Available online at www.sciencedirect.com

ScienceDirect

IFAC PapersOnLine 50-1 (2017) 13692–13697

Sustainable Maintenance: a Periodic Preventive Maintenance Model with Sustainable Spare Parts Management

Chiara Franciosi* Alfredo Lambiase*
Salvatore Miranda*

**Department of Industrial Engineering, University of Salerno, 84084, Fisciano (SA), Italy (e-mail: cfranciosi@unisa.it, lambiase@unisa.it, smiranda@unisa.it).*

Abstract: Industrial companies are among the largest responsible of materials and energy flows in an environment where natural resources are running out and impacts of human activities are still rising. Consequently, in the last few years, research is focusing on the new paradigm of sustainable manufacturing, which aims to develop sustainable production processes, innovative technologies, and new tools for evaluating economic, environmental, and social impacts of industrial assets. In this context, maintenance process, necessary to ensure availability, reliability, and safety of industrial assets, could become one of the main pillars for sustainable manufacturing. The purpose of the paper is to provide a periodic preventive maintenance model that establishes the optimal maintenance period for each system component, which minimizes conventional, environmental, and social costs generated by maintenance interventions. The model, moreover, integrates the concept of Circular Economy, choosing the most suitable spare parts to use in maintenance activities from a sustainable perspective. The model is applied on a part of a pasta production plant obtaining a maintenance plan, which evidences economic, environmental, and social benefits and confirms the necessity to introduce sustainability considerations into conventional maintenance procedures.

Keywords: maintenance models and services; sustainable maintenance; sustainability; preventive and corrective maintenance; maintenance cost; spare part management.

1. INTRODUCTION

The manufacturing pillar has evolved over time from mass production to lean manufacturing, to green manufacturing, up to the new paradigm of sustainable manufacturing (SM), which allows to pursue economic growth without undermining social and environmental issues (Uusitalo et al. (2017)). Sustainable manufacturing is one of the main contributor to sustainable development since allows to create products through the rational use of resources and with new cleaner technologies oriented to preserve the environment and guarantee people health and safety (Javal et al. (2010); Garetti and Taisch (2012)). Moreover, SM involves the need to move from Linear Economy to Circular Economy (CE), based on waste reduction through recycle, reuse, remanufacturing and recovery of materials becoming a paradigm for continued economic prosperity and ecological balance aiming at maintaining and guaranteeing human wellbeing and economic growth (Ghisellini et al. (2015); Elia et al.(2016); Jawahir and Bradley (2016)). To move towards economic, environmental, and social challenges, is necessary that all business processes become sustainable ensuring availability and reliability of system components, guaranteeing safety of employees and community, and minimizing environmental impacts. In this context, as already highlighted in 2010 by Liyanage and Badurdenn, the maintenance process has a large potential in pursuit of SM. In fact, maintenance has evolved together with manufacturing process from reactive function without any preventive actions, becoming firstly a preventive approach, later a green process (Ajukumar and Gandhi (2013)), until, nowadays, is considered as a process that needed to be managed in a sustainable perspective (Stuchly and Jasiulewicz-Kaczmarek (2014)). To date, some indicators, methods, and tools are used for evaluating and measuring sustainability level in companies (Demartini et al. (2016)) and in industrial maintenance. Tornese et al. (2014), for example, presented a first framework for selecting the most fitting environmental performance measurement methodology. In this frame, maintenance is a key actor and itself must be sustainable: new sustainable maintenance services have to be developed and defined according to CE and SM paradigms, integrating the sustainability goal within conventional maintenance processes with the aim of eliminating breakdown and sources of energy waste and reducing internal and external costs (Jasiulewicz-Kaczmarek (2013); Iung and Levrat (2014)). Pires et al. (2015) argued that new researches are necessary for more substantially discuss the impacts of industrial maintenance on organizational sustainability and vice-versa: the connection between maintenance and sustainability must be further explored in literature. Recently, Ba et al. (2016) have proposed a production plan and a maintenance policy, which integrates a spare parts strategy with consideration of CO_2 emissions.

This study focuses on sustainable maintenance management and proposes a new sustainable periodic preventive maintenance model which minimizes environmental and social impacts caused by maintenance interventions and allows to choose the most sustainable spare parts among new,

2405-8963 © 2017, IFAC (International Federation of Automatic Control) Hosting by Elsevier Ltd. All rights reserved.
Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2017.08.2536

used, remanufactured, and reconditioned (Long et al. (2016) provided the definition of different type of spare parts). Figure 1 shows how the proposed model is collocated among SM, CE, and Sustainable Maintenance paradigms.

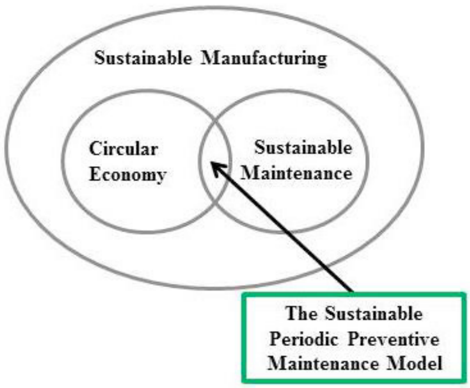

Fig. 1 – The Proposed Model within the Paradigms of SM, CE, and Sustainable Maintenance

2. NOTATION

η: component characteristic life [hours]
β: shape parameter of Weibull distribution
R: component reliability
MTTF: Mean Time to Failure [hours]
C: average maintenance cost per hour [€/hour]
PM: preventive maintenance
CM: corrective maintenance
Cp: total PM cost
Cc: total CM cost
tp: preventive maintenance period
Cp_m: manpower PM cost
Cc_m: manpower CM cost
C_{mh}: average manpower hourly cost
N: number of workers for maintenance intervention
h_P: hours necessary for PM intervention
h_C: hours necessary for CM intervention
Cp_{sp}: spare part management cost for PM intervention
Cc_{sp}: spare part management cost for CM intervention
P: component purchase value
x: parameter associated to spare part type of each component (x = 1 if spare part is new, otherwise x < 1 and its value depends on spare part type – i.e. remanufactured, reconditioned or used)
c_H: spare part holding cost
c_D: unit disposal cost of old spare part
w: component weight
i_r: recycling index
c_{WP}: work planning cost for preventive maintenance
Cp_{lp}: lost production cost for PM intervention
Cc_{lp}: lost production cost for CM intervention
m_{uc}: unit contribution margin
p_l: line productivity
Cc_i: direct and indirect cost of injury caused by failure
C_D: direct cost of injury caused by failure
C_I: indirect cost of injury caused by failure
f_i: occurrence frequency of injury caused by failures
Cp_e: environmental cost associated to PM activity
Cc_e: environmental cost associated to CM activity
e_i: emissions released by maintenance intervention [kg $CO_{2\text{-eq}}$]
e_{SP}: emissions released by spare part production [kg $CO_{2\text{-eq}}$]
e_D: emissions released by spare part disposal [kg $CO_{2\text{-eq}}$]
e_{Wp}: emissions released by production of wastes due to PM activity [kg $CO_{2\text{-eq}}$]
e_{Wc}: emissions released by production of wastes due to CM activity [kg $CO_{2\text{-eq}}$]
e_{WEp}: emissions released by energy wasted due to PM activity [kg $CO_{2\text{-eq}}$]
e_{WEc}: emissions released by energy wasted due to CM activity [kg $CO_{2\text{-eq}}$]
c_e: carbon cost coefficient
C_S: social cost of injury caused by failure
Cc_{si}: social cost of injury caused by failure per period

3. PERIODIC PREVENTIVE MAINTENANCE MODEL WITH SUSTAINABLE SPARE PARTS MANAGEMENT

A periodic preventive maintenance model that includes sustainable aspects is presented. In particular, the model allows to determine both the optimal preventive maintenance period that minimizes conventional, environmental, and social maintenance costs and the different type of spare parts to be used in maintenance interventions in order to limit the environmental and social impacts. The model permits to choose, where possible, among new, used, remanufactured, and reconditioned spare parts, in order to establish the most sustainable from an economic, environmental, and social point of view and to evaluate the right trade-off among economic convenience, reliability of spare parts, and their environmental impact (e.g. new spare part is more expensive and has more environmental impact than used spare part, but the latter present a less reliability).
The model establishes the preventive maintenance period - tp - that minimizes C according to equation (1), whereas the reliability of each component is calculated according to equation (2).

$$C(tp) = \{Cp \cdot R(tp) + Cc \cdot [1 - R(tp)]\} / \int_0^{tp} R(t)\, dt \qquad (1)$$

$$R(t) = e^{-(t/\eta)^{\beta}} \qquad (2)$$

The considered preventive (equation (3)) and corrective (equation (4)) maintenance costs are made up of internal costs, normally supported by the company, and the external costs generated by maintenance activities but which are not supported by who created them.

$$Cp = Cp_m + Cp_{sp} + Cp_{lp} + Cp_e \qquad (3)$$

$$Cc = Cc_m + Cc_{sp} + Cc_{lp} + Cc_i + Cc_e + Cc_{si} \qquad (4)$$

Table 1 and Table 2 show, respectively, internal and external maintenance costs calculated and considered in the model. The model, implemented in MatLab, takes, from an Excel worksheet, the data necessary for the calculation of all costs (Table 1 and Table 2) and reliability (function of time), and finds the optimal value of tp that minimizes C according to equation (1). The model allows to analyze 5 scenarios for each component/failure mode: a conventional scenario in which the spare part is new and only the internal costs are considered and minimized (Scenario A), and four sustainable scenarios that minimize both internal and external costs and consider, respectively, the use of new (Scenario B1), remanufactured