MAINTAINER OF THE FUTURE

Melinda R.Hodkiewicz

University of Western Australia

To be presented at the National Asset Management Conference (AMPeak) Perth, June 2014

Summary: In the last two decades we have seen significant changes in how assets are operated and in the duties of operators due to advances in process control, remote operations systems and development of autonomous assets. However the day to day work of maintenance technicians engaged in the resources and infrastructure sectors has changed very little. This paper looks at trends in asset management particularly with respect to assets in remote locations and how these trends might affect the role and competences of our maintainers of the future.

Keywords: Maintenance, maintainer, asset management, training, vocational education, skills, competence, automation

1 INTRODUCTION

A key element in ensuring that assets deliver on organisational objectives is the ability to restore asset functionality when it deteriorates and to execute proactive work to ensure assets perform as required. Maintainers are at the front line of both of these activities; they are the only people who have the skills and experience to perform this work. The quality of maintainers' work directly impacts future asset reliability and their competence and speed of work determines system availability. Despite the value they can add (or destroy) there has been relatively little research work into the motivations and aspirations of maintainers. The old fashioned view of a maintainer as a highly qualified artisan with a deep understanding of and care for the equipment he works on has made way for a view of maintainers as being capable "warm bodies" who can be deployed across a range of assets and sites.

Although many things have changed in the way maintainers today are trained, the nature of maintainers' day to day work has not changed much in the last 20 years. Engines still need lubricated, motors wired up, pipes welded and sensing systems repaired. However we may be at a tipping point as a combination of business drivers (cost, productivity, safety) and technical developments (automation and robotics) combine to change the nature of maintenance work. This paper examines the current drivers and looks at how these might influence the work and training of the maintainer of the future.

2 LITERATURE REVIEW

2.1 Research work on maintainers

Maintenance work is a synthesis of manual labour and knowledge intensive work. It is about maintaining complex technology by anticipating, monitoring, reflecting and reacting to it [1, 2]. Although there is a vast literature on how to organise maintenance (maintenance management) and what maintenance should be done (strategies, tactics and tasks) and when (operations research) there is a surprising lack of research about what a maintainer actually does day to day from the maintainer's perspective. What motivates maintainers? How do they resolve technically difficult issues? How does the maintenance team culture shape work attitudes? How does operations behaviour shape maintainers response? What do maintainers value in the work environment? There are plenty of papers on what good practice and process in maintenance should look like but remarkably few papers that include data collected directly from maintainers about the actual nature of their work. These are principally ethnographic studies [2, 3] or focus on the role of organisational culture on maintenance practices, particularly in the nuclear industry [4, 5]. Insight into actual practices is often only gained from boards of inquiry [6] and investigations conducted after accidents [7-10].

Of particular concern is the lack of research to understand how maintainers acquire and build technical skills, conceptual knowledge and cognitive skills. Oedewald and Reiman [11] is one of the few studies to look at conceptual knowledge development. Most of the work around maintainer training has been directed at exploring training and experience as contributors to maintenance errors [12] and safety [13] and not to the efficacy and appropriateness of training for day to day work. If nothing is done to increase our knowledge and understanding of what maintainers do and how they do it then maintenance will continue to be viewed as a "bottomless pit of expenses" rather than a lever for competitive advantage and safe operations [14].

3 APPROACH

This study seeks to answer four questions

1. What changes are expected to asset design, technical support equipment and organizational processes in the next 15 years?
2. How will these developments affect the role of maintainers and their day to day tasks?
3. How are maintainers currently trained and developed in Australia
4. What are the enablers and barriers to ensure an appropriate maintenance workforce for the changes expected?

This work has used three approaches to elicit data and ideas on the subject of maintainer of the future as well as the maintainer today. The first involved a workshop with industry professionals. The second involved interviews with selected professionals with specific sector expertise and the third involved a review of reports and literature relating to maintainer qualifications and training.

The workshop was held on 15th November 2013 at Engineers Australia in West Perth and coordinated by the WA chapter of the Asset Management Council. The 65 participants were divided into groups of 8-10, each led by an experienced facilitator. In the first half, two questions were posed:

- How do we expect asset design, technical support equipment and organizational processes to change in the next 15 years?
- How will this affect the role of maintainers and their day to day tasks?

Results were collated and reported back in a plenary session. Following discussions the groups reconvened to discuss the final two questions:

- What competences will the maintainer of the future need to have?
- How do these competences compare with those of the maintainers today and where are the major gaps?

Results were again collated and shared with the groups in a plenary session.

Following the workshop meetings were held with a number of government and industry stakeholders to better understand issues around current training practices and the organisation and structure of training delivery.

The results of these discussions, workshops and reports are described in the following sections.

4 RESULTS

4.1 Expected changes to asset design, technical support equipment and organizational processes in the next 15 years?

Industry participants at the workshop identified a number of changes that they expect will influence maintainers in the next decade. These have been grouped into three areas: asset design, technical support equipment and organisations processes as shown in Figure 1.

4.1.1 Asset design

Embedded sensors

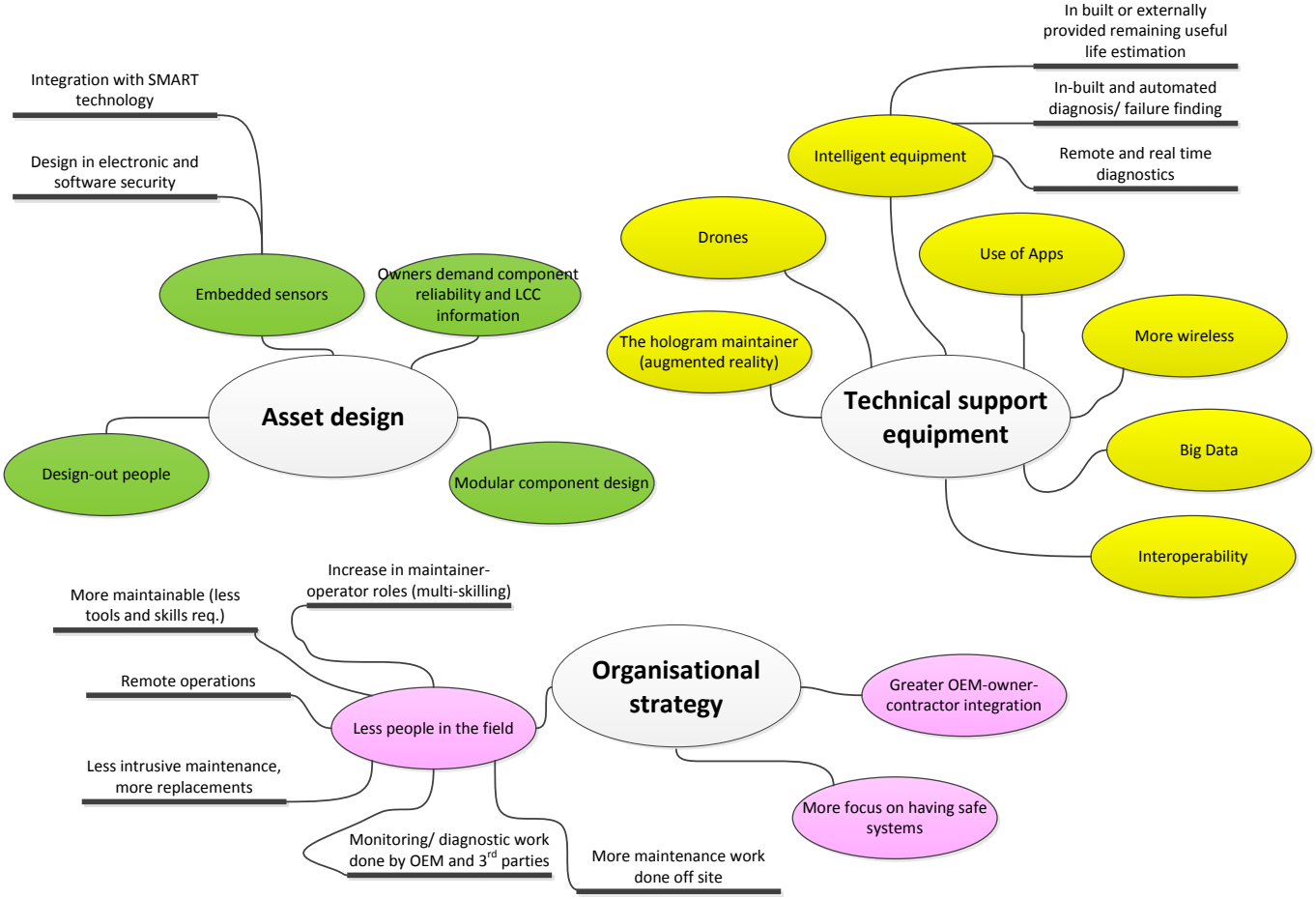
The last ten years has seen a significant increase in the use of embedded sensors on assets in both heavy industry and in consumer products. One example is the development of an “internet of things” popularised by the notion that your fridge can tell you when you need to buy more milk. In the industrial world the relatively low cost of adding sensors and of storing the data means that we now have more data than we can use and the struggle for many organisations is turning this data into information. The challenge is in being able to collate, synthesise and analyse data from different systems in order to be able to better understand the impact of factors such as actual usage patterns, operator behaviour and asset health on asset and business performance. The necessary skills to mine and make use of this “Big Data” are in demand across business sectors. Despite a lot of hype around the potential for big data for asset management, case studies of success in the maintenance area are still relatively rare. For most companies, there are challenges with the raw data in their systems, dealing with legacy systems and also having the business processes that support using the results of the analysis.

Design out people

In the Australian resource industry context, there has been a significant push by certain companies over the last 5 years to reduce the number of people in remote operations through the use of autonomous equipment. Significant progress has been made by both Rio Tinto and BHP Billiton Iron Ore through the former’s Mine of the Future program and the Remote Operations Centre at the Perth airport, and through the latter’s IROC centre in the Perth Central Business District. These Centres are used to operate equipment including trucks, drills, ore-car dumping and conveying that are located over 3000 km away in the Pilbara. There have been several drivers for this

development including safety, reduced personnel costs (flights, accommodation, housing and site allowances), as well as some operational benefits with higher utilisation and less operational wear and tear on the equipment.

Figure 1 What changes are expected to asset design, technical support equipment and organisational strategy?



Modular component design

When a group of asset managers and engineers comes together, the idea of modular design is often identified as one of the next big things. However in many industries little progress has been made in this area for decades. Most heavy mobile equipment is no easier to maintain today than it was 20 years ago. It is difficult to see the business case for Original Equipment Manufacturers (OEMs) to make products more maintainable. Many receive substantial income from sales of spare parts and/ or specialist serving and overhauls. As one OEM said when interviewed, “when we design components our first consideration is can we manufacture it, not can we maintain it”. Having said this, in some sectors, most notably commercial aviation, there has been significant progress in this area. Qantas has said publically that changes to design of the new aircraft have meant less frequent deeper maintenance and the modularity of components has resulted in development of a different class of technicians who can plug and play parts.

More information required by owners about the reliability of the assets

More and more organisations are realising that maintenance tactic developments include consideration of the failure behaviour and the consequences of failure. The blind adherence to OEM recommendations for maintenance tactics, which are based on the OEM’s understanding of failure behaviour but cannot include the risk context of the individual operator, is now moving to realisation that operators should develop their own tactics. In order to do this, operators need more information from the OEMs. Even today it is rare that OEMs provide basic information such as a list of failure modes and associated causes and reliability data on components. Each operator finds itself developing this data for themselves, often at significant expense in terms of the time and expertise required. Although this was identified as something that might happen in the future, it is difficult to see commercial drivers for the OEMs to change.

4.1.2 Organisational Strategy

Three trends were identified relating to organisational strategy. These are discussed below.

Less people in the field (on site)

There have been a number of major initiatives in the last 10 years, particularly in the resource sector, to move people off remote sites. There are number of obvious reasons for this. The first is health and safety, if the work can be done remotely using automation then there are potential benefits through reduced exposure. The second is cost, getting people to and housing people in remote areas is expensive, wages also tend to be higher. However the move of what has primarily been operators out of remote locations and into centralised operations centres in major cities has implications for who is left on site, who has to travel to site and when, and the nature of their work. It is likely that these changes will encourage organisations to develop more multi-skilled roles; for example operator-maintainer and cross-trade roles. Because of the potential loss of some skills there will be a rethink about what maintenance work can be done on site and if more complex repairs should be done off-site. Finally, there is substantially more data collected as part of remote operations and this can be used to also enhance asset health predictions and improve planning for maintenance activities. Potentially this will reduce the number of maintenance staff on-site needed for reactive work and chronic repairs.

More focus on safer systems

Although listed as a separate item, this issue is connected with the one above. However the move towards inherently safe systems is primarily being felt in the design of new systems in which the ability to reconfigure the system to be operated without people permanently on-site is being explored. An example of this would be Woodside's Angel platform which sits 120km from Karratha and is operated remotely [15].

Greater OEM-owner-contractor integration

Although there are few examples yet to point at outside of the aviation and defence sectors, a number of groups in the workshop identified this as a potential strategy change in the future. To a certain extent greater OEM-owner cooperation is occurring in the autonomous truck developments in the Pilbara as organisations have elected to work with one or another of the major OEMs in this area. The drivers for this are competitive advantage through superior technology or superior deployment of the technology. It is not clear what effect this might have though on maintainers.

In the owner-contractor space there have been well established partnerships for a number of years, particularly in the infrastructure area. Water, roads and power companies often have long term contracts with maintenance contractors. Again it is not clear that the role of the maintainer or the nature of the work changes much depending on who the maintainer is reporting to, owner or contractor.

4.1.3 Technical support equipment

There are a lot of exciting developments associated with technical support equipment, only some of which are shown in Figure 1. Many of these such as drones and augmented reality are already being used in certain sectors, notably military and aviation. 'Intelligent' equipment that provides an indication of remaining useful life and remote and real-time diagnostics exist for turbine engines, bearings and cranes for example. The potential to extend this to other sectors as built in sectors and wireless capability become ubiquitous and the ability to store, retrieve and use this "big data" improves. At present interoperability remains a barrier but groups like CSIRO are working on international standards in this area. While the attractions of integrating data and technology seem obvious on paper, there are still practical problems to solve. At present many OEMS have adopted a strategy of designing proprietary technology with limited, sometimes no, interconnectivity.

These developments taken together csould significantly impact the nature of maintenance work. As the predictability of work improves through more knowledge of the health and performance of the asset, work becomes less reactive and there is more demand for proactive work. At present a significant focus in maintenance training is on repairs rather than on the skills required to diagnose and respond to changes in asset performance and health prior to failure. This emphasis on diagnostics and troubleshooting rather than the physical manipulation of equipment is also now being supported remotely using tools such as location-tagged equipment and augmented reality. This ability to provide specialist help from a control centre to a maintainer on the ground through the use of "Google glasses" and other similar equipment changes what work can be done and by whom. We usually have very little idea of how maintenance work is done but the use of these devices will allow for recording of work that can subsequently be used to improve the quality of work and consistency of approach as well as to support training. Advances in simulation, initially directed at training operators and pilots, are now being considered for maintenance professionals as well.

4.2 How will these developments affect the role of maintainers and their day to day tasks?

The main predictions to emerge from this analysis suggest that the electrotechnical trades will be at the front line of changes associated with maintainer of the future. The increased use of automation and digital technologies will change the nature of much of their work and require the development of new skills sets [16-18]. In some sectors, particularly mining, there is concern around the current skills gap associated with mining automation and that the skills and knowledge required to support future automation is not catered to by existing programs [16].

For mechanical maintainers the impact will be relatively small as the essential nature of maintenance work in the

infrastructure and resource sector will not change much. The exception being that we expect to see more use of robotics in assisting with high hazard repairs. This will require maintainers to operate (and repair) equipment that is repairing equipment. Examples of this include robotic liner handlers for grinding mills and tyre changers for haul trucks. For mechanical trades on site there will be a growing need to have basic competence in instrumentation, electrical and digital systems.

It is possible that we might also see development of more defined roles within maintenance groups. Using an analogy from the medical profession, this could look like the following:

- First aid paramedics – front line, plug and play, reactive work
- Nurse – roving position, focus on preventative and proactive work (with augmented reality and real-time support)
- GP – Diagnostician and data analyst, primarily in the office and does the diagnostics and inputs to planning (supports the above 2 streams)
- Specialist Doctor – Subject matter expert and/or specialist repairer
- Medical research - Improvement process – Reliability engineer
- External support - Tradesmen who do specialist repairs in a maintenance shop

4.3 Number and sectors for maintainers

Australian Bureau of Statistics data was used to collate information on the number of people in selected trades and technicians groups and sectors. Maintainers are classified under a number of codes by the Australian Bureau of Statistics. There are 1.42 million people who classified themselves as Technicians and Trades Workers in the 2011 Census. The main sector for employment is Construction (412,894) followed by Manufacturing (236,825) and Other Services (176,510). Mining (41,974), Electricity, Gas, Water and Waste Services (28,553) and Transport, Postal and Warehousing (25,577) have smaller numbers assigned to them directly. There is no class in the ABS data for contractors that work across multiple sectors and this may account for the large numbers in the Other Services category.

Table 1 provides an indication of the number and type of technical trades involved in maintenance of equipment. The table excludes technical trades associated with the construction, manufacturing, trade, accommodation, food, agricultural, education and health care sectors.

Table 1: Trades people by selected sectors (ABS 2011 Census of Population and Housing)

	Mining	Electricity, Gas, Water and Waste Services	Transport, Postal and Warehousing	Information Media and Telecommunications	Professional, Scientific and Technical Services	Inadequately described or not stated	Total
ICT and Telecommunications Trades	563	728	1249	15564	14256	1063	33423
Automotive Electricians and Mechanics	835	110	557	9	138	340	1989
Motor Mechanics	1041	450	4477	15	250	1970	8203
Fabrication Trades	3204	744	1297	25	1925	2369	9564
Aircraft Maintenance Engineers	23	0	4735	5	364	104	5231
Metal Fitters, Machinists and Toolmakers	14662	2291	3729	235	2045	2244	25206
Electricians	5505	6708	2447	404	891	2094	18049
Electrical distribution	26	6516	292	11	42	97	6984
Electrotechnology and Electronics	555	742	626	735	2906	854	6418
Airconditioning and Refrigeration Mechanics	130	15	179	4	116	528	972
Total	26544	18304	19588	17007	22933	11663	116039

4.4 Where do maintainers come from?

For most maintenance tradesmen in Australia a Certificate IIII level qualification (or equivalent overseas qualification) in their trade is an entry level requirement. Training is done through the Vocational Education and Training (VET) sector. In order to understand how maintainers are trained and to appreciate some of the challenges facing today's employers and tomorrow's maintainers, a brief description of the structure of the VET sector is provided below.

4.4.1 Structure and regulation of the training environment

In Australia, vocational education and training is the responsibility of the Standing Council on Tertiary Education, Skills and Employment (SCOTESE), which is one of 12 standing councils established by the Council of Australian Governments COAG in 2011. SCOTESE receives advice from the National Skills Standards Council and from the National Advisory for Tertiary Education, Skills and Employment body (NATSE). The NSSC is responsible for developing and maintaining national standards for VET regulation and for endorsing Industry Training Packages [19]. There are around 70 Industry Training Packages (ITP), and these are a key element in the VET system. ITPs are the responsibility of the 11 Industry Skills Councils (ISC). The ISCs involved in training and development of maintainers for heavy industry are Auto Skills, Construction and Property Services, Electrical EE, Manufacturing,

Skills DMC (Drilling, Mining, Quarrying and Civil Infrastructure) and Transport and Logistics. Each ISC is recognised and funded by the Australian Government and governed by independent, industry led boards. Some of this structure is also duplicated at the state level.

An Industry Training Package is industry's specification of the skills and knowledge required to perform effectively in the workplace. It is a competency based recognition framework and is used to identify and assess the skills and knowledge people must demonstrate to work safely and effectively in the workplace. The ITPs provide learning and assessment materials but do not prescribe how an individual should be trained. Rather ITPs provide competencies required for the tasks undertaken in the workplace and consist of units of competency, skill sets, assessment requirements and qualifications.

It has always been a key tenet of Australia's VET system that Training Package qualifications and units do not specify delivery and/or learning strategies. The role of designing and delivering training is done by Registered Training Organisations (RTOs). RTOs must be registered by the Australian Skills Quality Authority (ASQA); there are about 5000 RTOs in Australia [20]. Only RTOs can deliver nationally recognised courses and accredited Australian Qualifications Framework (AQF) VET qualifications and apply for Australian, state and territory funding to deliver vocational education and training. The AQF is a major element in the design of a national standardised education and training framework. The taxonomy structure of the AQF framework sets out learning outcome descriptors for ten levels with 16 qualifications from Secondary School Certificate to Doctoral Degree. The taxonomic approach is designed to enable consistency in the way in which qualifications are described as well as clarity about the differences and relationships between qualification types. Of primary interest to this maintainer study is the Certificate III level which is the entry level for trades.

The VET policy environment affects all industries and (directly or indirectly) all enterprises. It establishes the framework for skills development, plays a determinative role in establishing the efficiency and effectiveness of investment in skills which, over the longer term and affects the skills base of the workforce [21]. Since 2009 there has been a reform agenda which has reviewed many aspects of the Australian VET System. This has resulted in significant changes in the broader VET environment including policy frameworks, endorsement schemes, regulatory requirements and management systems. A comprehensive summary of the various reviews and reforms is available in [21]. One of the major technical changes over the past 4 years has been a process to transition to a revised set of national streamlined Training Packages. On the political front, the last decade has been characterised by a dynamic and often uncertain policy environment for the VET sector with significant changes to VET funding by several State governments in response to fiscal constraints. This is forcing a rethink from all stakeholders about of what is expected from the sector and how this might most efficiently be delivered.

4.4.2 Qualifications for maintenance professionals

The entry level qualification for most maintenance professionals is AQF Certificate Level III. There is also a growing interest in higher qualifications such as AQF level 4. The skills and their application are described in Table 2.

Table 2: Australian Qualifications Framework descriptors for Certificate III

	Level 3	Level 4
Skills	Will have a range of cognitive, technical and communication skills to select and apply a specialised range of methods, tools, materials and information to: • complete routine activities • provide and transmit solutions to predictable and sometimes unpredictable problems	Will have a broad range of cognitive, technical and communication skills to select and apply a range of methods, tools, materials and information to: • complete routine and non-routine activities • provide and transmit solutions to a variety of predictable and sometimes unpredictable problems
Application of knowledge and skills	Will apply knowledge and skills to demonstrate autonomy and judgement and to take limited responsibility in known and stable contexts within established parameters	Will apply knowledge and skills to demonstrate autonomy, judgement and limited responsibility in known or changing contexts and within established parameters

The volume of learning of a Certificate III may be 1-2 years depending on prior learning but up to 4 years is typically required when done through a program of indentured training/ employment [22]. This length of time has come under criticism from some sectors. The actual rate of progression is contingent on both the apprentice's capability and the RTO's capacity to manage and provide training services which enable varied progression. Too often training still occurs as it did fifty years ago, with a technical trainer at the front of a class of students writing lines on the board. Too often students are held to the same timetable of scheduled delivery and assessment, denying them the opportunity for progression despite having the skills, knowledge and application of skills and knowledge required to progress at an earlier stage (or dooming them to failure, when they might have passed given additional support). These are missed opportunities. Treating a room full of individuals as a 'class' who move

through a designated curriculum together, represents an inefficient use of human capital at both extremes. Recognising and realising the potential of Blended Learning (BL) techniques, which incorporate Information and Communications Technology (ICT) to support flexible and appropriate training, holds the key to unlocking the full benefits of Competency Based Training. These techniques allow students in the same physical class to progress (while at different stages in their skill and knowledge development) and allow them to be assessed as and when they reach competence.

There are some innovations underway. For instance, the Energy Industry Apprentice Progression Management Systems (EIAPMS) pilot program is exploring options for flexible progression using BL techniques. Successful BL implementation relies on teacher/trainers to act as 'learning facilitators', helping apprentices to become independent learners through a combination of guided and individualised instruction. Achieving these outcomes is contingent on the ability of RTO's to accommodate individual learning needs. Specifically, it relies on the ability of VET practitioners to effectively apply individualised learning strategies [21].

4.4.3 Challenges for the training sector

As can be seen from the description above, the VET system is complicated to understand with numerous stakeholders and a high level of governance overhead involving federal, state and sector bodies. Conflicting stakeholder priorities and shifting political and funding environments impact the VET system, and changes to the system must be passed through a hierarchy of administrative bodies. Consequently, the system appears reactionary, convoluted and bureaucratic. The lag time between a proposed update to the system and this being realised in RTOs has been identified by many stakeholders as a significant shortcoming of the current system. By the time a change has been implemented, the new programs associated with the change are almost out of date, which had lead to the VET sector being branded as 'slow to evolve'.

Some sectors (mining in particular) have been very outspoken about their dissatisfaction with the VET sector. Two of their main concerns are that "Too often, training has been provider-led rather than industry-led " and "When engaging with RTOs the user is getting content and delivery models that are irrelevant to their needs. There is also concern regarding the quality of the training being delivered [23]. Irrelevant content calls into question the vocational education and training system's ability to meet the service provisions needed to provide a workforce capable of meeting the high supply and demand pressures of the industry [24]."

The minerals industry now spends a significant proportion of its training dollar ($1.15 bn in 2011/12) on private, non-accredited company training [23], i.e. outside of the VET sector. Providing in-house training is a useful short term solution from the company's perspective. However the net effect is that maintainers acquire a pick and mix set of often unrelated skills training without any nationally recognised and portable qualification or competence assessment. It is also difficult to scale this type of training quickly if demand for that skills increases. Both of these consequences can have industry wide ramifications. Labour mobility is an important part of the success of Australia's mining industry. Another avenue used by a number of sectors to quickly fill skills gaps has been the use of the skilled migration options; maintenance technicians of all types feature prominently on priority occupation lists produced by each state.

The issue of evolving new qualifications is complicated. New qualifications tend to be slow to evolve in absence of an immediate market and the commercial-in-confidence nature of many new technology developments (RITC, 2012). Skills to support new technologies traditionally begin as post trade specialisations. As a new technology matures and becomes ubiquitous (through incorporation into broader applications), it gradually becomes necessary for all industry practitioners to acquire and maintain those skills leading to its inevitable inclusion in the trade training programs [21]. A time lag exists between vocational training commencements and graduations. For example, in Electrical and Communications industries, Certificate IV training takes 5 years with 1280 hours of off-job training required; Diploma training takes 6 years with 1600 hours of off-job training required; advanced diploma takes up to 8 years with 2160 hours of off-job training required. This time lag means that skill demand must be predicted and training capacity and intakes increased well in advance of skill requirements. Given how fast technology is changing, this prediction is fraught with challenges and few are prepared to finance these developments in the absence of a proven business case[21].

Finding trainers is also an issue. It is highly likely that RTOs will have difficulty in employing qualified practitioners to fill technical teaching positions. If technical trainer shortages occur, it will significantly undermine growth in apprentice graduate output, with detrimental effect on skill levels in the longer term [21]. This lack of early engagement by industry players using new technologies with the VET sector means that training program development will always lag, sometimes by several years.

5 DISCUSSION AND CONCLUSIONS

5.1 Key themes

There is a pervasive sense of changes afoot in maintenance, driven by developments in automation, telecommunications and information technology. Most pundits expect these to be felt most in the electrotechnical trades. Change is obviously happening in some parts of some sectors faster than others. One of the main business

drivers for increased user of automation is safety but reduced operating costs and increased production efficiencies are also important contributions.

Almost all stakeholders associated with training maintainers have expressed reservations with the current structure(s) and regulations that govern the VET sector. The issues here are complex and made more complicated by the current Industrial Relations environment. It is not clear what the pathway forward is. It appears that some sectors have decided to develop local solutions in partnership with RTOs to look after their own skills development needs. Development of new training packages that are fit for purpose for the new skill sets anticipated is hampered by the complexity and proprietary nature of the new technologies, and the multiple layers of bureaucracy which sanction changes to the current VET system and its day to day operation. Little consideration seems to have been given to the need for specific roles and training to evolve simultaneously with technology

Despite these barriers, there is hope that new technologies can also be used to enhance and speed up the training process. Examples of the former include greater use of simulation, augmented reality and recording activities. Example of the latter is the proposed use of blended learning approach.

One of the recurring themes in the workshop was idea that there might be changes in asset design that would improve maintainability through increased modularisation and standardisation. This may be more of a hope than a reality as shown by the following extract of an article written in 1968. It is notable for two reasons. The first that many of the things the author predicted are much the same as items identified by industry players in the workshop in Perth in 2013, in other words not much has changed. The second is that 1968 is the last time that the prestigious management journal the Harvard Business Review published an article about maintenance management relevant to heavy industry.

"Gazing into a crystal hall, we would see, I suspect, completely standardized equipment and greatly improved maintenance procedures in the years ahead. For example, equipment will be designed for its production ability and maintainability. There will be free access to all parts and components, and machine life will be longer than is now the case. Economy of repair, or elimination of maintenance, will become a key feature of design. Equipment will be standardized to a point where complete transferability from machine to machine and plant to plant will be achieved.

Also in the offing are many more quick change and economically replaceable units. The high cost of maintenance labor compared with the purchase price of new factory-built components will stimulate users to consider buying instead of repairing.

Sometime in the future it will be possible to run the entire maintenance operation by computer. Under computerized maintenance, a new piece of equipment will be shipped, installed, and plugged into the computer so that data on temperature, vibrations, clearances, and the like will be automatically generated. The system will signal any danger or negative trend and ideally pre-plan repairs and preventive maintenance for each vital on-stream piece of equipment."[25]

5.2 What's missing

There are considerable gaps in our knowledge about maintainers. Some data that would have been helpful but has not proved possible to locate is listed below:

- Are specific competences required by employers for their maintenance workforce at different levels or for different roles in the organisation?
- How are these competences assessed by employers?
- How do maintainers develop new skills once they are employed? Are these skills associated with qualifications that are portable?
- What is the qualification spread of the maintenance workforce currently, particularly for individual sectors? Has this changed in the last 10 years?
- Who do maintainers work for? Has there been a shift towards job-hire companies and away from working for asset owners?

This work, based on an approach that largely involves talking to managers and professionals and reading reports generated by and for managers, falls into the same situation as much of the work it references in that is does not include the voice of the maintainer. Understanding their perspectives on the questions above and on the issues raised in this paper is essential.

5.3 Future work

This paper is part of what will be a White Paper looking specifically at the Maintainer of the Future for the mining industry. Further information is being sought from the VET sector and from some groups such as aviation which lead the way in how maintenance is managed and maintainers developed. Specific mining industry data is also being sought both from mining companies and via sources like the Australian Bureau of Statistics and the National Centre for Vocational Education Research.

5.4 Conclusions

There are many barriers that stand in the way of Australian business being able to take advantage of technical and business developments that could reshape the way in which maintenance is delivered. Change will need a whole of sector approach involving original equipment manufacturers, asset owners, employers of maintenance technicians, the training sector and government. Only limited progress will be made unless all players in the supply chain are involved. Individual organisations can manage this on a project by project basis but it is difficult to up-scale. Each group in this supply chain could take steps that will make a wider-scale adoption of new technologies and processes possible, examples are covered in this paper. The big question is, will they?

6 ACKNOWLEDGEMENTS

The author acknowledges and thanks CRC Mining for funding the project and William Jacobs for his work as the research assistant. In addition the following people have generously provided their time Professor Peter Knights (University of Queensland), GP Captain Ernie Walsh (Australian Defence Force), David Love (Electrical, Utilities and Public Administration Training Council Inc), Nigel Haywood (Resources Industry Training Council), and Jennifer Rumbles (Chamber of Minerals and Energy WA) Emeritus Professor Margaret Seares (UWA), Professor Trish Todd (UWA Business School) and Sandy Dunn (Assetivity). The views expressed in this article are those of the author. Finally a thank you to all of the AMC-WA branch committee members who helped organise and run the workshop.

7 BIBLIOGRAPHY

1. Barley, S.R., *Technicians in the workplace: ethnographic evidence for bringing work into organizational studies.* Administrative Science Quarterly, 1996. **41**: p. 404-441.
2. Orr, J., *Talking About Machines: An Ethnography of a Modern Job*1996, Ithaca, New York Cornell University Press.
3. Bourrier, M., *Organizimg maintenance at two American nuclear power plants.* Journal of Contingencies and Crisis Management, 1996. **4**: p. 104-112.
4. Reiman, T. and P. Oedewald, *Measuring maintenance culture and maintenance core task with CULTURE-questionnaire—a case study in the power industry.* Safety Science, 2004. **42**(9): p. 859-889.
5. Reiman, T., *Assessing organizational culture in complex sociotechnical systems: Methodological evidence from studies in nuclear power plant maintenance organizations*, 2007, VTT Publications: Espoo, Finland.
6. Defence, D.o., *Report of the Board of Inquiry into the Fire into HMAS Westralia on 5 May 1998*, 1998: Caberra, ACT.
7. Hopkins, A., *Lessons from Longford: The Esso Gas Plant Explosion*2000, Sydney: CCH Australia Limited.
8. Hopkins, A., *Safety, Culture and Risk: The organisational causes of disaster*2005, Sydney: CCH Australia Limited.
9. Hidden, A., *Investigation into the Clapham Junction Railway Accident*, 1989, HMSO: London.
10. Cullen, T.H.L., *Public Inquiry into the Piper Alpha Disaster*, 1990, HMSO: London.
11. Oedewald, P. and T. Reiman. *Measuring conceptual knowledge among NPP maintenance personnel-A tool for knowledge management*. in *Human Factors and Power Plants and HPRCT 13th Annual Meeting, 2007 IEEE 8th*. 2007. IEEE.
12. Reason, J. and A. Hobbs, *Managing maintenance error - a practical approach*2004, Burlington, VA: Ashgate Publishing Company.
13. Pettersen, K.A. and K. Aase, *Explaining safe work practices in aviation line maintenance.* Safety Science, 2008. **46**(3): p. 510-519.
14. Ighravwe, D.E. and S.A. Oke, *A non-zero integer non-linear programming model for maintenance workforce sizing.* International Journal of Production Economics, 2014. **150**: p. 204-214.
15. Woodside. *The Angel Platform*. 2014 [cited 2014 3/3/2014]; Available from: http://www.woodside.com.au/our-business/north-west-shelf/offshore/pages/angel.aspx.
16. Dudley, J., R. McAree, and P. Level, *Bridging the automation skills gap*, 2009, Cooperative Research Centre for Mining: Brisbane. p. 51.
17. MISC, *Automation for success*, 2010, Mining Industry Skills Centre Inc.: Queensland. p. 65.
18. AVC, *Rise of the Machines? Adoption of automation technology in the Australian resources industries and its implication for vocational education and training and higher education*, 2013, Australian Venture Consultants Perth.
19. NSSC. *Vet Standards*. 2014 [cited 2014 3/3/2014]; Available from: http://www.nssc.natese.gov.au/vet_standards.
20. ASQA. *About RTOs*. 2014 [cited 2014 3/3/2014]; Available from: http://www.asqa.gov.au/about-vet/about-rtos/about-rtos.html.
21. EOz, *Energy Skills Australia: Enviroscan 2013*, 2013, Electrocomms and Energy Utilities Industry Skills

Council Ltd: Braddon ACT. p. 88.
22. AQFC, *Australian Qualifications Framework*, 2013, Australian Qualifications Framework Council: South Australia.
23. MCA, *Minerals Council of Australia Policy Brief for the 44th Commonwealth Parliament*, 2013, Minerals Council of Australia: Canberra.
24. DMC, S., *Environmental Scan 2013: Resources and Infrastructure Industry - responding to challenges and opportunities*, 2013, Skills DMC National Industry Skills Council: Canberra. p. 48.
25. Wilkinson, J.J., *How to manage maintenance.* Harvard Business Review, 1968(March-April): p. 100-111.