CIRP Annals - Manufacturing Technology xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

CIRP Annals - Manufacturing Technology

journal homepage: http://ees.elsevier.com/cirp/default.asp

Continuous maintenance and the future – Foundations and technological challenges

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ARTICLE INFO

Keywords:
Maintenance
Lifecycle
Service

ABSTRACT

High value and long life products require continuous maintenance throughout their life cycle to achieve required performance with optimum through-life cost. This paper presents foundations and technologies required to offer the maintenance service. Component and system level degradation science, assessment and modelling along with life cycle 'big data' analytics are the two most important knowledge and skill base required for the continuous maintenance. Advanced computing and visualisation technologies will improve efficiency of the maintenance and reduce through-life cost of the product. Future of continuous maintenance within the Industry 4.0 context also identifies the role of IoT, standards and cyber security.

1. Introduction and motivation

High value products are typically technology intensive, expensive and reliability critical requiring continuous maintenance throughout their life cycle. Continuous maintenance is an engineering service that allows products to achieve required performance through-life with optimum through-life cost. Examples of the high value products include high-tech machine tools, aircraft engine, nuclear power station, train, defence equipment, high-end car, medical equipment, and wind turbine (Fig. 1). In addition, manufacturers are looking for opportunities to provide the maintenance service within the in-service phase of the product life cycle to generate additional revenue and profit. Customers and end users are expecting to pay for the usage of the product rather than the full ownership. This is known as 'servitisation' phenomenon within the manufacturing sector. A full study of the phenomenon under the 'Industrial Product-Service Systems (IPS^2)' CIRP Collaborative Working Group was presented in 2010 [113]. When manufacturers provide continuous maintenance for a product they have developed, especially within an industrial product-service system context, it provides additional opportunities to improve the design and production of those products using the in-service feedback. This can lead to overall reduction of the through-life cost together with reduction in material consumption. There are also new challenges in the area of maintenance service [144] [22] due to the new context. Continuous maintenance of high value products to achieve enhanced durability and reliability is also consistent with the European Commissions recent action plan on Circular Economy [36]. The action plan emphasises on better product design by aligning the producers, users and the recyclers. The new IPS^2 model has prompted additional changes and has become the key motivation for continuous maintenance:

- Engineering for life and extending life of the legacy high value products with optimum cost [7].
- Better understanding of the foundations of product in-service degradation.
- Applying new technologies to improve efficiency and effectiveness of the maintenance: large scale data analytics (or Big Data), automation and autonomy.

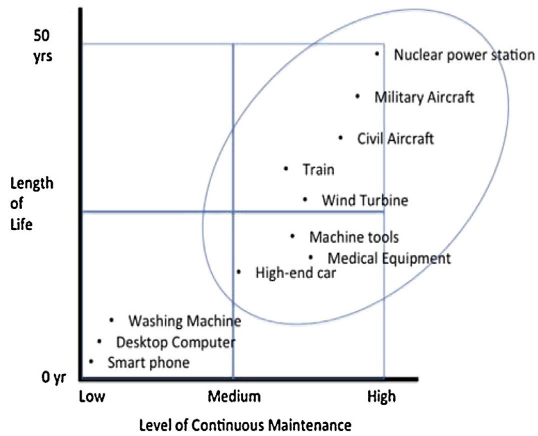

Fig. 1. Scope of the keynote.

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http://dx.doi.org/10.1016/j.cirp.2016.06.006

Within next 5 years	Within 5-10 years
Predictive analytics Deep learning 3D printing Virtual/Augmented reality Smart virtual personal assistants Cyber secure manufacturing	Autonomous vehicles Change capable systems Industry 4.0 and servitisation Multi-functional materials IoT/IoE/Wearables Distributed Manufacturing
Beyond 10 years	
Quantum computers Real time prediction of through-life performance Material for long-life Self-configuring production systems Affordable space travel	

Fig. 2. Technological challenges that will affect manufacturing significantly (based on [46,52,180]).

- Applying advanced repair and retrofit technologies for legacy systems.
- Functional improvement of a high value product over time.

With technological developments such as Additive Layer Manufacturing (ALM), Industry 4.0 and Internet of Things (IoT) (Fig. 2) there is a paradigm shift in our ability to better repair or replace individual components, better understand the health of a product and plan maintenance based on the availability of significantly large volume of data. The increasing amount of data collected requires the development of new product-service business models. Whether the collected data belongs to the manufacturer or the customer/user of equipment is a critical issue to be solved when designing the product-service business models. Manufacturers could pay customers for providing the usage data, because with the data the manufacturer improves product quality by feeding back retrieved information in the product development process following the example of "Total Cost of Ownership (TCO)" contracts. The data collection could improve the quality of service received by the customer (as "serviceability") and implement autonomous maintenance approach to reduce the through-life cost of the equipment and increase the customer satisfaction [27].

This keynote presents different technologies and fundamental knowledge that is essential to provide continuous maintenance, their challenges and how the technologies are changing in the future, associated opportunities, uncertainties and risks. The scope of this keynote (Fig. 3) includes continuous maintenance of high value and long life industrial products and the manufacturing facilities for the products within the industrial product-service system context. The keynote will cover technologies that are relevant at component level as well as the whole system level and will also include continuous maintenance approaches used for both workshop-based maintenance and 'in-situ' maintenance of large equipment (e.g., power generation gas turbines). The paper will not consider shorter life products (e.g., consumer products) and will not include retrofitting technologies used to maintain the legacy systems. The keynote does not include 'design for continuous maintenance' or associated product design challenges. This keynote does not also cover the environmental effect of the maintenance and the decision making process for upgrade, overhaul or renewal.

There are several terminologies used in academia and in practice that have similarities with continuous maintenance. The terminologies are Maintenance, Repair and Overhaul (MRO); Through-life Engineering Services; Life Cycle Engineering and Asset Management. The context of this keynote is based on industrial product-service systems and includes several similar terminologies such as product-service systems, performance based contracts, 'power by hour' contracts and availability contracts. Although the terminologies have similarities there are some differences. For the purpose of this paper, the term continuous maintenance is being used in this document. The earliest paper related to computer-assisted maintenance within the CIRP Annals is from 1981 [24]. There are 66 maintenance related papers within the Annals so far with several more papers published within the CIRP Life Cycle Engineering and CIRP Sponsored Through-life Engineering Services conferences. Spur et al. [153] discussed challenges in robotics task execution for maintenance in space platforms, then an extension of the task classification for automation was reported by Farnsworth and

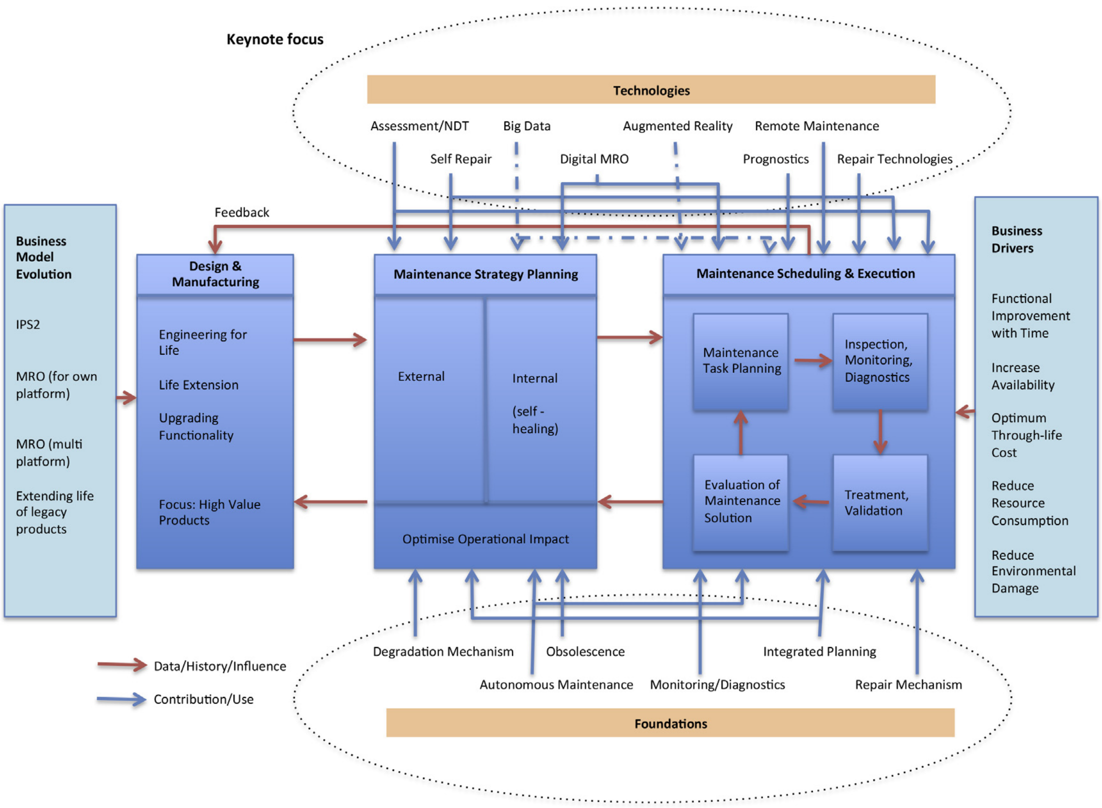

Fig. 3. Continuous maintenance – fundamental knowledge required and technological challenges.

Please cite this article in press as: Roy R, et al. Continuous maintenance and the future – Foundations andtechnological challenges. CIRP Annals - Manufacturing Technology (2016), http://dx.doi.org/10.1016/j.cirp.2016.06.006