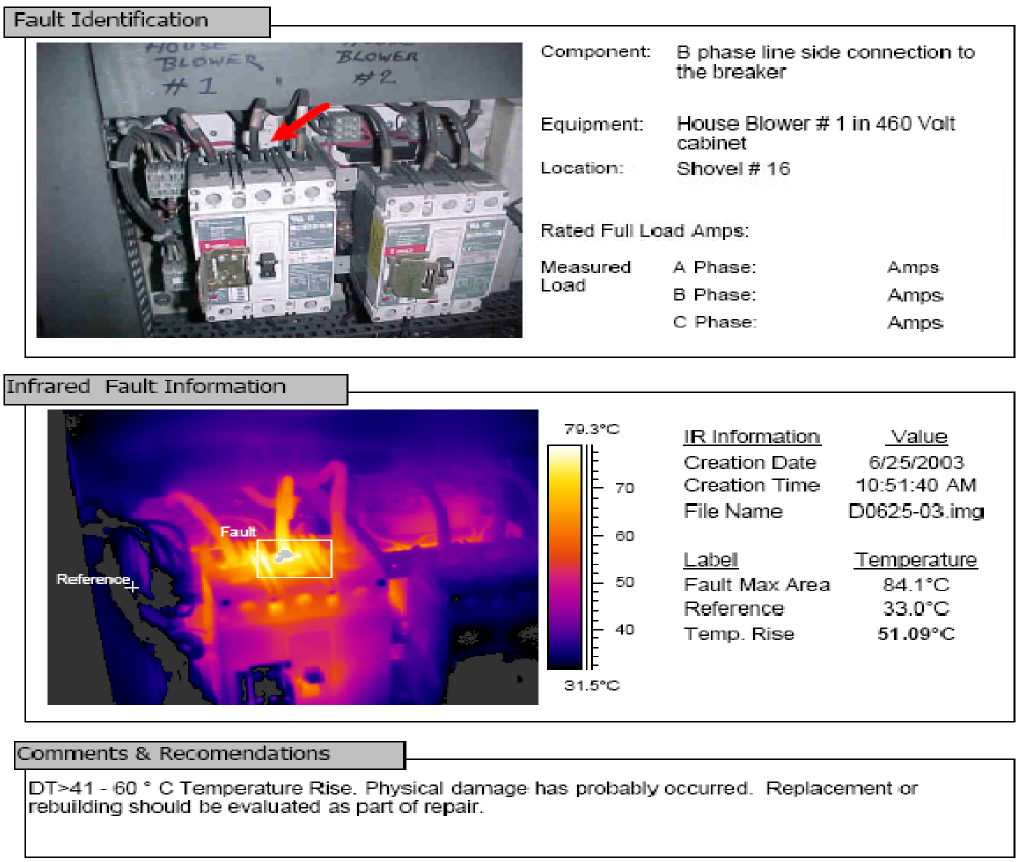
Application	Condition Detected
Conveyors, Rollers, Idlers, Pulleys, Shafts, Belts, Couplings	Failed Bearings, misalignment of components, uneven load, lubrication issues
Transmissions, Gearboxes, Drivers, Planetaries, Differentials	Lubrication issues, overheating bearings, friction, overheating brakes
Electrical Systems- Transformers, Overhead Distribution Lines, Insulators, Wiring, Motors, Breakers, Generators, Alternators, Wheelmotors, Connections	Bearing issues, lubrication issues, misalignments, winding problems, cooling issues, friction, uneven brush contact, loose connections, cracked insulators, overloads, overheating breakers
Pumps, Motors, Compressors, Coolers, Blowers, Fans	Overheating bearings, worn pump vanes, failed or plugged cooler, blocked cooler lines
Engines	Failing turbos, valve or injector issues, radiator effectiveness, over-fuelling
Tires	Uneven heat distribution, separation failure, brake drag, over/under inflation, TKPH exceedance
Brakes, Bearings, Bushings, Suspensions	Overheating brakes, brake drag, bearing issue, overwork, poor dampening, lubrication issues, misalignments, poor fit
Pipes	Degraded insulation or lining, uneven distribution, plugged lines
Hydraulic Systems- Motors, Pumps, Valves, Cylinders	Bypassing valve, cylinder, pump or motor, worn impellers, failed or plugged cooler, valve issue, leakage

Source- Drawn by Author

Extending the use of this diagnostic technology to a host of new applications will provide a significantly enhanced understanding of equipment condition. The data can be downloaded from the instrumentation to a central server where trending and alarms can be automatically generated. Real-time thermography is new technology, which presents a significant opportunity with respect to condition monitoring. This real-time technology can also be integrated into the

SmartSignal software allowing for its optimized use in assessing equipment condition. This technology can be leveraged with SmartSignal to create the competitive differentiation from routine thermography. Regardless of the real-time application, using routine thermography in numerous new applications will fit within the new strategy as this is a necessity for effective condition based maintenance and moving to proactive maintenance through the early detection of problems. The illustration below, Figure 19, *Example of Thermography Benefits,* shows when using a normal visual inspection process the electrical breaker appears to be in satisfactory condition, yet the thermography technology highlights a problem with a connection which can easily be tightened to prevent the breaker from unexpectedly failing.

Figure 19- Example of Thermographic Benefits



Source- Taken from Author's Teck Coal Photos

5.4.2 Vibration Analyzer- Expert and On-line Systems

Vibration analysis used on equipment provides invaluable data on machinery health. Historically, vibration analyzers were complex and required a high level of sophistication to operate and understand what corrective actions were necessary to resolve a vibration issue. It took several years of experience using traditional analyzers for the user to become proficient and this was limited to only a few individuals. This technology provides insight to the condition of rotating components, particularly; diesel engines, electric and hydraulic motors, pumps, compressors, gearboxes, fans and blowers. Vibration analysis provides information about bearing condition, misalignments, looseness or unbalance. This information is important in the assessment of equipment health.

New technology makes the use of this once complicated diagnostic tool, considerably simpler. Some of the expertise for vibration analysis is now built into new vibration analyzers (Fluke Website, http://www.fluke.com/fluke/usen/vibration/fluke- 810.htm?PID=56137&trk= vibration). The “built-in” intelligence within the instrument prompts the user to provide basic machine information about the configuration of what is being tested and where on the component the measurement is being taken. Once the vibration data is taken for the system being tested, the vibration analyzer identifies the root cause of the problem, its location and how severe the problem is.

The built-in expertise of new vibration equipment can be used to leverage the lost experience of the in-house expertise. Technology provides a new approach to vibration testing and allows for consistency in data collection and in the interpretation of results so it requires very little experience to perform this function. Being much simpler to use, also provides the opportunity to increase the application of this tool by more tradespeople after some minor training is completed. This is essential in addressing the problem of the expertise loss within Teck Coal.

Vibration analysis can also be completed on a real-time basis for critical equipment components. This provides invaluable condition monitoring data on equipment that could only otherwise be gathered by removing the equipment from services on a scheduled basis. This minimizes operational disruptions. This real-time data gathering technology also lends itself to be leveraged with the SmartSignal condition monitoring software, creating alarms for data that is uncharacteristic of the normal healthy operating condition as soon as a problem occurs.

The simplicity in using newer vibration analyzers and the ability for on-line monitoring capabilities greatly advances the applicability of this type of analysis on mobile equipment and provides critical information on machinery health. Similar to thermography, this technology must be a part of the overall strategy in moving towards proactive maintenance and assists in identifying the correct work.

5.5 Managing the Scarcity of Tradespeople and Experience Loss Through Knowledge Capture

Several of the proposed solutions are essential in addressing the problems associated with a loss of expertise and the decline in the availability of tradespeople. By effectively implementing the strategies previously reviewed, there will be less maintenance work required. This is a critical goal of improving the maintenance paradigm. Less work requires fewer tradespeople. Tradespeople will be focusing on doing the right work. Their efficiency will improve through the avoidance of breakdowns resulting in an increase in wrench-time. However, there are other opportunities technology can provide to mitigate the scarcity of tradespeople.

A strategic advantage is creating an opportunity from a scarce resource and managing the risks associated with this resource better than others (Currie, 2006). The imminent retirement of an aging workforce combined with the competition for experienced and skilled tradespeople is today's reality. Treating this resource as a strategic asset is essential. This is supported by SmartSignal, *"Maintaining the expertise necessary to operate critical assets has become a crucial enterprise risk factor for executives and managers"* (SmartSignal, 2006, 1)[78]

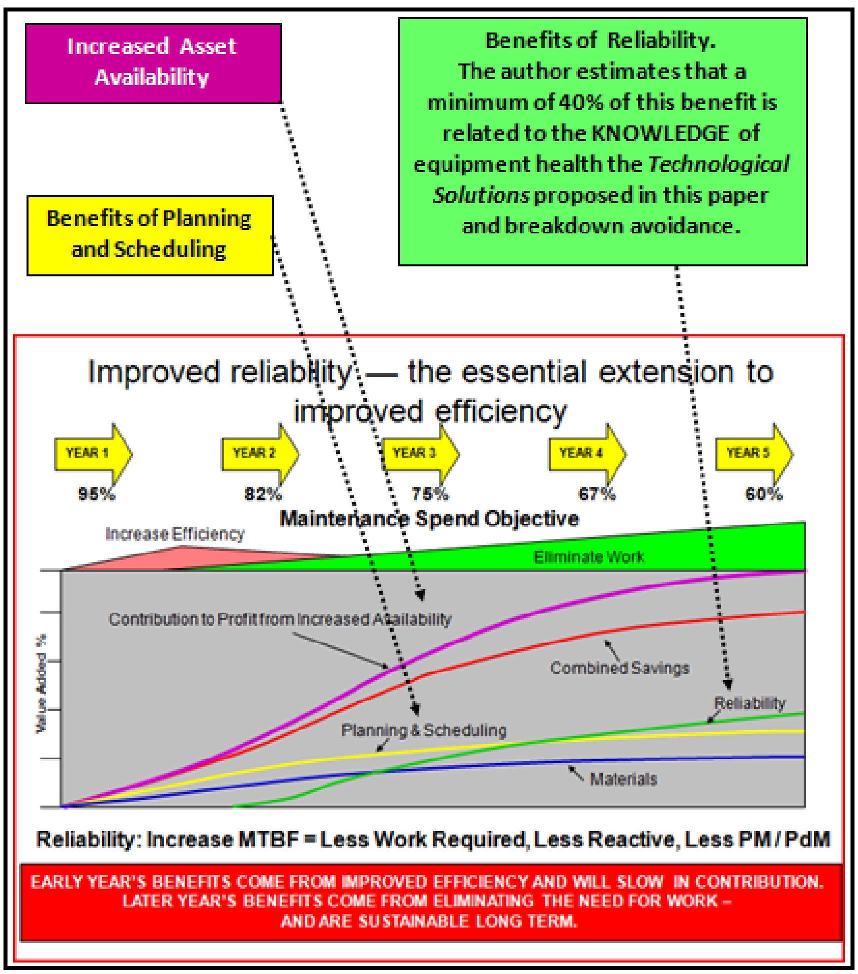
Capturing and retaining the valuable maintenance knowledge and equipment experience of this scarce resource is a challenge of today's mining companies but also presents a significant opportunity. When this experience is gone, a knowledge void is created and results in a less efficient workforce. For this reason, repairs could take longer or problems on equipment could be misdiagnosed resulting in longer repair times. This negatively impacts productive capacity as equipment would be out of operation for longer durations. With proficient tradespeople, repairs are quick, efficient and often completed safer.

In recognition of this scarcity issue and expertise loss, expert software systems have been developed to capture and store the knowledge of experienced tradespeople so it can be used by the future generation (Ivara, 2008). Using technology, knowledge and expertise can be incorporated back into software systems such as SmartSignal's Shield software in the form of logic, identifying the maintenance intervention required for a specific alarm condition before a failure occurs. Building this knowledge into these systems takes commitment, resources and discipline to ensure it is continuously updated. This provides a tremendous advantage for the less experienced tradespeople as the software can serve as a troubleshooting guide. Expertise can be used to build this knowledge, but it will take some time to build the expert system. The use of expert systems where expertise and knowledge is captured and then reused to expedite the troubleshooting and repair processes as well as expediting the training and skill development of the new generation of tradespeople will provide a strategic advantage.

5.6 Financial Benefits of Solutions

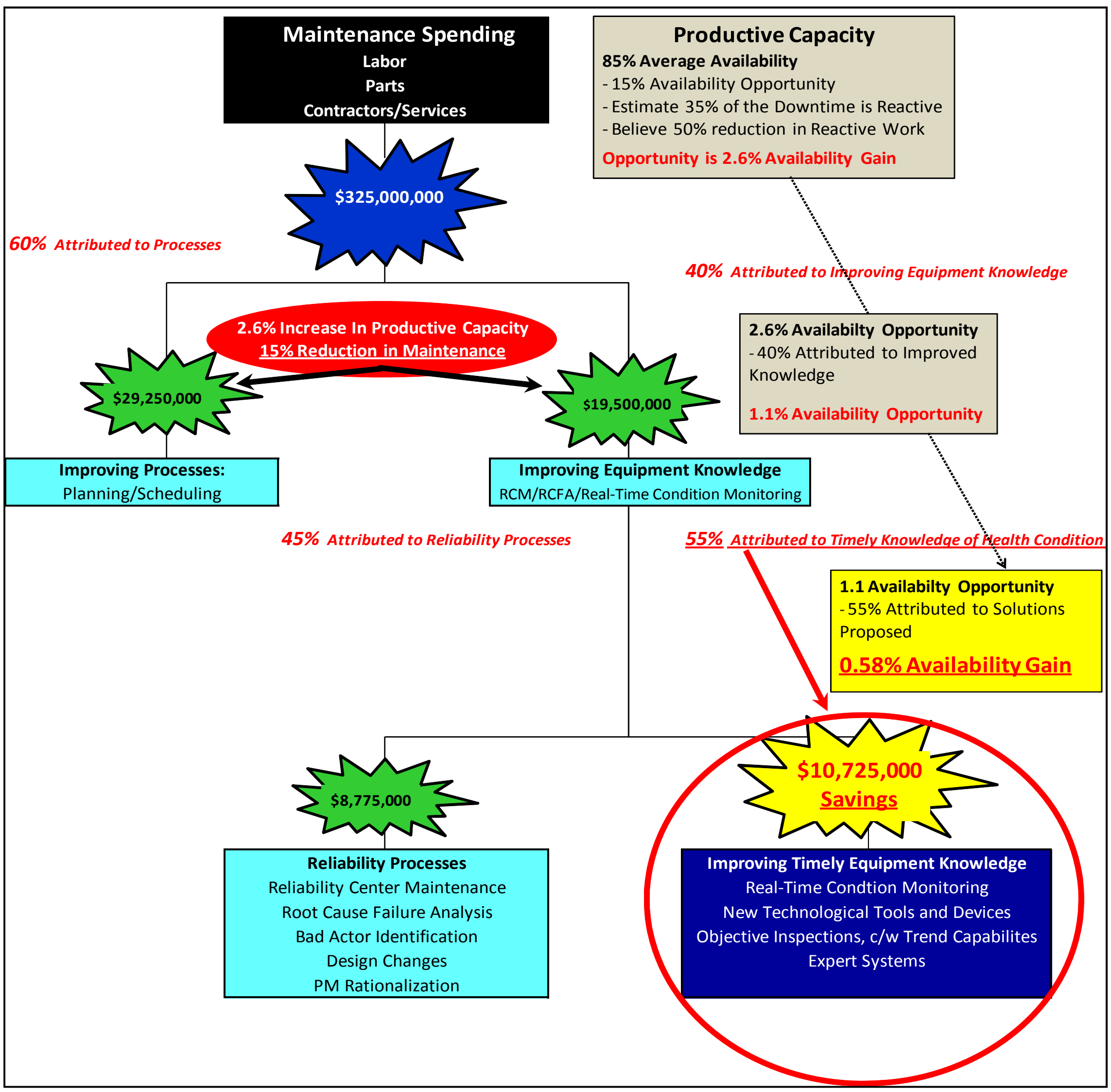
Teck Coal's current annual spending on mobile equipment maintenance is $325M. This amount consists of $100M in maintenance labour, $180M in parts/supplies and the balance is contractor labour. This cost is used in the following analysis to determine the potential savings the proposed solutions would provide. The estimates used in the analysis are based on research available, which is combined with the author's experience, to determine the costs and savings. These are believed to be very conservative estimates. The estimated financial benefits by transforming to an effective proactive maintenance paradigm are based on Figure 20, *Benefits of Proactive Maintenance*. The total combined maintenance savings shown below are a result of

Figure 20- Benefits of Proactive Maintenance



Source- Mitchell, J. S., (n.d.), Asset Management Handbook, Edited by Author, Reprinted with Permission effective planning/scheduling processes and improved equipment knowledge, which is an outcome of implementing reliability. Equipment knowledge can be further broken down into the actual reliability processes (root cause failure analysis, reliability centred maintenance and others) and improving the timely knowledge of equipment health by implementing the solutions proposed in this chapter. Both improved planning/scheduling and improving equipment knowledge reduce materials required. In addition, higher profits from achieving an increase in equipment availability are a result of a proactive maintenance strategy. Figure 21, *Breakdown of Opportunities- Cost and Availability,* illustrates the estimated benefits attributed to the various factors that contribute to proactive maintenance.

Figure 21- Breakdown of Opportunities- Cost and Availability



Source- Drawn by Author

To be conservative, the author used a 60/40 split between the benefits associated with processes (planning/scheduling) and improved equipment knowledge. Furthermore, an estimated split of 45/55 was used to distinguish the benefits associated to reliability processes and improving timely equipment knowledge through the implementation of the solutions proposed, refer to Figure 21.

The overall maintenance savings resulting from the transition to a more proactive maintenance strategy, based on the target established by Teck Coal, is a 15% reduction, or $49M. From this opportunity and the ratios specified above, the net annual maintenance savings are shown to be $10.7M based on implementing the solutions proposed in this chapter. This is shown in Table 1, *Financial Benefits of Implementing Solutions Proposed*. In addition, in considering the benefits of improved availability, the analysis uses an average equipment availability of 85% as the baseline. From this, it is recognized that 15% remains as an availability opportunity, see Figure 21. From an early chapter, Ivara Corporation concluded that 35% of the work in maintenance, at a Teck Coal Operation, was reactionary and that an opportunity to reduce this by 50% was possible, or a 1.1% improvement on equipment availability. Using the contributing ratios illustrated (45/55), the net availability improvement is 0.58%, as a result of implementing the proposed solutions to significantly enhance the equipment health condition. To be conservative in the cost benefit of the availability improvement of 0.58%, it is assumed that the operations use this increased productive capacity to produce the same material volume, but can now achieve this in fewer operating days. This equates to 2.05 fewer operating days to achieve the same production level in the operations group. Using variable cost to move material, the net cost savings for the 2 days is calculated to be $4.05M, see Appendix A- Financial Benefits from Improved Availability. In a strong HCC market, the Teck Coal sites whose processing plants are not the operation's bottleneck, increasing equipment availability and reliability will yield more coal production, which represents a significant opportunity.

The cost of implementing the solutions proposed is estimated to be 2% of the total maintenance spending for the first year as a result of establishing real-time condition monitoring, licensing fees, data manager set-ups, the cost of using the performance monitoring center, various infrastructure upgrades and new diagnostic equipment. The 2% is believed to a reasonable estimate based the authors knowledge. After the initial set-up, it is expected annual costs will decrease to 1%, or $3.25M to sustain of the solutions proposed. This would cover training, new equipment, software licences renewals and the continued use of the performance center support.

The business case approximates the annual financial profit for Teck Coal to be approximately 0.8% of the total Teck Coal maintenance spending for the first year, or $5M, with a 3.5% annual margin improvement thereafter, or $11.5M. The estimated margins that would be realized by implementing the solutions in this chapter are summarized in Table 1 below.

Table 1- Financial Benefits of Implementing Solutions Proposed

	Implementing Proposed Solutions									
	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Total Maintenance Spent (Mobile Fleet)	$325.0	$341.3	$358.3	$376.2	$395.0	$414.8	$435.5	$457.3	$480.2	$504.2
Cost of Implementation (2% initial yr)	$6.5	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	$0.0	
Annual System Costs (1%)	$3.3	$3.4	$3.6	$3.8	$4.0	$4.1	$4.4	$4.6	$4.8	$5.0
Annual Maintenance Savings (3%)	($10.7)	($11.3)	($11.8)	($12.4)	($13.0)	($13.7)	($14.4)	($15.1)	($15.8)	($16.6)
Production Gains (min)										
Same Production with less Equipment	($4.0)	($4.3)	($4.5)	($4.7)	($4.9)	($5.2)	($5.4)	($5.7)	($6.0)	($6.3)
Total Margins	$5.0	$12.1	$12.7	$13.3	$14.0	$14.7	$15.4	$16.2	$17.0	$17.9
Margins as a Percentage of Total Maintenance Spent	1.5%	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%	3.5%

The transition to the new maintenance paradigm and achieving world-class maintenance is expected to take approximately five years to become fully sustainable. The operations will benefit from lower equipment costs, higher availability and reduced maintenance effort required for the same fleets. After this time, employees will only know the new maintenance paradigm and will be quite experienced in the new technologies proposed in this paper. Continuous improvement and seeking newer technologies to implement that would further advance the maintenance effectiveness must be part of the strategy. Information provided by SmartSignal supports the financial benefits used in Table 1,*"…benefits to users include improved understanding of asset readiness, improved maintenance costs and improved resource utilization- all leading to improved business performance in highly competitive industries"* (Gandhi, et al., 2010, 8).

Lastly, equipment that is maintained by world-class maintenance strategy is expected to be able to operate for longer durations, extending its useful life and reducing capital requirements associated with sustaining, and quite possibly, expansion capital.

6.0 Implementation Phase

The introduction of technology, as a strategy to provide a competitive advantage, is not sufficient on its own. In order to be sustainable, a new maintenance paradigm requires a culture change within the organization. This change management process could be the most challenging and rewarding aspect of transformational change. This chapter will review the necessary aspects of the change management process using John P. Kotter's principles on leading change (Kotter, 2007) that will be required to institutionalize the solutions proposed, as they are all related to one another.

A critical aspect to change management is leadership. Without strong leadership best intentions on making change within an organization fail. A structured approach to change management to avoid pitfalls is required through the transformation process. Mistakes along the path of change can have a devastatingly negative impact on the momentum being generated. The following citation is from Debbie Zmorenski and reminds those in the process of change, not to forget the people, "*Yet making the plan work is an even bigger challenge than creating the plan, in large part because execution requires a disciplined process or a logical set of connected activities that enables the organization to successfully integrate the strategies into the operation. Many factors inhibit the successful execution of the strategic plan, and all of them are tied to the people of the organization."*(Zmorenski, 2010, 1).

Today, because mining companies are utilizing fewer units but significantly larger pieces of equipment, all breakdowns have a direct effect on reducing company revenue. Having a high degree of equipment availability and reliability is key and will distinguish profitable organizations from those struggling to meet ends meet, and ultimately provides a strategic advantage. Coupled with this is the emerging scarcity of tradespeople that is counted on to maintain this equipment. This has resulted from growth in the mining sector which has created competition for labor resources and demographic statistics point to an ominous retirement problem for tradespeople within Teck Coal. A reoccurring belief is maintenance departments will be required to do more with less. This suggests a new way of thinking and behaving will be required to be sustainable or possibly just to survive.

Avoiding equipment failures and reducing the amount of work required to maintain equipment through condition monitoring is a necessity. If implemented effectively, utilizing technology to monitor equipment health, assist in transferring expertise and collecting objective data for analysis, will allow Teck Coal to shift some of the tradespeople's efforts from low value to value added work. The transformation to a proactive maintenance culture will improve the organization's bottom line by maximizing asset returns while assisting in mitigating a resource scarcity problem.

6.1 Create a Sense of Urgency- Understand Why?

Increasing costs and diminishing production levels is evident in the coal division, primarily due to higher strip ratios and longer waste hauls. This challenge has been communicated to the workforce yet the notion of any type of difficulty in Teck Coal's ability to compete in this HCC industry (at least for some of the higher cost operations in Teck Coal) needs to be emphatically articulated to create a sense of urgency in the need for organizational change. Carrying out maintenance in the existing paradigm but expecting different results is the definition of insanity.

Maximizing the efficiency and effectiveness of critical assets, namely employees and mining equipment is required. At the same time, the workforce does recognize an impending problem in securing sufficient tradespeople for future demands. This is apparent when employees look around at their peers. Numerous experienced tradespeople are approaching retirement and the remaining group is either young and inexperienced or just inexperienced. Maintenance crews are also aware that the operations have tradespeople vacancies and the situation is only projected to worsen. Trades retention payout strategies have helped as has the introduction of numerous apprenticeships; however, the operations cannot have apprentices training apprentices. Contractor usage is higher than ever as is trades overtime, nevertheless it is not uncommon to have equipment left with no one available to work on it. These situations result in high costs and a sustainable solution is necessary. Breakdowns consume too much of the trades time and also disrupts production so this must be eliminated.

As part of establishing a sense of urgency with a transformational change, is the ability to genuinely describe the opportunities that exist within the organization by creating change. In addition to portraying the competitive realities in the mining industry, motivating employees to achieve a higher level of performance and personal development will be instrumental in eliciting buy-in. Tradespeople need to realize the tremendous opportunity that the solutions proposed present through the improvemrnt of current practices and doing things much better.

6.2 Forming a Powerful Guiding Coalition

Teck Coal currently has a functional group know as Operational Excellence which guides numerous activities within the organization. Part of this group's responsibility is defining and coordinating best practices amongst the sites in achieving the overall goal of establishing world-class maintenance strategies.

When considering innovation, the Operational Excellence group has some organizational capacity that could be exploited. The group has resources and shares the same goal, which is improving the current maintenance strategy, and could assist in the coordination of the changes proposed in this paper. The focus of this group is very much aligned with the solutions proposed in this paper. They also have established and developed change agents with a reliability focus at each Teck Coal operation, the reliability engineers, that can form part of a team used to implement the technologies proposed in this paper, such as conditioned based monitoring. Using new technology to improve maintenance through understanding equipment condition to reduce breakdowns, managing the inordinate amount of data and capturing expert knowledge are completely aligned with their vision and will dovetail very well with the organizational goals for maintenance.

Considerable effort is currently underway through all of Teck Coal on improving the effectiveness of the maintenance effort by improving the planning and scheduling processes. Celerant Consulting, has been engaged to assist with this change process (plan the work and work the plan) and to coach employees and management until it is sustainable. The essence of the strategy to use technology in mobile equipment maintenance to provide a competitive advantage is aligned with the current focus in maintenance. This provides a tremendous opportunity to collectively pursue the strategies presented in this paper.

Using this functional team to help drive the needed change will expedite its implementation and thus creates the necessary enthusiasm to drive sustainable results.

6.3 Creating a Vision

The most important aspect of creating change and having a vision that supports it, is the need to have a convincing reason for the change. Change will not be successful unless the group affected by the change can envision where the organization wants to be and why this is critical to the business success and ultimately, to them. This means the employees must believe in the strategies required to achieve the vision and are motivated by the outcome. Most employees will be assessing the change based on *what's in it for me?* This is an opportunity to reinforce the need to change from fire-fighting, due to breakdowns, to performing work that is planned, organized and efficient which in turn not only reduces stress and is safer, but also less frustrating. The specific vision created for this transformation requires a change in culture, philosophy and work processes within maintenance and must be supported by the operations group. The introduction of new technology is alone not the vision, but is merely a strategy in achieving the vision. The vision focuses on the larger picture, which is, implementing new more effective maintenance strategies within Teck Coal, in other words, using proactive maintenance in order to be more competitive and sustainable in the global market. The manner in which equipment is currently maintained must change.

The overall vision must be clearly communicated and should paint a picture of a superior future, a sense of urgency in getting there and should inspire the workforce. As part of the vision, the organizational culture must transform from the belief that maintenance is merely a cost center, or "necessary evil", to the belief that maintenance provides a critical function in the overall success of the business. It is important to wire the organization for success.

6.4 Communicate the Vision

Teck Resources has already created a Maintenance Vision statement which describes the goal to improve maintenance activities in the organization within a 5 year period. The solutions proposed in this paper support this goal and the vision for maintenance. This vision has been communicated and emphasized with a video presentation in various meetings with employees. The video utilized senior executives, in addition to a variety of site personnel, to elicit the need for change and the need for immediate change. It is described below:

> ***Doing the Right Thing – Every Time.*** *We will lead our industry in having the right equipment available, at the right time, and at the right cost*

In addition to the vision statement, four strategies have been identified as critical in achieving the vision. These are the following:

1. Maintenance and Operations take joint responsibility for equipment
2. Use best practices in the core maintenance functions (planning and scheduling)
3. Apply Reliability tools and techniques
4. Share knowledge and learn from others to drive improvement

Celerant Consulting is engaged with Teck Coal in supporting and expediting the implementation of these strategies, in particular the planning and scheduling aspects. The application of new technology to identify equipment health in a timely manner as presented, supports the four strategies.

As Teck Coal progresses on its journey in fulfilling its vision, it is critical in the change management process to continuously link the strategies employed back to the overall vision at every opportunity. This reinforces the commitment to the vision. Teck Coal must ensure the employees are continually reminded of what and of how it needs the organization to transform to.

It is important to recognize that communicators must be credible with the employees and be able to motivate the workforce. Site leadership must be visible in the various work areas communicating with the employees and reiterating key messages in support of the vision. In turn, this provides the opportunity to support front line supervisors and to listen to the ideas and concerns from the workforce, a form of visible felt leadership. Consistent communication and leadership behaviours in support of the strategy are required in the change management process to improve the "stickiness" of the messaging and to demonstrate that the direction of the organization is continually progressing. Inconsistency creates confusion and doubt in the process.

6.5 Empower Others to Act on the Vision

After communicating the strategies, which describe how technology will transition the operation from less reactive to more proactive through real-time conditioning monitoring and how technology would automate tasks previously completed by tradespeople, an inherent fear could be created in the workplace. This includes the fear of job losses and the fear of the unknown to what extent technology could be used as a substitution for the labour resource.

This issue must be confronted immediately to lessen fears and anxiety. Instead, the scarcity of trades and the potential that operations could fail to meet production requirements because of this problem must be reinforced. Employees must be assured that the strategy is not about reducing head counts, rather the strategy is about improving maintenance, developing tradespeople and helping to secure the longevity of the operations. The successful implementation of the strategy will make the maintenance organization more effective and manpower levels will be managed through attrition and a reduced dependence on contractors and overtime.

It is important to discuss the “moose on the table” to confront fears and any negative backroom discussions opposing the strategy. This helps to weaken the inertia of resistors.

The positive aspects of the changes in maintenance strategy must be promoted to motivate employees. These include the reduction of monotonous and repetitive work, which typically is a source of boredom for tradespeople. As mentioned, this includes the reduction of reactive work, or fire-fighting, which is typically stressful as there is pressure to get equipment back into service as quickly as possible. Unplanned jobs are inefficient and frustrating for tradespeople as there is a significant amount of disorganization with this work. Instead, the transition to a proactive approach means more planned work is completed and barriers that previously prevented the tradespeople from effectively completing their assignment are considerably reduced. With the new strategies, tradespeople have the opportunity to gain valuable experience with leading edge technologies and maintenance processes, which will develop their skills. This also provides the opportunity for tradespeople to recognize the potential personal benefits, or *what’s in it for them*. Introducing new tools or new technology, such as PDA’s for inspections, thermography cameras, vibration analyzers, and laser alignment tools creates excitement as these are viewed as developmental and learning opportunities for the tradespeople. A critical aspect of the use of new technology for the tradespeople is the need to understand why they are using this technology and what happens to the results collected (i.e.- what is it used for). Using the technology alone and not relating it to the strategy and why it is being applied could be detrimental to its success. Training also becomes an integral part of new technology.

Finding and using change agents on the various maintenance crews, those who are genuinely interested and motivated to apply the new technology, will be important to the transformation process. These change agents are powerful resources that can drum up momentum and offer encouragement. Having change agents actively participate within their site reliability team is important for providing this group feedback on how the processes are viewed from the grass roots. These change agents also become armed with up-to-date information, which will be shared with their peers. Sometimes, this information is viewed as being more credible when tradespeople are empowered to present this to their own group.

Using tradespeople to participate in brainstorming sessions empowers the trades group. Sessions could be focused on additional applications for the new technology or resolving problems that exist with current strategy implementations. Following through with the good ideas and suggestions presented by tradespeople, or simply providing feedback to other ideas helps build the desired culture. Trying to generate creativity within this group, such as suggesting the use of thermography to assist in resolving a hydraulic overheating problem can become a catalyst to the overall stimulation of additional creativity. Once tradespeople recognize technology has made their jobs easier and more fulfilling, they are bound to seek other applications for its use.

An evaluation of the organizational structure and resources required to effectively support the changes and new processes such that the maximum benefits are achieved has to be undertaken. This evaluation could be difficult as organizations tend to believe their current organizational structure is the most effective model. Status-quo needs to be reviewed and assessed against the new way of conducting business. Traditional beliefs and ideas may no longer be valid, or produce less than optimal outcomes.

6.6 Create Short Term Wins

Celebrating short term victories during this change management is critical in maintaining motivation and in helping to drive the new behaviours the organization is aiming for. This also curbs any momentum that resistors may have been able to generate. Demonstrating the advantages and capabilities of the new technology and having tradespeople use this technology to both diagnose and resolve equipment issues should be recognized often, with the occasional reward for a significant achievement. An effective manner in recognizing specific achievements of individuals is in front of their peer group.

With every change it is vital to understand the baseline key performance indices (KPI's). The effectiveness of the new strategies can be measured against the baselines to monitor performance. It is important to establish both leading and lagging KPI's to assist in monitoring the success of the change management process (Sundberg, 2003). Some important KPI's include:

- Percent Planned Work
- Percent Breakdown Maintenance
- Equipment Availabilities
- Equipment Reliability (Meant Time Before Failure- MTBF, Mean Repair Time- MRT)
- Equipment Costs
- Wrench Time Percentage
- Labor factor
- Percent of Components in Critical or Warning Condition.

Again, frequent communication in the form of presentations, tool box meetings and displaying KPI's in common areas where employees gather so successes can be publicized is important.   Throughout the change management process, restating the vision and strategy needs to occur regularly and reporting against milestones to show employees how strategies are progressing should also be communicated.

Sharing stories to demonstrate the successes of the change management process is powerful when used to reinforce the strategies. As an example, a success story of how condition monitoring highlighted an abnormality on a piece of equipment and some type of timely maintenance intervention resolved the issue and prevented what normally would have been an component failure or costly repair is the type of story that must be shared. To improve the effectiveness of this type of story, using the financial benefits of both the cost avoidance and the additional production achieved, should be emphasized.

The real wins begin when attitudes start to change and the tradespeople cannot remember the old way of doing things. As tradespeople recognize how the new strategies are shifting maintenance to an increasing amount of proactive work, and when they understand the "why's" and the "how's" associated with the new way things are done, going back to the old way of doing things will no longer be an option.

With success clearly being established and a large reduction in breakdowns is evident, trades requirements would decrease as the efficiency and effectiveness of maintenance improves. By letting attrition take its natural course to reduce manpower levels, assuming the same amount of equipment, will build credibility and trust within the organizational culture and reaffirms the commitment at the onset of the transformation.

Being consistent and dedicated in the condition based maintenance requires a partnership between operations and maintenance. It will be critical to establish complete asset management such that the operations group allows maintenance to schedule and execute adjustments, repairs or other checks on equipment in a timely fashion. Every time maintenance is refused the opportunity to resolve a known equipment problem and a breakdown results, the credibility of the vision suffers.   Asset management is a partnership between operations and maintenance with both having the same goals and this is joint responsibility for equipment performance.   Both groups must maximize equipment uptime and performance by recognizing this is accomplished through timely maintenance and avoiding failures and extended outages.   The same communication, process updates and success stories used to support the change is required in the operations group as well. The same success stories that make the tradespeople feel good about the new way of doing things, should make the operators feel the same way.

6.7 Consolidate Improvements

From a change management perspective, it is important to recognize that culture change and transformation take several years before it becomes sustainable. In making the change "stick", management must behave and communicate in a manner consistent with the new strategies the organization is implementing to achieve its vision. Consistently demonstrating support for the vision throughout the change management process must be clearly evident. Where required, new resources are introduced to support the processes and training of new practices is conducted. It is important that Teck Coal ensures future selections and promotions of management personnel support the new vision and share the appropriate beliefs. Eventually, the hiring practices for all employees must transition such that only incumbents who are aligned with the new culture are considered. The organization must ensure all aspects of its business have become aligned with the vision. Slowly, resistors become fewer and these alienated employees either must move on or give up resisting. The continued celebration of successes and the acknowledgement of areas requiring attention and resolving these issues create unity and are important in overcoming resistance.

Using the solutions presented in this paper to improve maintenance, would not only be beneficial from a competitive strategy standpoint, it would also be beneficial for the development of employees. Unfortunately, in the current state, there are tradespeople who do not feel part of the organization and are not driven to help make the company successful. This group is merely there to collect a paycheck and this is typically a result from a lack of engagement. This needs to change. Leading and developing employees, showing them how their contributions are improving the organization and giving them feedback on their work, such as sharing success stories, creates a culture of teamwork and dedication. Employee motivation will improve when they are listened to, their suggestions are considered or are acted upon and when they feel they are providing value. Employees need to be engaged.

Having employees being developed and utilizing leading edge technology also serves as a powerful retention tool. If the tradespeople are developing their skills, learning new maintenance techniques, enjoying their work and feel they are contributing to the organization, they are more likely to stay with the organization. This could also provide an opportunity if tradespeople promote the positive aspects of Teck Coal within their network and this attracts other tradespeople to apply for openings.

In time, there will be an increased belief that Teck Coal will achieve its vision. Additional stories focused on bigger savings or failure avoidance continue to be highlighted and promoted. Charts and graphs illustrating how the strategies are improving equipment performance and reducing breakdowns need to be continually updated, promoted and shared within each operation. Successes should also be promoted throughout Teck Coal.

6.8 Institutionalize New Approaches

In the end, the new paradigm for equipment maintenance moves from transformational to sustainable. Employees understand the organizational goals and values and contribute towards achieving these. New strategies become processes that are simply considered to be “the way we do things around here”. Employees and management demonstrate behaviours that are rooted in shared values and the change management becomes institutionalized so it is no longer viewed as merely a “flash in the pan”.

Management must continuously evaluate new technological advances to determine how these might further improve the efficiency and effectiveness of the maintenance departments and provide opportunities to improve operational performance. Continuous reinforcement of successes to showcase the efforts of people is required. The maintenance department becomes proud of its achievements. This new maintenance paradigm will undoubtedly, improve equipment performance and workforce morale. Nothing satisfies a tradesperson more than the ability to work on a planned job, have all the parts, tools and knowledge necessary to complete the job proficiently. The tradespeople understand their purpose and can see first-hand the results of their effort.

The benefits of being able to execute more work with fewer tradespeople is a result of exploiting technology to allow the maintenance organization to work smarter, more effectively, more efficiently as breakdowns are minimized due to an increased knowledge of equipment health. In addition to advancing Teck Coal in condition based maintenance, technology becomes a substitute for a tradesperson’s time. Technology will be used to identify the work for tradespeople. Utilizing leading edge technologies and changing the approach to maintenance will also improve the organizations competitiveness.

Finally, to ensure sustainability, it is important to ensure new incumbents at all levels, especially the more senior positions within the organization, exemplify and promote the new maintenance values. All future processes and initiatives must be connected to the vision. People promoted into new roles of influence from top to bottom must be passionate about the vision and must share the same aligned values. Sustainability requires that a development plan be established for the expected successors within the organization to ensure the leadership and effectiveness of the vision continue as people change roles and move on.

7.0 Conclusion

The current maintenance practices must be changed to provide a viable future for Teck Coal. The metallurgical coal market is competitive and with new entrants soon to participate in the supply chain, competitive advantages must be actively sought. With larger equipment, the dependence on its reliability is key and disruptions to equipment availability now have a greater impact on the operations performance and thus must be avoided.

Teck Coal must ensure it will be cost competitive and prepared for the return of a balanced market. The maintenance of mobile equipment is a significant cost and the ability to control these costs would be greatly improved by transitioning to a more proactive maintenance culture. A current initiative underway is focused on improving the scheduling and planning aspects of maintenance, however the most critical aspect of having a competitive advantage is the ability to define the right work at the right time. This paper recommends the use of new technology to assist in transitioning to a more proactive maintenance strategy where the identification of equipment health conditions in a timely manner is achieved and the effectiveness and efficiency of tradespeople is realized.

In particular, Teck Coal must expedite the implementation of real-time condition based monitoring of equipment health with an expert system. SmartSignal is disruptive technology and its unique modelling allows accurate condition monitoring for the highly transient behaviours associated with mobile equipment operating parameters. This technology also provides the earliest warning alarms. Its ability to microscopically review the signal has the ability to provide knowledge of the correct action that previously resolved the identical problem. This technology assists less experienced tradespeople in the troubleshooting of problems which expedites the repairs. The author recommends that this technology be prototyped at one of the operations to assess its performance. Teck Coal must also invest in newer and easy to use diagnostic tools and expand the application of these devices to broader uses including real-time monitoring. Lastly, maintenance inspection processes must transition such that the collection of data is objective and done with the assistance of a PDA. The information must be trended and used to predict current or future threshold exceedances, which will greatly assist the planning and scheduling processes.

Furthermore, without improving the effectiveness and efficiency of the maintenance crews, there will simply be too few tradespeople to meet the repair demands, as Teck Coal will be faced with numerous retirements. In order to be properly prepared for the future as a competitive entity, new technology must be used to minimize breakdowns, and make all maintenance activities more efficient and effective. Maintenance must change by eliminating non-value activities and adding those that provide value. With the impending shortage of this scarce resource, the time of tradespeople cannot be wasted. The workload associated with breakdowns must be reduced by the transition to more proactive work.

The use of new technology alone will not resolve the problems identified in this paper. Adding technology into maintenance program is the easy part. The significant challenge becomes the change management aspect of the implementation of the proposed solutions. An opportunity to dovetail onto an existing maintenance initiative and significantly enhance the effort of implementing these proposed solutions is opportunistically available. This would expedite the sustainable transition to a more proactive maintenance approach. The vision must be reinforced and supported by constant communication while on this transformational journey. This process will take considerable time and effort. Alignment to the vision is enhanced by sharing successes along the way, ensuring resources are in place to support the change and ensuring the people hired, promoted and in the succession plan all support the objectives of the new maintenance paradigm. The development of tradepeople and their skills in leading edge technology can be used as a powerful leverage to gain support for the necessary change. Never assume you are sustainable until you are truly there.

References

Conkright, G. (2010). *A New Approach to Asset Health Monitoring and Prediction*, SmartSignal Corporation Presentation, pg. 7

Currie, M. (2006). Where Did All the People Go? The New Case For Condition Monitoring, *Whitepaper on Asset Management*, *Matrikon, Inc.*, pgs. 1-3

Dorehoff, D. (2010). It Pays to Take a Picture, Seeing ROI in Infrared, Even in a Down Economy*, Uptime, The Magazine for Maintenance and Reliability Professionals*, *Feb/Mar 2010*, pg. 24

Fluke Website. (2011). Retrieved from http://www.fluke.com/fluke/usen/vibration/fluke-810.htm?PID=56137&trck=vibration

Friedman, A. (2009). Avoiding Pitfalls, Why Do Predictive Maintenance Programs Fail? *Maintenance Management Upload*, *April/May 2009*, pg. 34

Gandhi, D., Herzog, J., Nieman, B. (2010). Predictive Analytics Technology Review: Making Decisions About the Best Technology to Implement, SmartSignal Corporation*, Industry Whitepaper: Predictive Analytics,* pgs. 3, 8, 9 and 11

Idhammer, C. (2010) Part 1: From Good to Great with Lean Maintenance, IDCON, Inc., *Maintenance Technology, An Applied Technology Publication*, pg. 19

Ivara. (2000). Iron Ore Project Citation- Quebec Cartier Mining Company Selects Ivara as Software and Services. Retrieved from http://www.ivara.com/index.php/news-events/press-releases/archive/prior-releases/quebec-cartier-mining-company-selects-ivaraas-software-and-services/Jul 2000

Ivara. (2005). Dofasco uses Ivara Reliability Solution to Capture Plant Engineering and Maintenance Magazine's 2005 Award. Retrieved from *http:/www.ivara.com/index.php/news-events/press-releases/archive/2005-releases/Ivara-congratulates-dofasco-on-best-managed-maintenance-facility-win/*

Ivara.(2006A). Ivara Business Case Analysis: *Reliability Assessment Details*, pgs 6,15-20

Ivara.(2006B). Financial Improvement Plan Addendum: *Reliability Assessment Details*, pg. 47

Ivara. (2008). Mining Excellence Strategies: Driving Mining Profitability with Optimized Equipment Performance, *A Whitepaper by Ivara Corporation,* pg.5

Kotter, J. (2007). Leading Change, Why Transformation Efforts Fail*, Harvard Business Review*, *January 2007*, pg. 96-103

Liptrot, D., Palarchio, G., Thomas, R. (2000). Utilizing Advanced Maintenance Practices and Information Technology to Achieve Maximum Equipment Reliability, *Paper presented at AISE Steel Technology*, pgs. 29-32

Mitchell, John S. (n.d.) *Physical Asset Management Handbook*

Payne, Boyd. (2008), One Purpose, One Plan, One Team, *PowerPoint Presentation to Sr. Management Team*- Coal, pg.37

SmartSignal Corporation. (2006) Solving the Experience Gap: How Advanced Analytics Can Leverage Workforce Expertise, *Industry Viewpoint Series: Power Generation. SmartSignal Corporation*, pg. 1

SmartSignal Corporation. (2010). Technology Explanation, *A Whitepaper,* pg.8

SmartSignal Corporation. (n.d.) Success Stories Examples, *Pdf Document*, pg. 35

SmartSignal Corporation. (n.d.) Technology, Simple Explanation*, Pdf Document*, pg.7

Sundberg, A. (2003). Management Aspects on Condition Based Maintenance- The New Opportunity for Maritime Industry, *A Whitepaper Presented at the ICMES 2003 (Internationals Cooperation on Marine Engineering Systems)*, pg. 4

Teck Resources Limited. (2009). *Annual Report 2009*, pgs. 17, 39, 40, and 66

Well, Paul. (2007). Not Enough Labour, Building Entire Towns in the Tar Pits, Labour Pool Will Continue To Be Stretched As More Projects Come On Board. Retrieved from *http://oilsandstruth.org/not-enough-labour-building-entire-towns-tar-pits*

Zmorenski, D. (2010). When it Comes to Strategic Planning, Don’t Forget People, ReliablePlant Blogs. Retrieved from *http://blogs.reliableplant.com/1203/strategic-planning-people*

Appendix A: Financial Benefits from Improved Availability

Financial Benefits from Improved Availability

Net Production Gains; Using Figure 21 as a Reference					
Baseline					Net Improvement
Equipment Availability Baseline	Net Downtime	Reactive Work- *Use 35%	Estimate a 50% Reduction in Reactive Work	**Improvement from Equipment Knowledge-Reliabilty and Proposed Solutions (40% overall)	**Gain in Availbility from Improving Health Knowledge Use 55%
85.0%	15.0%	5.3%	2.6%	1.1%	0.58%

* Note1: From Ivara Study in 2006 at Teck Coal
**Note 2: Same Percentages Used as Illustrated in Figure21

Operational Financial Benefit- Minimum, Produce the Same in Fewer Days as More Equipment is Available								
Operating Days Per Year	Additional Capacity from Availabiilty	Fewer Days Required to Operate	***TCL Weighted Average Direct Mining Costs	***TCL Total Mined Volume (BCM)	Total Costs to Move Volume	Cost Per Day- (Mining Only)	****Use Variable Cost of 80%	Estimated Savings Per Year by Shutting Mine Operations Down for 2 Days
355	0.58%	2.05	$3.52	255,197,294	$898,294,475	$2,530,407	$2,024,326	$4,048,651

*** Note3: From Internal Cost Report
****Note4: From Internal TCL Finance Dept

Table 2- Financial Benefits from Improved Availability