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Sustainable maintenance performances and EN 15341:2019: an integration proposal

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Abstract. Maintenance is a key process contributing to sustainable manufacturing operations. According to this vision, recent scientific studies underline the need for indicators to assess maintenance sustainable performances. In the normative field, the EN 15341:2019 standard about Key Performance Indicators of the Maintenance Function was recently released covering all major aspects of maintenance and physical assets management, giving more emphasis to sustainability. Nevertheless, a complete set of indicators covering the environmental and social dimensions of maintenance sustainability under the sustainable manufacturing perspective is still missing. Therefore, in this paper the relevant factors to be considered for integrating the existing standard and to achieve a complete maintenance performance measurement system tackling sustainability are identified by analyzing the wider literature and normative frameworks about sustainable manufacturing performances. A validation in the industrial reality is identified as a next step to assess the factors' applicability in terms of measurability.

Keywords: Maintenance, Sustainable Performance, Sustainable Manufacturing, Performance indicators.

1 Introduction

Nowadays, manufacturing organizations are facing the urge to adopt new sustainable strategies to respond to the market and customer's demand for sustainable products, considering the scarcity of the natural resources and the growing pressure coming from governments [1], moving towards sustainable manufacturing practices [2]. In this frame, in recent years maintenance is more and more recognized both in the scientific and normative worlds, as a key process within manufacturing that can strongly contribute to promote sustainable development if properly managed [3]. However, for achieving such goals, it is relevant to define shared indicators to assess sustainable performances of maintenance [4,5]. The aim of this paper is to provide an overview of the normative and scientific advances as well as the existing gaps on maintenance performance measurement to go towards this direction. In particular, new considerations for building a practical maintenance performance measurement system focusing on sustainability are provided.

The paper is organized as follows. Section 2 presents the state of the art of the advances both in the scientific literature and technical standards, concerning maintenance and sustainable performances. Section 3 provides the factors identified as missing in the EN 15341:2019 technical standard, and relevant for measuring maintenance performance and its impact on sustainability. Section 4 discusses the conclusion and future research steps.

2 Scientific and normative state of the art

Despite the maintenance strategic role in manufacturing systems, only in the last years it has started to be more deeply investigated with a sustainable vision that goes beyond the consideration of the merely technical and economic aspects [6]. In fact, maintenance activities have several non-negligible impacts on the technical condition of production systems (e.g. reliability and availability performance as well as on the product quality), but also on the three dimensions of sustainability, i.e. economic, environmental, and social [7]. A recent study conducted by Holgado et al., 2020 [8] showed some advanced and best maintenance practices adopted by few virtuous industrial realities to contribute to sustainable business strategy concluding that maintenance needs to be taken more into consideration and given a more central role in future research and practice addressing sustainability in manufacturing. To achieve such goals, maintenance managers need to understand the relationship among the maintenance processes, including the impact of their realization, and sustainable performance with the aim to assess how they contribute to the achievement of business objectives towards sustainable development. Effectiveness, efficiency, and quality of maintenance must be assessed through specific indicators [5], and technical, economic, environmental, and social factors must be identified with the aim of constructing sensible maintenance sustainable indicators. Scientific literature only recently proposed studies considering sustainability-related factors and indicators for maintenance in different industrial sectors, for automotive companies [9], cement industry [10], or rubber industry [11]. Although few recent papers propose a first classification of sustainable maintenance performance measures, they focused on specific aspects of sustainability connected with maintenance system, not providing an exhaustive framework of factors and indicators for measuring sustainable maintenance performances. Addressing such gap, Franciosi, Voisin et al., 2020 [7] provide factors that were not considered in previous studies, tackling the wider sustainable perspective. For this reason, their paper is considered as reference for this research.

Standardized definitions for best practice for building up a maintenance performance measurement system have been established at international level by the European Federation of National Maintenance Societies (EFNMS) and the Society of Maintenance and Reliability Professionals (SMRP, an American society). Two major standards exist, the European Standards' EN 15341:2019 [12] and the North American SMRP best practice metrics [13, 14, 15]. In 2019, the European standard BS EN 15341:2019 was released, replacing the previous version from 2007. The older version of the standard proposed 71 KPIs and only the economic dimension of sustainability was explicitly considered. The environmental dimension was considered in a very global way through the concept of "environmental damage". While the social dimension was indirectly considered through worker safety with the number of personal injuries due to maintenance [16, 17]. A step forward to explicitly consider sustainability indicators was done with the publication of the EN 15341:2019 [12]. With respect to the older version, the recently published standard lists maintenance Key Performance Indicators and gives guidelines to define a set of suitable indicators to appraise and to improve not only effectiveness and efficiency but also some sustainability aspects in the maintenance of physical assets. In particular, the standard still addresses the economical, technical, organizational KPIs of the previous edition but enlarges the vision covering all the major aspects of physical assets management (PHA), structuring the KPIs into 8 groups, one for PHA, six dedicated to maintenance subfunctions (Health – Safety Environment, Maintenance Management, People Competence, Maintenance Engineering, Organization and Support, Administration and Supply), and one for information communication technologies. Nevertheless, despite more importance is given to sustainability, only still few KPIs are introduced addressing the environmental and the social dimensions.

Enlarging the perspective over sustainable manufacturing, a growing number of initiatives and organizations are trying to develop environmental, social and sustainability indicators for companies [18]. Veleva and Ellenbecker, 2001 [18], Marimon et al., 2012 [19], Joung et al., 2013 [20] claim that there is a wide list of sustainability reporting standards, proposing indicator sets that are publicly available and that can be used to measure sustainability in manufacturing processes. Among them, the GRI Standards [21] are most often used by large companies worldwide. Thus, these standards, developed in 1997 and now in their sixth version, deserve particular attention [22] and sustainability aspects here reported should be considered also from the maintenance performance perspective while their primary intention is dedicated to the sustainable performance of an organization as a whole.

3 Performance indicators for sustainable maintenance

Given the current technical and scientific advances on maintenance performance measurement systems, the objective of this paper is to identify gaps in the existing standard EN 15341:2019 for reaching an exhaustive list of indicators addressing maintenance sustainability assessment from a holistic viewpoint. For such a purpose, on one hand, Franciosi, Voisin et al. 2020 [7] proposed an extensive review of the literature and then a reference framework, including a list of indicators. Hence, it will be used as the scientific reference document. On the other hand, as presented in the previous section, the EN 15341:2019 standard [12] is the technical reference document providing an industrial viewpoint. Hence, the list of factors in the EN 15341:2019 [12] to calculate the proposed KPIs, was analyzed and compared with the list of factors proposed by Franciosi, Voisin et al. 2020 [7]. At the end of the process, a list of missing factors in the standard that could bring a more complete perspective over maintenance sustainability is identified, as shown in the next tables (Tables 1-5).

In the EN 15341:2019 [12] the sustainability area is explicitly introduced as one of the driven areas related to three KPIs included in the sub-function "Maintenance within physical asset management". Specifically, the economic indicator "PHA1: Maintenance contribution to improve sustainability (%)", is proposed and is defined as the ratio between the cost of maintenance resources spent yearly to improve the sustainability and Physical assets turnover. It is still very general though, not specifying which kind of actions could be considered. Considering the environmental dimension, a section of the standard is dedicated to 22 KPIs of Sub-function "Health-Safety-Environment (HSE)" on Maintenance. This sub-function concerns the implementation of policies and procedures by the maintenance management to prevent injuries and losses and be compliant with laws, rules, and company objectives. The 4 main driven areas of HSE, related to the maintenance performances and the KPIs, are: i) Conformity to Laws and Rules, ii) Statistical Records (relating to injuries and their impact on people and productivity), iii) Maintenance safety practices (including the impact of potential failures to the environment but also safety management practices in place), iv) Prevention-Improvements (relating to prevention actions in place to reduce HSE risks). Looking at the social dimension, 21 KPIs of Sub-function "People Competence" are introduced in the standard, referring to the EN 15628:2014 [23] and relating to the different qualification levels of maintenance personnel addressing education, field experience, skill and training. Concerning the economic dimension of sustainability, although the EN 15341:2019 [12] provides many factors and indicators aimed at assessing the economic impact of maintenance, still economic aspects related to the environmental sustainability are neglected (e.g. cost for maintenance waste treatment and disposal, costs to recycle spare parts or Waste Electric and Electronic Equipment for maintenance).

Tables 1, 2, and 3 show the environmental factors (and associated IDs) directly affected by maintenance performance, as reported in Franciosi, Voisin et al., 2020 [7], but lacking in the new EN 15341: 2019 [12]. These indicators address several aspects of maintenance impact: Land, Materials & Water Resources; Energy; Emissions, Effluents & Wastes, to cite a few. Indeed, while the norm considers materials and spare parts needed for maintenance activities and the cost associated to their purchase and management, no reference to the type of materials adopted, such as renewable and non-renewable materials, virgin, reused, recycled, repurposed, remanufactured, lubricants, cleaners, oils, chemicals (IDs 3, 4 and 5 in Table 1), is found. However, these are fundamental aspects that must be considered and monitored for contributing to the no longer negligible paradigm of the circular economy.

Table 1. Environmental Sustainability dimension: Land, Materials & Water Resources

ID	Factor Name
1	Maintenance waste effects on land quality (e.g. indicated by surface integrity, soil nutrients and contaminants, non-fertile land)
2	Land used by maintenance infrastructure, categorized by fertile and non-fertile areas
3	Materials used for maintenance process (spare parts, documentation) divided in renewable and non-renewable materials and with a breakdown on type of used materials (virgin, reused, recycled, repurposed, remanufactured)
4	Quantity of PBT (persistent, bio accumulative and toxic) chemicals used due to maintenance processes
5	Quantity of auxiliary fluids used by maintenance processes (lubricants, cleaners, oils, …)
6	Volume of water withdrawn for maintenance process with a breakdown by the sources

Concerning the energy aspects in maintenance, the norm only considers very generic factors such as "energy cost" or "number of maintenance actions implemented to improve energy conservation", while the details related to the energy consumption within the organization for maintenance processes (ID 7 in Table 2) and outside the organization (ID 8 in Table 2) are not considered.

Table 2. Environmental Sustainability dimension: Energy

ID	Factor Name
7	Energy consumption within an organization for maintenance processes (fuel, electricity, heating, cooling, steam) through equipment and tools
8	Energy consumption outside the organization for maintenance processes (e.g. transportation and distribution of spare part suppliers)
9	Energy emitted (e.g. heat, vibration) by maintenance processes

Factors related to maintenance wastes, effluents and emissions are totally missing in the norm. However, Table 3 provides several aspects that should be considered. Indeed, evaluating factors such as the amount of wastes generated by maintenance processes specifying the waste type and the disposal method (i.e. hazardous and non-hazardous, recyclable, reusable, remanufacturable, disposable) (ID 10 in Table 3), the maintenance WEEE (ID 13 in Table 3), the Greenhouse Gases Emissions or Ozone-depleting substances or air emissions or noise emissions generated due to maintenance processes (see details in IDs 16, 17, 18, 19, 20, 21 in Table 3), could concretely allow highlighting maintenance environmental impacts on sustainability.

Table 3. Environmental Sustainability dimension: Emissions, Effluents & Wastes

ID	Factor Name
10	Amount of wastes generated by maintenance processes (e.g. replaced items, used tools, lubricants, oils, documentation) specified by waste type and disposal method (i.e. hazardous and non-hazardous, recyclable, reusable, remanufacturable, disposable)
11	Amount of waste water discharged by maintenance processes specified by quality (e.g. eco-toxic, hazardous, treated, non-treated, reused) and destination
12	Volume of recorded significant spills (i.e. accidental release of hazardous substances that can affect human health, land, vegetation, water bodies, and ground water) derived by maintenance processes

13	Amount of WEEE produced by maintenance processes
14	Transport of hazardous waste generated by maintenance activities
15	Maintenance waste effects on the surface integrity of surrounding buildings and places
16	Direct GHG emissions: CO2-eq due to electricity, heating, cooling and steam consumed by maintenance processes; transportation of materials, spare parts, and maintenance workers on the field.
17	Indirect GHG emissions: CO2-eq due to purchased or acquired electricity, heating, cooling, and steam consumed by maintenance processes
18	Reduction of GHG emissions as a direct result of reduction initiatives taken by maintenance processes
19	Ozone-depleting substances produced due to maintenance processes
20	Air emissions (such as NOX, SOX, POP (Persistent Organic Pollutants), VOC (Volatile Organic Compounds), HAP (Hazardous Air Pollutants), PM (Particulate Matter)) deriving from used chemicals, additives for lubricants, waste incineration, transportation and other, due to maintenance activities
21	Noise emissions for maintenance processes
22	Air quality within an organization and in its surrounding areas due to maintenance processes (smog, visibility, odor, GHG concentration, pollutant concentration, etc.)

Furthermore, as reported in Table 4, suppliers of maintenance materials play a role and as such should be assessed through both environmental (ID 23 in Table 4) and social (ID 24 in Table 4) criteria going beyond the merely economic aspects generally considered.

Table 4. Environmental and Social Sustainability dimensions: Supplier Assessment

ID	Factor Name
23	% Suppliers that were screened using environmental criteria
24	% Suppliers that were screened with social criteria

Concerning the social dimension of sustainability, while maintenance safety issues have traditionally been considered in the maintenance norms and further detailed factors in the new version are provided, what is still missing is the evaluation of maintenance employees involvement and employee suggestions, in terms of quality, social and EHS performance (ID 32 in Table 5), safety measured adopted or safety equipment installed (ID 29 in Table 5), but also in terms of maintenance employees who report complete job satisfaction (ID 31 in Table 5). Assessing social sustainability in maintenance means also evaluating maintenance employees, by gender, who received a regular performance and career development review (ID 30 in Table 5) and number of employee hires and turnover, categorized by age group, gender, and region (ID 25 in Table 5). In addition, although the training of maintenance stakeholders constitutes a relevant part of the existing norm, there is no reference on maintenance employees trained in basic sustainability concepts (ID 27 in Table 5) or maintenance employees' empowerment (ID 34 in Table 5). Table 5 reports details of the factors that should be considered.

Table 5. Social Sustainability dimension: Maintenance employees

ID	Factor Name
25	New employee hires and employee turnover: number and rate of new maintenance employee hires during the reporting period, by age group, gender and region; number and

	rate of maintenance employee turnover during the reporting period, by age group, gender and region
26	Revitalization of maintenance employee suggestions for improvement and specific effort periods (e.g. One month, one week a month)
27	%Maintenance employees trained in basic sustainability concepts and/or current sustainability initiatives
28	Absentee rate (maintenance employees)
29	Number of safety measures adopted, and safety/fail-safe equipment installed due to maintenance employee suggestions, and improvements in safety performance from these suggestions
30	Maintenance employees by gender who received a regular performance and career development review
31	%Maintenance employees who report complete job satisfaction (e.g. through use of questionnaire, surveys)
32	Number of maintenance employee suggestions in quality, social and EHS performance
33	Education, training, counselling, prevention, and risk-control programs in place to assist maintenance workforce members and their families regarding serious diseases
34	Number or % maintenance employees empowered with the knowledge to make safer choices for themselves and coach their peers to do the same

4 Conclusions and further steps

The identified factors allow the development of a maintenance performance measurement system to monitor the activities of the maintenance function as a contributor to a sustainable manufacturing approach. The reference standard to date (EN 15341:2019) neither includes the use of maintenance resources in a circular way nor the wastes, effluents and emissions generated by maintenance function. Moreover, the social dimension of sustainability is still missing mainly in terms of maintenance employees' involvement and satisfaction, and inclusion of diversity related issues (gender, region, age group). Therefore, considering and assessing the factors reported in Tables 1-5 allow designing sustainable performance indicators to quantify maintenance impacts on sustainability and taking more "sustainability-aware" maintenance actions and choices for contributing actively and effectively to environmental-conscious and socially responsible performance of manufacturing systems. Following this research, further research steps will have to focus on the following issues:

- Validation of the identified factors in the industrial reality to show their applicability in terms of measurability of the factor itself and of availability of mandatory data to compute it. For this reason, a survey is in the way to be designed to collect opinions from manufacturing companies across Europe.
- Definition of formalized relationships and rules among indicators that are designed based on the identified sustainability factors and conventional technical and economic indicators.
- Integration of the sustainable indicators in maintenance decision-making tools to quantitatively measure maintenance impacts on sustainability aiming at contributing to organizations' sustainability targets.

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