Risk based reliability centered maintenance pdf free pdf free

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© 1996-2015, Amazon.com, Inc. or its affiliates Something went wrong. Wait a moment and try again. Reliability centred maintenance identifies the functions of the company that are most critical and then seeks to optimize their maintenance strategies to minimize system failures and ultimately increase equipment reliability and availability. The most critical assets are those that are likely to fail often or have large consequences of failure. With this maintenance strategy, possible failure modes and their consequences are identified; all while the function of the equipment is considered. Cost-effective maintenance techniques that minimize the possibility of failure can then be determined. The most effective techniques are then adopted to improve the reliability of the facility as a whole. Implementing RCM increases equipment availability, and reduces maintenance and resource costs. Jardine and Tsang give an example of a utility company who reduced maintenance costs by up to 40%. Disadvantages RCM does not readily consider the total cost of owning and maintaining an asset. Additional costs of ownership, like those considered in evidence-based maintenance, are not taken into account, and are therefore not factored into the maintenance considerations. There are several different methods for implementing reliability centred maintenance that are recommended, summarized in the following 7 steps. Step 1: Selection of equipment for RCM analysis The first step is to select the piece of equipment for reliability centred maintenance analysis. The equipment selected should be critical in terms of its effect on operations, its previous costs of repair, and previous costs of preventive maintenance. Find the best equipment for RCM with this criticality analysis template Step 2: Define the boundaries and function of the systems that contain the selected equipment The equipment belongs to a system that performs a crucial function. The system can be large or small, but the function of the system, and its inputs and outputs, should be known. For example, the function of a conveyor belt system is to transport goods. Its inputs are the goods and mechanical energy powering the belt, while its outputs are the goods at the other end. In this case, the electric motor supplying the mechanical energy would be considered as part of a different system. Step 3: Define the ways in which the system can fail (failure modes) In step 3 the objective is to list all of the ways that the function of the system can fail. For example, the conveyor belt may fail by being unable to transport the goods from one end to the other, or perhaps it does not transport the goods quickly enough. Step 4: Identify the root causes of the failure modes With the help of operators, experienced technicians, RCM experts and equipment experts, the root causes of each of the failure modes can be identified. Root causes for failure of the conveyor could include a lack of lubrication on the rollers, a failure of a bearing, or a loosened belt. Use this template and stop spending hours doing a root cause analysis Step 5: Assess the effects of failure In this step, the effects of each failure mode are considered. Equipment failures may affect safety, operations, and other equipment. The criticality of each of these failure modes can also be considered. There are various recommended techniques that are used to give this step a systematic approach. These include: Failure modes and effects analysis (FMEA) Failure, mode, effect and criticality analysis Hazard and operability studies (HAZOPS) Fault tree analysis (FTA) Risk-based inspection (RBI) The most important failure modes will be determined at the conclusion of this systematic analysis. Ask yourself questions such as "Does this failure mode have safety implications?", and "Does this failure mode result in a full or partial outage of operations?". Your answer is the most important failure modes that should be prioritized for further analysis. Importantly, the failure modes that are retained include only those that have a real probability of occurring under realistic operating conditions. Step 6: Select a maintenance tactic for each failure mode At this step, the most appropriate maintenance tactic for each failure mode is determined. The maintenance tactic that is selected must be technically and economically feasible. Condition-based maintenance is selected when it is technically and economically feasible to detect the onset of the failure mode. Time or usage-based preventive maintenance is selected when it is technically and economically feasible to reduce the risk of failure using this method. For failure modes that do not have satisfactory condition-based maintenance or preventive maintenance options, then a redesign of the system to eliminate or modify the failure mode should be considered. Failure modes that were not identified as being critical in Step 6 may, at this stage, be identified as good candidates for a run-to-failure maintenance schedule. Step 7: Implement and then regularly review the maintenance tactic selected Importantly, the RCM methodology will only be useful if its maintenance recommendations are put into practice. When that has been done, it is important that the recommendations are constantly reviewed and renewed as additional information is found. The popular RCMII methodology has been around since the late '90s, but it was what professionals call a consequence-based approach. This work represents a revision to that bestselling work, by John Moubray, with more modern thinking, an emphasis on a risk-based methodology, and alignment with International ISO standards (55000 and 31000). The result is a more holistic, integrated, and rigorous way for developing asset care and risk-mitigating strategies for physical assets. Since the release of the ISO 31000 and ISO 55000 Standards for Risk Management and Asset Management respectively, Aladon developed RCM3, a risk-based RCM methodology that places managing the risk and reliability of physical assets mainstream with other business management systems in an organization. RCM3 fully complies and exceeds the requirements of the SAEJA 1011 Standard and fully aligns with the frameworks of the ISO Standards. The new risk-based focus of RCM3 features the following principles: • The proactive management of physical and economic risks. • Updated approach for testing and managing of protective systems. • Based on the requirements of the fourth industrial revolution (Industry 4.0) and its challenges. • Covers new expectations and new maintenance techniques for fourth-generation maintenance. • Places reliability & risk management mainstream with organizational objectives and management systems. • Aligned and integrated with International ISO Standards for Physical Asset Management and Risk Management (ISO 55000 & ISO 31000). • Now part of an integrated asset strategy for full life-cycle management of physical assets. *Indicates Print on Demand books. Takes 10 – 14 days from time of order to produce. The popular RCMII methodology has been around since the late '90s, but it was what professionals call a consequence-based approach. This work represents a revision to that bestselling work, by John Moubray, with more modern thinking, an emphasis on a risk-based methodology, and alignment with International ISO standards (55000 and 31000). The result is a more holistic, integrated, and rigorous way for developing asset care and risk-mitigating strategies for physical assets. Since the release of the ISO 31000 and ISO 55000 Standards, Aladon developed RCM3, a risk-based RCM methodology that places managing the risk and reliability of physical assets mainstream with other business management systems in an organization. RCM3 fully complies and exceeds the requirements of the SAEJA 1011 Standard and fully aligns with the frameworks of the ISO Standards. The new risk-based focus of RCM3 features the following principles: The proactive management of intolerable physical and economic risks. Updated approach for testing and managing of protective systems. Based on the requirements of the fourth industrial revolution (Industry 4.0) and its challenges. Covers new expectations and new maintenance techniques for fourth-generation maintenance. Places reliability & risk management mainstream with organizational objectives and management systems. Aligned and integrated with International ISO Standards for Physical Asset Management and Risk Management (ISO 55000 & ISO 31000). Now part of an integrated asset strategy for full life-cycle management of physical assets. Purchase This Book | Ebook When I first learned about RCM in the 90s, I never thought that one day my career would center around it, nor that I would never stop learning about RCM and its powerful philosophy. A philosophy is a way of thinking and works by asking very basic questions about all things and the connections between them. RCM is more than a methodology or a process, it is a philosophy. When you study RCM, you realize how things really work and how they are connected. The power of RCM and what it can achieve is often underestimated. In the forty years since RCM was first applied in the airline industry, it has been applied to almost all types of assets. as RCM practitioners, we have learned much about how and where to apply it. Over the years, true RCM has drawn criticism for taking too long and tying up too many resources. For me, a properly executed RCM process is the only way to ensure an asset will continue to do what its users want it to do (intended function) in its present operating context. The SAE JA 1011 standard defines the criteria that any process must possess to be called RCM. For many years the aladon RCM2™ methodology has been recognized as the gold standard for rcM processes. The rcMII book by John Moubray was a key reference in the standard, and has sold more than 100,000 copies. RCM2 has been applied globally on more sites than any other rcM process and The aladon network trained more people in rcM than any other organization. That collective knowledge and collaboration of the aladon network led to the development of the RCM3™ methodology. RCM3 is a risk-based approach, and profoundly different from the RCM process defined by the sae Ja 1011 standard. RCM3 is not only more advanced and aligned with the international standards for physical asset management and risk management, but it also allows users to fully understand and quantify the risks associated with owning and operating assets. The RCM3 methodology is based on the initial work introduced by John Moubray in 2003 and is a continuation of many years of rigorous development and testing. In the process of improving the hugely successful RCM2 methodology (RCM2), we have come to realize the absolute brilliance and pioneering work of John Moubray. People who know rcMII will recognize the terminologies and process. The RCM3 process, however. changes the way we look at the importance of the operating context, how protective systems are managed and more importantly, how risk is quantified and mitigated. The major difference between the two processes is the treatment of failures. In RCM, the major distinction was between hidden and evident failures. Proactive treatment of evident failures (routine maintenance) were considered first before the default actions (run to failure or redesign) were selected. In RCM3, the focus is still on the distinction between hidden and evident failures, but RCM3 now differentiates clearly between intolerable and tolerable risks. This has a profound impact on how decisions are made— the proactive risk management strategies are now more comprehensive, and more decisions are made during the analysis. The time it takes to perform an RCM3 analysis is impacted by the treatment of identified risks. The RCM3 facilitator now focuses on the mitigation of intolerable risks (as defined by the organization's risk framework) during the RCM workshop and treats tolerable risks (if it can be done in a cost-effective way) outside the RCM analysis meetings, using the expertise of individuals rather than the whole review group, thus saving time and money. This work is intended for everyone who wants to learn more about the risk and reliability associated with operating and maintaining physical assets. The book further provides an overview of the RCM3 process and its benefits, how to apply it and how to build a sustainable reliability program. Enjoy your RCM3 journey! Marius Basson Wilmington North Carolina November 2018 CHAPTER 1 RCM3 Background Since the release of the Nowlan and Heap report in 1978 when the process was first called reliability-centered maintenance (RCM), RCM became very popular, but it also became very distorted through many variations and derivatives that followed since. RCM has been in the minds and on the lips of many people throughout the industrial world for more than 37 years. A number of attempts by different people and organizations have been made to industrialize RCM. There have been spectacular successes, the most notable of which was the development of RCM2™ by John Moubray and the application thereof by the worldwide Aladon Network since 1991. Subsequent significant developments include the development and release of the standards SAE JA1011, Evaluation Criteria for RCM Processes, and SAE JA1012, A Guide to the RCM Standard. Many RCM service providers started up during the same time, but very few maintained the rigor and intent that was produced through the years of research and development. A number of other works on the subject of RCM (formal and informal) have been published around the world. This simply illustrates that RCM has become a familiar name in the industry. Over the years, John Moubray and Marius Basson (the author of this edition) realized that the RCM process, if applied correctly, would change not just the way we do things (in maintenance), but also the way we think. Marius Basson was trained by John Moubray in RCM2 and has been implementing RCM2 for over 20 years on a full-time basis. After his acquisition of Aladon, he realized it was time for a change and approached a longtime friend and colleague, Theuns Koekemoer, who had left the Aladon Network a decade earlier to develop his own version of RCM, a risk-based approach. This risk-based approach was started by John Moubray more than 15 years ago. John unfortunately passed away before he could finalize and launch his risk-based process. John struggled with two issues at the time when he started to revise the popular RCM2 approach: the first centered on commercial acceptance (RCM2 was and still is a very popular methodology), and the second was the confusion it may have created in the industry. Theuns Koekemoer took John's ideas and ground-breaking work and developed a revised RCM process, calling it risk-based RCM. Then Marius and Theuns came together and polished the process and rebranded it as the Aladon RCM3 process. Since the start of their work together in 2014, it soon became evident that the new process had some holes in it, and it needed to be tested and implemented before it could be fully qualified and released. This took 4 years of hard work and many revisions, mostly around the decision logic. To most people familiar with RCM, the changes in RCM3 may seem to be minor (even cosmetic), but it is a dramatic departure from the RCM process described in SAE Standard JA1011, having profound benefits and a shift in the way it is performed and implemented. RCM3 adds a new dimension to how maintenance and risk management strategies are defined. RCM3 complies fully with SAE Standard JA1011 and surpasses it by extending the functionality to align with the newer ISO standards for risk and asset management while incorporating all the valid RCM methodology steps. Reliability management has become highly specialized, and with the introduction of new standards and technology, RCM3 places reliability mainstream with organization management systems. RCM3 moves closer to directly influencing and contributing to other business processes. RCM3 fully integrates with other risk-based approaches such as risk-based inspection (RBI) and root cause failure analysis (RCFA). RBI is mainly focused on vessels under pressure, which are subject to statutory prescriptive inspections. Traditional statutory inspections have some shortcomings, and RBI attempts to address these shortcomings through identifying risks associated with equipment failures. The mechanical deterioration mechanisms are identified through inspections. RBI, like RCM3, takes into consideration the condition of equipment, the risks associated with possible failures, and the specific operating context. RCM3 is applicable to all equipment and plant types. The scope of RCM3 is not limited to any specific type of equipment, plant, or processes. The Aladon RCFA process fully integrates with RCM3 and provides the continuous improvement cycle. The combination of a failure, the effect of the failure, and the associated consequence poses a specific risk. RCM3 is focused on first identifying the risks involved with possible failures, then quantifying the risks, and then determining the most effective way to deal with such risks in the most appropriate way. When considering physical risk (safety and environmental) and economic risk, the RCM3 process deals with the risks altogether, eliminating or mitigating the risk of equipment failure to a level that will be tolerable to the organization. Every organization has very specific responsibilities to the organization's owners and investors, to its employees, and to society in general. Therefore, the risks associated with plant, equipment (physical assets), and processes should always be assessed within the context of the organization as a whole. Risk management has always been an inherent characteristic of RCM. To the experienced practitioner, risk management is, in fact, intuitive, and integrating risk management into RCM is considered a necessary evolution. RCM3 sets out to highlight and formalize the identification, categorization, and management of risk as part of developing the failure management and maintenance management plan. About This Book This book is an updated version of the popular book by John Moubray, called RCMII, which has been translated in multiple languages with over 100,000 copies sold. This book uses many of the same concepts and terminology, but includes the updated methodology also known as risk-based RCM. The book describes the RCM3 process and covers the requirements and the process as well as the implementation strategies. While Appendix I traces the progression from RCM2 to RCM3 in detail, the following summarizes the highlights, presents the eight questions that characterize the RCM3 process, and describes how RCM3 fully aligns with ISO 31000 and ISO 55000: The development of the operating context is not only referred to as an important step; in RCM3 it is now a definite requirement, and it also is the first question of the RCM3 process: What are the operating conditions (how the equipment or system is being used)? Together with the functional requirements and associated performance standards, it provides the context for risk management associated with physical assets. The second question in the RCM3 process asks, What are the functions and associated performance standards of the asset in its present operating context? ISO 31000 defines risk as the combination of the severity of the consequence and the probability that the consequence will happen. The events that pose a risk to the organization (negative deviation from what is expected) can be compared with failed states or functional failures in RCM, which leads to the third question: In what ways does it fail to fulfill its functions (failed states)? Each failed state poses a risk, and the failure modes are the events that cause the failed states. RCM3 makes a clear distinction between the causes of failure and the mechanisms of failure, therefore minimizing mistakes and ambiguities. The fourth question deals with failure modes and asks, What causes each failed state (failure modes)? Both the failure characteristics associated with each failure mode and the inherent reliability of the asset or component under consideration will determine the likelihood or probability of failure. RCM3 categorizes risk in two categories—physical and economic risks—and it uses the severity of the consequence and the probability to quantify the inherent risk for each likely failure mode. This information is captured as failure effects, which is the fifth question in the process: What happens when each failure occurs (failure effects and consequence severity)? RCM3 focuses on the risk associated with each failure mode. To determine whether the failure matters or not—in other words, whether the failure poses an intolerable risk—the sixth question asks, "What are the risks associated with each failure (inherent risk quantified)?" All intolerable risks must be mitigated. The seventh question of the RCM3 process asks, "What must be done to reduce intolerable risks to a tolerable level (using proactive risk management strategies)? Where risks are tolerable, the RCM review group doesn't have to consider any further action, saving time, money, and valuable resources. The eighth and last question asks, What can be done to reduce or manage tolerable risks in a cost-effective way?" When risks are tolerable, further optimization can be achieved provided it is done in a cost-effective manner. RCM ensures that the minimum safe amount of maintenance and engineering solutions will be considered to reduce or manage the risks to tolerable levels as specified by the organization's risk management framework. CHAPTER 2 Introduction to RCM 2.1 The Changing World of Maintenance Over the past 50 years, maintenance has changed, and continues to change perhaps more so than any other management discipline. The changes are due to a huge increase in the number and variety of physical assets (plant, equipment, and buildings) that must be maintained throughout the world, much more complex designs, new maintenance techniques, and changing views on maintenance organization and responsibilities. Maintenance is also responding to changing expectations. These include a rapidly growing awareness of the extent to which equipment failure affects safety and the environment, a growing awareness of the connection between maintenance and product quality, and increasing pressure to achieve high plant availability and to contain costs. The developments and awareness of renewable energy, carbon trading, greenhouse gas (GHG) effects, and climate change brought renewed focus on equipment reliability and the carbon footprint these assets possess. Attempting to comply with governments' and society's environmental expectations, while at the same time maintaining profitable production facilities, tends to create conflict and work in opposite directions. The changes are testing attitudes and skills in all branches of industry to the limit. Maintenance people are having to adopt completely new ways of thinking and acting, as engineers and as managers. At the same time the limitations of maintenance systems are becoming increasingly apparent, no matter how much they are computerized. In the face of this avalanche of change, managers everywhere continue to look for the newest approach to maintenance. They want to avoid the false starts and dead ends that always accompany major upheavals. Instead they seek a strategic framework that synthesizes the new developments into a coherent pattern, so that they can evaluate the developments sensibly and apply those likely to be of most value to them and their companies. RCM3 is a philosophy that provides just such a framework, and if applied correctly within the maintenance and operations organizations, RCM3 will provide the asset integrity and reliability to fulfill the business needs set by the managers and stakeholders. If it is applied correctly, RCM transforms the relationships bet ween the undertakings that use it, their existing physical assets, and the people who operate and maintain those assets. It also enables new assets to be put into effective service with great speed, confidence, and precision. This chapter provides a brief introduction to RCM, starting with a look at how maintenance has evolved over the past 80 years. Since the 1930s, the evolution of maintenance can be traced through four generations. RCM quickly became the cornerstone of the third generation, and the current generation (the fourth generation) can only be viewed in the light of the previous generations. During three previous generations the focus was very much on availability, reliability, safety, and environmental integrity, and even with the strong focus on these aspects, companies still failed to deliver to society's expectations. If we consider all the major industrial accidents caused by equipment failure since the turn of the century (Chernobyl, Piper Alpha, Bhopal, Texas City explosion, Deep Water Horizon, etc.), it is very much proof that a lot must still be done even though the number of deaths caused by industrial accidents is declining. Figure 2.1 illustrates the decline in fatal injuries over the past 20 years. Data from multiple sources reflect the large decreases in work-related deaths from the high rates and numbers of deaths among workers during the early twentieth century. The earliest systematic survey of workplace fatalities in the United States in the twentieth century covered Allegheny County, Pennsylvania, from July 1906 through June 1907; that year in the one county, 526 workers died in work accidents; 195 of these were steel-workers. In contrast, in 1997, 17 steelworker fatalities occurred nationwide. The National Safety Council estimated that in 1912, 18,000–21,000 workers died from work-related injuries. And in 1913, the Bureau of Labor Statistics documented approximately 23,000 industrial deaths among a workforce of 38 million, equivalent to a rate of 61 deaths per 100,000 workers. FIGURE 2.1 Rate of fatalities Under a different reporting system, data from the National Safety Council from 1933 through 1997 indicate that deaths from unintentional work-related injuries declined 90%, from 37 per 100,000 workers to 4 per 100,000. The corresponding annual number of deaths decreased from 14,500 to 5,100; during this same period, the workforce more than tripled, from 39 million to approximately 130 million. More recent and probably more complete data from death certificates were compiled from the CDC's National Institute for Occupational Safety and Health (NIOSH) National Traumatic Occupational Fatalities (NTOF) surveillance system. These data indicate that the annual number of deaths declined 28%, from 7,405 in 1980 to 5,314 in 1995 (the most recent year for which complete NTOF data are available). The average rate of deaths from occupational injuries decreased 43% during the same time, from 7.5 to 4.3 per 100,000 workers. Industries with the highest average rates for fatal occupational injury during 1980–1995 included mining (30.3 deaths per 100,000 workers), agriculture/forestry/fishing (20.1), construction (15.2), and transportation/communications/public utilities (13.4) as illustrated in Figure 2.2. Leading causes of fatal occupational injury during the period include motor vehicle–related injuries, workplace homicides, and machine-related injuries. FIGURE 2.2 Occupational injury death rates by industry division, United States, 1980–1995 Companies became preoccupied with safety, and it became top management's performance indicator. Safety and Reliability Are Directly Related One reason for the decline in fatalities is the fact that operations people are no longer working next to or close to the equipment, as was the case 50 years ago. However, because of automatization and modernization, incidents and accidents became fewer in numbers but much more severe. Safety is now related to the state of equipment and assets. Safety and reliability are therefore directly related; however, more maintenance does not mean safer operations, which brings us to realize that there is no direct relationship between the amount of maintenance and safety and thus the amount of maintenance and reliability. More maintenance ≠ more reliable The First-generation Maintenance It is important to understand how industry moved maintenance and the changes in maintenance along. The First Industrial Revolution was a fundamental change in the way goods were produced, from human labor to machines and more efficient means of production and subsequent higher levels of production, triggering far-reaching changes in industrialized societies. The First Industrial Revolution started largely in the UK during the last quarter of the eighteenth century; achievements included the harnessing of steam power, the mechanization of the textile industry, developments in transportation (trains and trams), advances in communication (telegraph, telephone, and radio), and the birth of the modern factory. Machines started to replace humans in agriculture and manufacturing. The First-Generation Maintenance covers the period up to World War II. In those days, industry was not very highly mechanized, so down-time did not matter much. This meant that the prevention of equipment failure was not a very high priority in the minds of most managers. At the same time, most equipment was simple and much of it was overdesigned. This made it reliable and easy to repair. As a result, there was no need for systematic maintenance of any sort beyond simple cleaning, servicing, and lubrication routines. The need for skills was also lower than it is today. The Second Industrial Revolution, also known as the Technological Revolution, was a phase of the larger Industrial Revolution corresponding to the latter half of the nineteenth century until World War I. It is considered to have begun with the development of the Bessemer process for making inexpensive steel in the 1860s and culminated in mass production and the production line, improved workflow, and scientific management. The Second Industrial Revolution was driven by electricity, a cluster of inventions, internal combustion engines, airplanes, and moving pictures. Increased mechanization of industry and improvements in worker efficiency increased the productivity of factories while undercutting the need for skilled labor. The Second-generation Maintenance Things changed dramatically during World War II. Wartime pressures increased the demand for goods of all kinds while the supply of industrial labor dropped sharply. This led to increased mechanization. By the 1950s, machines of all types were more numerous and more complex. Industry was beginning to depend on them. As this dependence grew, downtime came into sharper focus. This led to the idea that equipment failures could and should be prevented, which led, in turn, to the concept of preventive maintenance. In the 1960s, this consisted mainly of equipment overhauls done at fixed intervals. The cost of maintenance also started to rise sharply relative to other operating costs. This led to the growth of maintenance planning and control systems. These systems have helped greatly to bring the cost of maintenance under control and are now an established part of the practice of maintenance. Finally, the amount of capital tied up in fixed assets, together with a sharp increase in the cost of that capital, led people to start seeking ways in which they could maximize the life of the assets. The Third-generation Maintenance The first two Industrial Revolutions made people richer and more urban. The Third Industrial Revolution made life and manufacturing go digital. The Third Industrial Revolution included digital technology, personal computing, the internet, and mass customization. According to the Economist the Third Industrial Revolution is known for a number of remarkable technologies that converged: clever software, novel materials, more dexterous robots, new processes (notably three- dimensional printing), and a whole range of web-based services. The factory of the past was based on producing identical products: Ford famously said that car buyers could have any color they liked, as long as it was black. Factories now focus on mass customization, using new and lighter materials that are stronger and more durable than the old ones. New techniques shape engineering, and the internet allows ever more designers to collaborate on new products. Since the mid-seventies, the process of change in industry has gathered even greater momentum. The changes can be classified under the headings of new expectations, new research, and new techniques. Expectations changed from having high availability to wanting reliability also. It placed a great emphasis on maintenance. Digital technology changed the media and retailing industries. Factories are no longer full of grimy machines manned by workers in oily overalls. Many factories are squeaky clean and almost deserted. Most jobs are no longer on the factory floor but in the offices nearby, full of designers, engineers, IT specialists, logistics experts, marketing staff, and other professionals. Manufacturing jobs require more skills, and dull repetitive tasks have become almost obsolete. The Third Industrial Revolution affected not only how things are made today, but also where. As a result of the Third Industrial Revolution, labor costs are growing less and less important: Offshore production is increasingly moving back to rich countries, not because Chinese wages are rising, but because companies now want to be closer to their customers so that they can respond more quickly to changes in demand and customization. The lines between manufacturing and services are blurring. Rolls-Royce no longer sells jet engines; it sells the hours that each engine is actually thrusting an airplane through the sky. OEMs (original equipment manufacturers) would rather sell equipment capability while continuing to own and to maintain the assets. Another example is a large shovel manufacturer that sells tons moved but keeps ownership of the shovels. The operating company pays for the tons and has guaranteed uptime, while the equipment maintenance and repairs remain the responsibility of the OEM. This places an even greater emphasis on inherent reliability and maintenance efficiency. The Fourth-generation Maintenance The Fourth Industrial Revolution is upon us. The following tweet by an IBM global entrepreneur captures the essence of the technological upheavals of the Fourth Industrial Revolution that is currently sweeping through the global economy (this was at the time of writing): World's largest taxi company owns no taxis (Uber). Largest accommodation provider owns no real estate (Airbnb). Largest phone companies own no telecom infrastructure (Skype, WeChat). World's most valuable retailers keep no inventory (Amazon and Alibaba). Most popular media owner creates no content (Facebook). Fastest-growing bank has no actual money (SocietyOne). World's largest movie distributor owns no cinemas (Netflix). Largest software vendors don't write the apps (Apple and Google). The Fourth Industrial Revolution, also known as the Second Machine Age, is fundamentally changing each and every aspect of our life and is very different from the previous ones! Professor Klaus Schwab, founder and executive chairman of the World Economic Forum and author of the recently published book The Fourth Industrial Revolution, mentions that the lines between the physical, digital, and biological spheres are getting blurred in the Fourth Industrial Revolution. The revolution is disrupting almost every industry in every country. The breadth and depth of these changes herald the transformation of entire systems of production, management, and governance. Not only does the Fourth Industrial Revolution change what we are doing, but it also changes us. We need new economic models and a value shift. It changes the way we collaborate on every level of society and civilization. It will fundamentally alter the way we live, work, and relate to one another, how we generate, supply, and move energy around and interact with machines. Millions of traditional jobs may be lost to technology and robots, but with new education and innovation, millions more will be created. The Fourth Industrial Revolution (and how we respond to it) will lead to better productivity and improved safety, reliability, and quality. Digitalist Magazine summarizes five key factors that are changing modern businesses: 1. Hyperconnected products that wirelessly collect, store, and send data through the Internet of Things 2. Supercomputing analytical tools that provide, store, and interpret Big Data 3. Cloud computing platforms that collect and store large sets of data 4. Smart technology like wearables, robotics, machine learning, artificial intelligence, and 3D printing 5. Cybersecurity solutions that protect data and soothe privacy concerns from varying physical, human, and virtual threats For manufacturers this means real-time factory and enterprise-level insights, zooming in on granular levels of the supply chain with high-tech sensors. These sensors securely enable virtual tracking of assets, processes, resources, and products to optimize and automate supply and demand. As more manufacturers employ smart processes into workflows, the amount of waste, energy, and unplanned downtime is forecasted to decrease. None of this will be possible without the correct maintenance response. Since the early 2000s, more emphasis has been placed on controlling the way organizations apply asset management. Although it is still a long way from being legislated, and very much left to the organizations to demonstrate due diligence toward safety and environmental responsibility, more organizations are being sued and more individuals have had to stand in front of a court explaining why their asset management programs were flawed. RCM3 provides the rigor and a robust methodology to face the challenges of the Fourth Industrial Revolution. This is our Fourth-Generation Maintenance approach. John Moubray wrote about the Third-Generation Maintenance in his book Reliability-Centered Maintenance (RCMII, Second Edition), where he explained the growing expectations of maintenance, the changing views of equipment failure, and changing maintenance techniques. Similar to how the Fourth Industrial Revolution is building on the Third, Aladon took the foundation of the Third-Generation Maintenance and lessons learned over 30 years in industry and developed the Fourth-Generation Maintenance methodology (RCM3™), which recognizes the shift in demographics, even more changing expectations (outcome based), asset performance monitoring and predictive analytics (Industrial Internet of Things, or IIoT), mobility (World in Motion), and defect elimination (Reliability Centered Design™), all to meet the challenges the Fourth Industrial Revolution brings. According to Marius Basson from Aladon, the Fourth-Generation Maintenance will bring about the same change in how industry views maintenance when compared with industry's response after Nowlan and Heap released their report Reliability-Centered Maintenance in 1978. However, the velocity, scope, and system impact of the Fourth-Generation Maintenance are exponentially faster than the generations passed. See Figure 2.3. FIGURE 2.3 Increasing demand on equipment It is the view of the author that management of critical physical assets will be regulated and could soon be legislated, similar to bookkeeping. Companies will no longer be allowed to get away with ignoring their responsibility to maintain assets and the infrastructure better. The risk associated with owning and operating critical assets is just becoming too far-reaching and important. For example, owners of data centers are now regulated, and compliance is essential. Keeping medical records and financial data is regulated and overseen by government agencies. Companies responsible for keeping data are liable for the data customers put on to those servers. The following is from an article written on the compliance issues faced by data center designers and operators. Health care is a major area where compliance is critical to offering data center services. Here, the primary concern is maintaining privacy of patient records and information. Laws protect the data that is kept on these servers and data centers that store, process or transmit electronic protected health information must comply with these legislative standards. Again, since health care is such a tremendous portion of the U.S. economy, neglecting compliance in this area cuts data center companies off from access to a very large base of potential customers. Another big concern is dealing with financial customers. Here, financial regulations such as Sarbanes-Oxley are the focus. A broader area of compliance is the Payment Card Industry (PCI) Data Security Standard (DSS), which applies to companies handling credit card information, for example. In this case, the scope of clients for whom PCI DSS compliance is critical goes beyond market segments like health care or finance. This multidimensional security standard includes requirements for security management, policies, procedures, network architecture, software design and other critical protective measures to ensure a controlled and secure environment for processing the sensitive information. It is almost certain that any of the above (if not all) impact our lives directly. The Fourth-Generation Maintenance is required to go beyond traditional methods of dealing with symptoms, most of the requirements are now based on information and how it is collected and distributed. See Figure 2.4. FIGURE 2.4 Changing expectations Downtime has always affected the productive capability of physical assets by reducing output, increasing operating costs, and interfering with customer service. By the 1960s and 1970s this was already a major concern in the mining, manufacturing, and transport sectors. In manufacturing, the effects of downtime are being aggravated by the worldwide move towards just-in-time systems, where reduced stocks of work-in-progress mean that quite small breakdowns are now much more likely to stop a whole plant. In recent times, the growth of mechanization and automation has meant that reliability and availability have now also become key issues in sectors as diverse as health care, data processing and warehousing, telecommunications, space exploration, global internet and shared networks (the cloud), and building management. Greater automation also means that more and more failures affect our ability to sustain satisfactory quality standards. This applies as much to standards of service as it does to product quality. For instance, equipment failures can affect data integrity, financial security, stability of governments, climate control in buildings and the punctuality of transport networks as much as they can interfere with the consistent achievement of specified tolerances in manufacturing. More and more failures have serious safety or environmental consequences at a time when standards in these areas are rising rapidly. In most parts of the world, the point is approaching where organizations either conform to society's safety and environmental expectations or they cease to operate. This adds an order of magnitude to our dependence on the integrity of our physical assets, one which goes beyond cost and which becomes a simple matter of organizational survival. At the same time as our dependence on physical assets is growing, so too is their cost to operate and to own. To secure the maximum return on the investment which they represent, they must be kept working efficiently for as long as we want them to. Finally, the cost of maintenance itself is still rising, in absolute terms and as a proportion of total expenditure. In some industries, it is now the second highest or even the highest element of operating costs. As a result, in only 50 years it has moved from almost nowhere to the top of the league as a cost control priority. Managing Physical and Economic Risks. Management has always been chartered with maximizing stakeholder and investor share price while trying to avoid disruptions and production losses. This creates opposing priorities. On the one hand, managers are trying to save cost (reducing maintenance expenditure), while on the other hand, they are trying to increase revenue (extending the equipment beyond its capability). Management also takes a view of risk avoidance rather than risk management. An avoidance policy forces management to avoid risks by adopting a zero-tolerance approach (which is unaffordable and unsustainable) or by ignoring the risks and doing nothing (taking zero action) to manage them appropriately. Management either takes a paranoiac view (avoid it at all costs) or takes a view of feeling lucky (this will not happen to us). Neither of these approaches is sustainable; the first is not achievable, and the second is no longer acceptable. With the release of the international asset management and risk management standards (ISO 55000 and ISO 31000), a renewed focus is placed on managing physical and economic risks rather than avoiding or ignoring them. Companies may acknowledge the criticality of their operations and assets but do nothing or little about it unless they recognize it is a risk to attaining business objectives. Once organizations fully understand the risks to their operations, they will act (How can we reduce our risk?). Most industrial incidents and accidents are proof of how companies ignored the risk of very critical assets and operations. RCM3 is such a philosophy that brings reliability and risk management mainstream with other important business processes. RCM3 cuts through and eliminates any differences between industries, cultures, and societies and allows a pragmatic view of risk management. Example: A Canadian-based coal company acquired a coal mine in Wales, UK. When the Canadian managers showed up at the mine in Wales for the first time, they were shocked to find out that the underground workers used the incline conveyor to ride out of the mine. At every shift change, production would stop and the workers would jump on the belt at the bottom, lie down to avoid being bumped off, and jump off at the top. It was a very safe and acceptable practice that had been performed at the mine for many years. According to the Canadian Health and Safety Laws, this practice was unacceptable, and the company's management banned this practice immediately. Miners had to walk out of the mine now. This created a big uproar with the Welsh, and management was under pressure to find alternative ways for transporting the miners quickly; there was no rail system in place, and the mine was not set up for using vehicles for personnel transport. After some review and the review of the incident records, management determined that riding the belt was actually a safe practice and reinstated it. The culture, laws, and regulations between the two countries were vastly different, and it became quite the experience when Canadians went to visit. This was not the only difference that had to be overcome. A pragmatic view of the risk associated with this practice allowed the Canadians to be more open to the idea. The risk associated with this practice was well understood and managed and did not have to be avoided. Standardization and Adopting Standards. More emphasis is being placed on standardization, not only in equipment selection but also in the way we do things. In order to measure and compare performance across an organization, the need for establishing rules and metrics becomes crucial. Companies want to measure and compare between divisions or locations (where they operate in multiple locations), different regions, market sectors, and industries. Standardization leads to adoption of best practices and the creation of centers of excellence (COEs). This further leads to standardized work management practices and standardized approaches for operations and maintenance. In our example of the Canadian company and the Welsh mine, standardization and templating turned out to be problematic, especially when considering diversity in cultures, regulations and regulatory requirements, governments, and government agencies. What was needed was better risk management strategies where everyone was involved. Globalization. With the popularity of the internet and internet buying, the market has opened up to everyone. People are buying and getting exposed to information and equipment they never have seen or heard of before. It allows organizations to buy at competitive and lower overall costs. The challenges this brings also have never been experienced before: Controls and program logic are programmed in foreign languages, and so are the maintenance and operating manuals that come with the equipment. As well, equipment reliability (the prevention of failure) has become much more important, because engineers and maintainers are no longer dealing with the supplier or agent two towns over; they are now dealing with OEMs on the opposite side of the world, most times not even speaking the same language. This emphasizes the need for a common language and common set of values to ensure reliability and maintainability. Responsible Custodians and Environmental Responsibility. Society as a whole is placing pressure on organizations to be responsible and accountable. The four components of corporate social responsibility (CSR)—economic, legal, ethical, and altruistic duties—should be recognized and supported by management. The different perspectives and proper role of business in society, from profit making to community service provider, are required to be successful. Much of the confusion and controversy over CSR stems from a failure to distinguish among ethical, altruistic, and strategic forms of CSR. On the basis of a thorough examination, altruistic CSR is not a legitimate role of business. The ethical CSR, grounded in the concept of ethical duties and responsibilities, is mandatory, and strategic CSR is good for business and society. This responsibility places enormous pressure on the maintenance function. Failures causing health problems (and injuries or deaths), damage to the environment, and harm to society's valuables (drinking water, wild life, air quality, etc.) are no longer acceptable. Managers and asset owners are being tried and jailed for ignoring their responsibilities. Renewable Strategies. Renewable strategies are created for sustainable development and a sustainable environment. These strategies typically involve three major technological changes: savings on the demand side (more effective utilization and preservation), efficiency improvements on the production side (increased reliability and availability), and the replacement of current sources (e.g., oil and coal). Consequently, large-scale renewable strategies must include strategies for integrating renewable sources in coherent systems influenced by energy savings and efficiency measures. These strategies introduced new equipment and thinking to the industry. It also changed the way maintenance is done. Through preservation, recycling, renewal, and conservation, societies are more sustainable compared with traditional thinking of obsolescence and replacement. Companies are incentivized through buying renewable energy, and soon this incentive will spread to other essential resources. Defect Elimination. Defect elimination is a proactive maintenance strategy with seemingly obvious value. Defects are also referred to as failed states. This is so whether the machine has a defect and still works but produces unacceptable quality or whether the machine is unable to produce anything at all. Maybe the machine still works, but production is slow and the number produced over time is less. The value of the product is reduced in all three cases, and all defects are undesirable. Defects cost money. If end users candidly investigate, they may see that they are investing money in keeping their defects. How? Money is lost because the products are being sold at a reduced price or because the maximum number of products was not produced. Slowed production or downtime is money invested in keeping defects. According to Webster's, eliminate means to put an end to or get rid of. An asset that is free of defects is an asset that can be optimally profitable. Innovation. Organizations are constantly looking for innovative ideas. More millionaires are produced through people selling innovative ideas than millionaires producing things. Consider the twenty-first-century ideas and the products we are getting used to more and more: for example, the innovation in energy (wind, solar, wave, and biomass), electric cars and other modes of transport, drones, unmanned vehicles, autonomous mining, etc. The list goes on. For all these new ideas and assets, we have to come up with new maintenance techniques and operating procedures. Equipment is monitored by other equipment, operations are centralized and remote (sometimes in other countries), driving is done via satellite and GPS, and maintenance has to use the diagnostics rather than the firsthand feedback from an operator at the end of a mission or shift. Maintenance must produce innovative ideas for maintaining new types of equipment also. New Expectations and Reality Quite apart from greater expectations and new technologies, research changed many of our most basic beliefs about age and failure. In particular, it is apparent that there is less and less connection between the operating age of most assets and the likelihood they will fail. It is even truer in modern facilities and installations. Figure 2.5 shows that the earliest view of failure was simply that as things got older, they were more likely to fail. A growing awareness of start-up failure led to a widespread second-generation belief in the bathtub curve. However, third-generation research has revealed that not one or two, but six failure patterns actually occur in practice. This is discussed in detail later, but it too had a profound effect on maintenance. FIGURE 2.5 Changing world of maintenance In the fourth generation the focus is still on recognizing the six failure patterns, but more so on eliminating failures altogether—a tough ask and even more pressure on design integrity, production assurance practices, process safety, and maintenance. Failures can no longer be tolerated, and equipment has to be performing at acceptable standards right from the start. Understanding the failure characteristics is essential in the development of risk management strategies, especially predictive and preventive maintenance strategies. The impact this has on the development of cost- effective maintenance strategies is still underestimated and misunderstood. New Techniques There has been explosive growth in new maintenance concepts and techniques. Hundreds have been developed over the past 30 years, and more are emerging every week. Figure 2.6 shows how the classical emphasis on overhauls and administrative systems has grown to include many new developments in a number of different fields. The New Developments With the development of new tools such as decision support, hazard studies, failure modes and effects analysis, expert systems, and condition monitoring, and with a much greater emphasis on reliability and maintainability when designing equipment, as well as a shift in organizational thinking toward participation, teamwork, and flexibility (internal collaboration), the industry has seen a movement toward communities of practice and knowledge sharing and the establishment of standards and certifications. More reliance is placed on collective experience and proven best practices (external collaboration). FIGURE 2.6 New maintenance techniques A major challenge for maintenance people continues to be learning and understanding what these new techniques are and to decide which are worthwhile and which are not in their own organizations. Figure 2.7 illustrates how the world of maintenance evolved from a simplistic few of fix it when it broke mentality to more comprehensive maintenance management of planning and scheduling. Figure 2.7 further illustrates that modern thinking involves much more than just maintenance management, encompassing a holistic view of physical asset management. They have to deal not only with these new techniques but also with new equipment they have never experienced before. If we make the right choices, it is possible to improve asset performance and at the same time contain and even reduce the cost of maintenance. If we make the wrong choices, new problems are created while existing problems only get worse. FIGURE 2.7 Physical asset management The Challenges Facing Maintenance In a nutshell, the key challenges facing modern maintenance managers can be summarized as follows: To select the most appropriate techniques To deal with each type of failure process In order to fulfill all the expectations of the owners of the assets, the users of the assets, and of society as a whole In the most cost-effective and enduring fashion With the active support and cooperation of all the people involved To demonstrate corporate and social responsibility while achieving

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