Chapter 2
Introduction to Smart Maintenance

Abstract This chapter introduces some general knowledge relative to the broad area of maintenance. Unlike other easy to automate processes (e.g., product systems), maintenance work usually involves one-off, backdrop-sensitive activities. Some general classification of maintenance are discussed in Sect. 2.1. The reactive and proactive types of maintenance strategy are briefed in Sects. 2.2 and 2.3, respectively. Then, a holistic smart maintenance strategy (followed throughout this book) is explained in Sect. 2.4. Section 2.5 summarises this chapter.

2.1 Introduction

Maintenance is an assemblage of technologies and practices that consist of technical skills, engineering techniques, practical methodologies, and scientific theories. If we look at our society as a huge moving system, then the aim of maintenance is to "keep the teeth of every single gear within such system fitting each other nicely" (Radzevich, 2013). The high prices and risks resulting from inappropriate maintenance have been both widely observed and well-documented as well, such as Latorella and Prabhu (2000), Onohaebi and Lawai (2010). Under these circumstances, during the last decades, various maintenance plans and strategies have been developed for the purpose of organizing the maintenance work as effectively as possible. Broadly speaking, maintenance can be classified into two types, that is, reactive- and proactive-maintenance strategy as depicted in Fig. 2.1 in which a snapshot of selected maintenance practices under each category is also illustrated.

2.2 Reactive Maintenance Strategy

This type of maintenance is also known as breakdown, run-to-failure, or fix-when-fail. Traditionally, practitioners (who developed a manufacturing schedule to assign machines to process products) made production decision that are only

B. Xing and T. Marwala, *Smart Maintenance for Human–Robot Interaction*,
Studies in Systems, Decision and Control 129, DOI 10.1007/978-3-319-67480-3_2

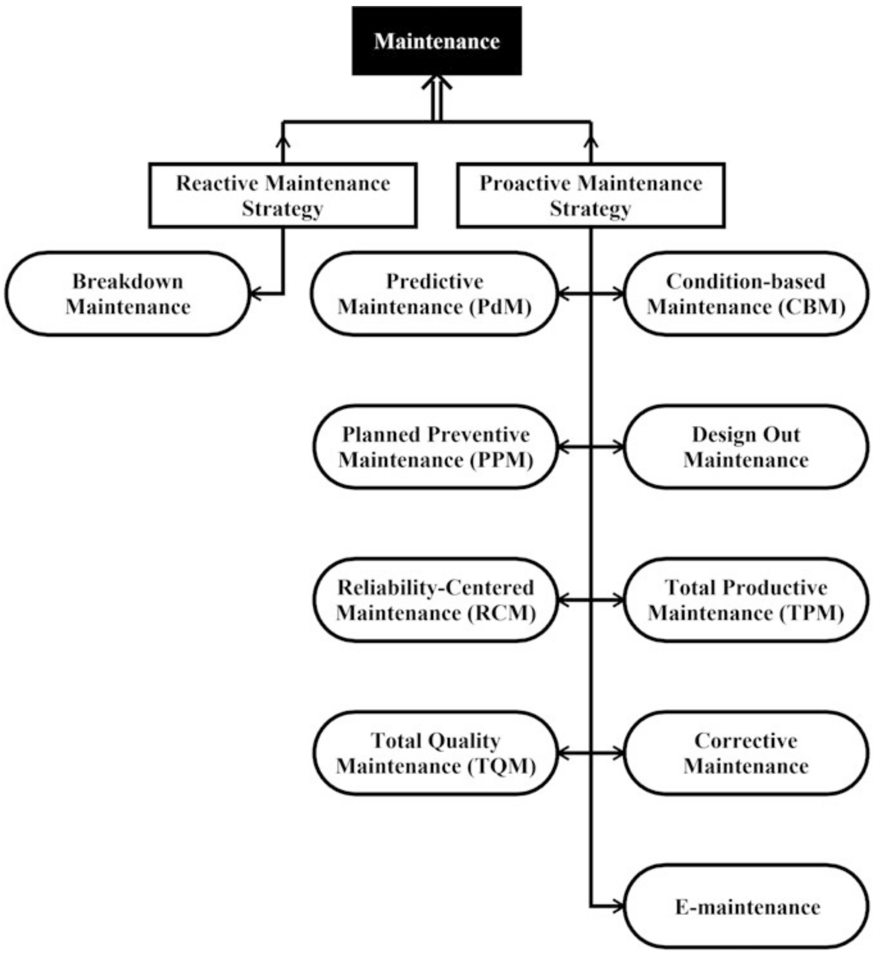

Fig. 2.1 Maintenance—building blocks and selected sub-divisions

based on the analysis of manufacturing capacity and customer demand. The problem lies in the fact that they ignored the operating condition of critical plant machinery, equipment, or systems. And it is naive to assume that when the production is interrupted, it can be fixed quickly. In other words, historically managers emphasized repairing failures rather than preventing them. However, we have significant evidence that such assumption is false, and that this reactive maintenance results in not only ineffective but also extremely costly. Several researchers pointed out, though reactive maintenance can make machines return to service, a number of issues such as poor planning, uncertain reliability, only focusing on a single component, incomplete repair, and lack of experiences accumulation have become major drawbacks for the reactive maintenance strategy (Bloch & Geitner, 2005; Dhillon, 2002; Mobley, Higgins, & Wikoff, 2008). As a result, once the machines breakdown, there is a continuous rescheduling problem due to inefficient maintenance planning.

2.3 Proactive Maintenance Strategy

The proactive maintenance strategy, which is built on the ideas of both safety lead-times and reliability, is the most popular maintenance philosophy in recent years. Its main advantages include (Bloch & Geitner, 2005; Eti, Ogaji, & Probert, 2006; Léger & Morel, 2001): (1) using real-time feedback communication technologies to detect defect causes; (2) providing a customised maintenance method to each application; and (3) improving the overall maintenance effectiveness and safety. Typically, an effective proactive maintenance strategy covers four aspects, namely monitoring, diagnosis, prognosis, and decision-making (Muller, Suhner, & Iung, 2008). Some typical proactive maintenance plans and strategies are summarized as follows:

- **Condition-based Maintenance**: (Besnard & Bertling, 2010; Campos, 2009; Golmakani & Fattahipour, 2011; Jardine, Lin, & Banjevic, 2006; Kwon, Chiou, & Stepanskíy, 2009; Marwala, 2010, 2012; Niu, Bo-SukYang, & Pecht, 2010; Shin & Jun, 2015; Yam, Tse, Li, & Tu, 2001; Yang, 2004)
- **Corrective Maintenance**: (Kenne, Boukas, & Gharbi, 2003; Kenne & Nkeungoue, 2008; Lucia, Pompella, & Stefanucci, 2005; Wang, Deng, Wu, Wang, & Xiong, 2014)
- **Design Out Maintenance**: (Ajukumar & Gandhi, 2013; Mobley et al., 2008; Tsai, 2005)
- **E-maintenance**: (Al-Qahtani & Aramco, 2012; Candell, Karim, & Parida, 2011; Chebel-Morello et al., 2012; Emmanouilidis, Jantunen, Gilabert, Arnaiz, & Starr, 2011; Garcia, Guyennet, Lapayre, & Zerhouni, 2004; Guillén, Crespo, Gómez, & Sanz, 2016; Haider & Koronios, 2006; Han & Yang, 2006; Hausladen & Bechheim, 2004; Holmberg et al., 2010; Hu, 2005; Iung, 2003; Iung, Levrat, Marquez, & Erbe, 2009; Iung & Marquez, 2006; Jantunen, Emmanouilidis, Arnaiz, & Gilabert, 2011; Jonsson, Holmström, & Levén, 2010; Kajko-Mattsson, Karim, & Mirjamdotter, 2011; Karim, Candell, & Söderholm, 2009; Lee, Ni, Djurdjanovic, Qiu, & Liao, 2006; Levrat, Iung, & Marquez, 2008; Lung, Levrat, Crespo-Márquez, & Erbe, 2007; Macchi & Garetti, 2006; Muller, Marquez, & Iung, 2008; Muller, Suhner, & Iung, 2007; Pistofidis, Emmanouilidis, Koulamas, Karampatzakis, & Papathanassiou, 2012; Tao, Ding, & Xiong, 2003; Ucar & Qiu, 2005; Yu, Iung, & Panetto, 2003; Zhang, Halang, & Diedrich, 2003)
- **Planned Preventive Maintenance (PPM)**: (Eti et al., 2006; Muller, Suhner, et al., 2008; Ni, Lee, & Djurdjanovic, 2003)

- **Predictive Maintenance (PdM)**: (Aladesaye, 2008; Carnero, 2006; Ekpenyong, 2011; Marwala, 2009; Mobley, 2002; Moya, 2004)
- **Reliability-Centred Maintenance (RCM)**: (Bloom, 2006; Endrenyi et al., 2001; Hameed, Vatn, & Heggset, 2011; Marwala, Boulkaibet, & Adhikari, 2017; Tsarouhas & Arvanitoyannis, 2010; Zio, 2009)
- **Total Productive Maintenance (TPM)**: (Ahuja & Khamba, 2008; Mckone & Wiess, 1998; Pinto, Pimentel, & Cunha, 2016; Tsang, 2008)
- **Total Quality Maintenance (TQM)**: (Mobley et al., 2008).

2.4 Smart Maintenance Strategy

To achieve a harmonized human robot relationship, the intelligent robotic systems should be able to mimic any naturally occurring system. Accordingly, the proposal of "smart maintenance" has evolved to a stage where technologies have been developed to keep man-made systems achieving optimal systematic functionalities. In the context of artificial intelligence, when intelligent techniques are involved in a system's adaptation, one can consider it as a "smart adaptive system". In this chapter, our "smartness" is determined against the following measures (Varadan, Vinoy, & Gopalakrishnan, 2006):

- Adaptability to constant changing circumstances.
- Adaptability to a reassembling setting with no extra need of being "ported" to it.
- Adaptability to an unfamiliar/unknown situation.

The practical implications of smart maintenance are to search for solutions (both technological and institutional) for managing the following assets appropriately:

- **Tangible Asset**: either large (e.g., plants, power generation facilities, automobiles, railways, aircrafts, water distribution pipelines, bridge, and construction equipment) (Bloch & Geitner, 2005; Fernández & Márquez, 2012; Gill, 2009; Guo, Song, Ghalambor, & Lin, 2014; Hastings, 2010, 2015; Li, Lin, & Chen, 2017; Piper, 1999; Tavner, 2012; Wu, Yuan, Kumfer, & Liu, 2017) or small (e.g., household appliances, consumer products, laboratory equipments, and toys) (Carey & Carey, 2010; Elston, 2007);
- **Intangible Asset**: either software (Dhillon, 2002; Erdil et al., 2003; Pessoa et al., 2017; Tchoffa & Mhamedi, 2012; Thongmak & Muenchaisri, 2009), data (Ozmen-Ertekin & Ozbay, 2012; Zhang & Rundensteiner, 2002), or Cyberinfrastructure (Buford, Yu, & Lua, 2009; Huang, Duy, & Fang, 2014; Meng & Zhang, 2014; Morimoto, 2010; Senthilkumar, Chandrasekaran, Suresh, Arumugam, & Mohanraj, 2012); and
- **Hybrid Asset**: This type of asset is often overlooked by most existing maintenance plans. The reason why we include human as a hybrid asset in our smart maintenance strategy for human robot interaction (HRI) is twofold—(1) human

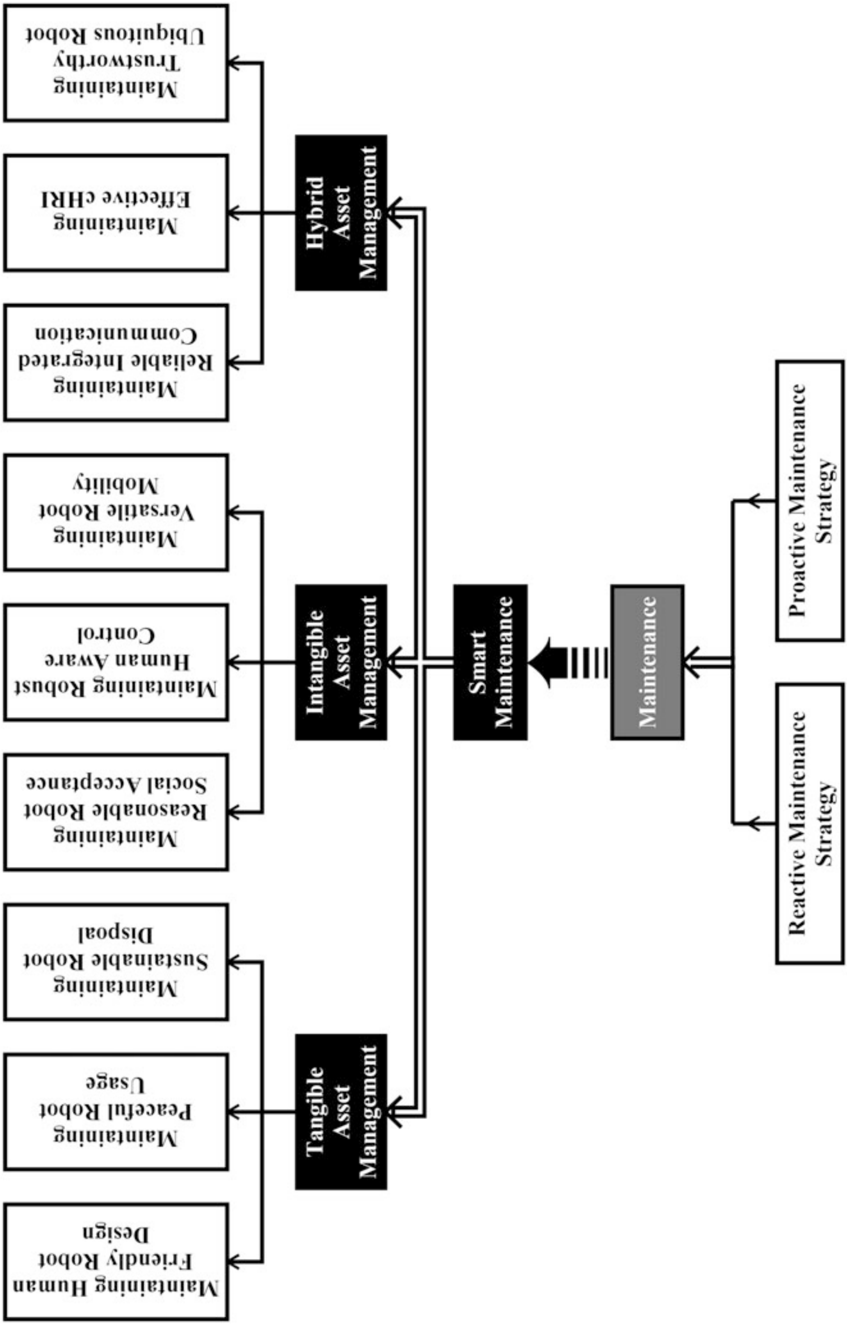

Fig. 2.2 Smart maintenance—main categories and selected maintaining avenues

capital is often regarded as the most important asset within an organization. In almost all cases, humans contribute an establishment's success. In practice, we all believe that people are critical (Phillips & Phillips, 2015); (2) it was estimated that about 10–15% of all deadly accidents and 15–20% of all mishaps are maintenance-related operations. A large body of studies also demonstrate that occupational and work-related diseases or health issues (e.g., hearing decline, cancer/tumour, asbestosis, and musculoskeletal disorders) are also more commonly founded among personnel involved in the maintenance tasks (Grusenmeyer, 2014; Kumar, Khan, & Gandhi, 2011; Muylaert et al., 2010). It is thus often safe to link maintenance to a high-risk job. As such, the awareness of the risks related to the maintenance itself and the seriousness of workers' safety and health maintenance must be raised.

The resultant solutions must keep our society's various assets not only working with each other smoothly in a cost-effective, energy-economic, and environment-friendly manner but also under a securable, controllable, reliable, and predictable way. Based on the above observations, the proposed smart maintenance strategy and selected maintaining avenues are illustrated in Fig. 2.2.

2.5 Conclusions

The role of maintenance within our society lies in that it supports and retains a functional condition for any equipment and facility. In the context of human robot interaction (HRI), maintenance is not only a compulsory function to ensure robot's productivity and its associated technical structures' reliability, but regular maintenance is also an indispensable part in terms of offering a safer and healthier relationship between robots and humans. Negligence of maintenance or insufficient maintenance can both result in severe and fatal accidents or health related issues. For the forthcoming robotized society to be possible, robotic systems must own a high degree of dexterity, adaptability, disposability, and dependability. Accordingly, the materials, components, and modules in a robotic system are equipped with various sensors and actuators so that they can not only be linked with each other but also share connectivity with humans. The resultant unceasing timely information stream makes it simpler to predict system performance and schedule necessary maintenance work. However, assembling all the elements in a robotic system to create desirable cyber-physical system also causes a sharp rise in the number of parts requiring maintenance. The concept of "smart maintenance" is thus proposed in this chapter to fit this requirement. It integrates various existing maintenance engineering analytical principles and maintenance practices. As opposed to previous maintenance initiatives which tended to mechanize maintenance job and focus on enhancing equipment solely, smart maintenance strategy proposes a new maintenance philosophy which encompasses the management of all tangible-, intangible, and hybrid assets.

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Smart Maintenance for Human–Robot Interaction
An Intelligent Search Algorithmic Perspective
Xing, B.; Marwala, T.
2018, XXIX, 305 p. 68 illus., Hardcover
ISBN: 978-3-319-67479-7