

How Much Do the Objectives and KPIs of Maintenance Cover Sustainability Dimensions?



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Abstract This research points out which of the Key Performance Indicators (KPIs) and objectives commonly applied to measure maintenance cover the three dimensions of triple bottom line (TBL). First, it was performed literature review focusing in maintenance KPIs that have been used to evaluate the performance of the maintenance and the maintenance objectives related to them, linking the results to the sustainability dimensions. In a second step, a survey was conducted to identify relationship among sustainability dimensions and maintenance objectives and KPIs. After all, the data collected were analyzed leading to the conclusion of the research. It was evidenced the unbalance of maintenance KPIs in covering the three dimensions of sustainability, once the KPIs and objectives analyzed mainly cover the economic dimension of sustainability which implies in a scarcity of such indicators in covering environmental and social aspects of maintenance operations. No weights were assigned to the maintenance KPIs in order to help managers in driving their efforts. It is suggested the development of maintenance KPIs, in order to cover aspects linked to companies' image, such as responsibility to customers. This research is inserted within an evident gap on the scientific literature: the scarcity of researches that link maintenance to sustainability. It contributes in fulfilling this gap, by mapping how much do the maintenance KPIs cover the sustainability dimensions. The results should be useful for managers and researchers, supporting them in reviewing maintenance indicators in order to produce more operations more sustainable.

Keywords Maintenance · Sustainability · Key performance indicators

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1 Introduction

Maintenance can enhance productivity, quality, health and safety [1]. So, any framework designed to measure maintenance performance should encompass results in different areas [2–5]. In this scenario, sets of KPIs related to different aspects of maintenance have been developed recently in [6–9]. As sustainability objectives rise as strategic for organizations [10], companies should know how their maintenance process impact the TBL, as discussed in [11–16]. But, with a few exceptions such as [17, 18], sustainability is rarely mentioned in researches about maintenance. This paper contributes to fulfill his gab by highlight the relationship between TBL and the main KPIs mentioned in previous researches and also those used by companies. It discovered the KPIs most suitable to measure the accomplishment of each maintenance objective and which maintenance objective are related to each sustainability dimension.

2 Methodology

As the space for this paper is constrained, we focused in describing the main results instead of providing details about methodology. We highlight that literature review is a part of the methodology, once its results are used as input in the other research steps as it occurs in [19].

2.1 Literature Review

The steps for the literature review were inspired in [20–24]. First of all, it was done a search using the terms “maintenance” and “performance” and “indicators” or “KPI” or “metrics” into Scopus and Web of Science (WOS). The choice of these sources aims to reduce the probability of using “grey science” as mentioned in [25], or even paper published in predatory journals without a qualified peer review process. As the terms used for the query are not specific for the maintenance context, it was necessary to screen the articles removing those not related to industrial maintenance. The full-text of the remaining articles were read, searching for any KPIs used to measure performance of maintenance. A full list of KPIs used on these articles was built and from this step it was possible to perform quantitative analysis on the amount of KPIs used for each maintenance objective and sustainability dimension.

2.2 *Exploratory Survey*

Aside the literature review, it was explored the perception of maintenance professionals about the TBL. In order to elucidate the main goals and priorities of professional's companies, maintenance experts answered a survey about their main maintenance objectives, and which KPIS are used for each sustainability dimension. The invitation of maintenance professionals to answer the questionnaire occurred over a professional social network. A link to the questions was shared on several groups regarding maintenance. Sustainability groups were also chosen, because professionals within those groups may contribute with ideas and insights different than those related only to maintenance. The next step was the comparison between the answers from the survey and the results from the literature review. The questions about maintenance objectives and KPIS were open-ended, so it was necessary to refine and sort the answers in order to help the integration with the results from literature review.

2.3 *Survey for Mapping Maintenance KPIS Linked to Sustainability*

After selecting the main maintenance KPIS and objectives from the previous steps, a second survey was performed. This time the aim was to stablish what KPIS were adequate to measure de accomplishment of each objective, and assess which objectives were related to each sustainability dimension. It was announced on the same groups of the first survey, and an e-mail was sent to the previous respondents.

3 Results

3.1 *Literature Review*

The queries performed on the Scopus and Web of Science returned a initial list consisting of 1237 articles, as it appears in Fig. 1. After processing filtering steps, it resulted in a set composed by 77 articles for deeper analysis (see Fig. 2). As a result, some prominent topics were found and aggregated into categories. It follows some comments about the main finds in this step.

- The large number of papers modifying or creating KPIS, indicates that there is still a lack for the creation or improvement of existing metrics.
- The Overall Equipment Effectiveness (OEE) is the most mentioned indicator, as it is often modified.

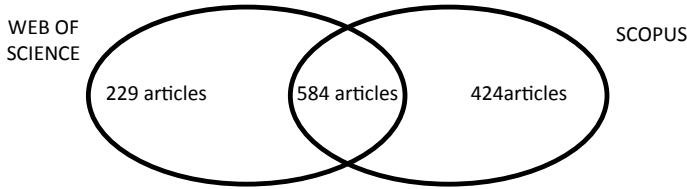


Fig. 1 Number of articles mapped in the scientific bases

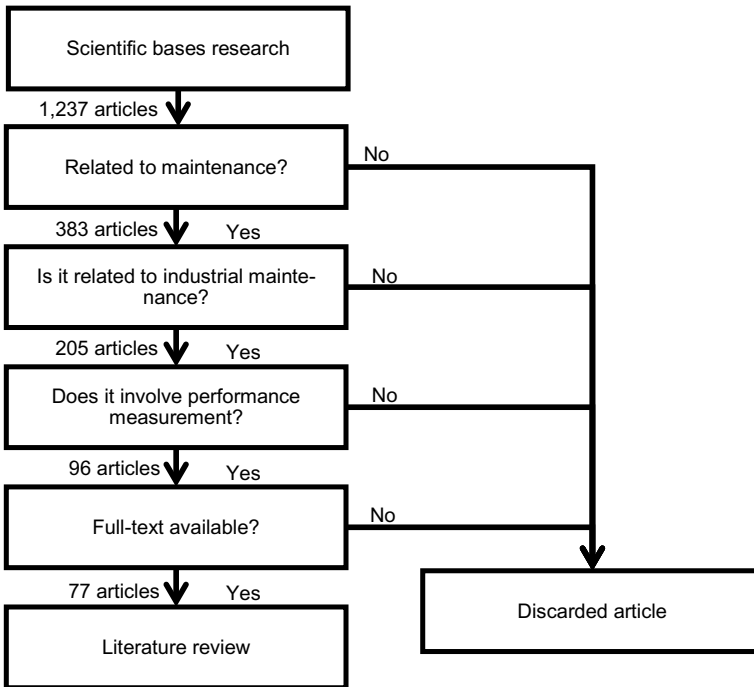


Fig. 2 Articles filtering process

- A rising topic was the comparison between different maintenance strategies to discover which of maintenance strategies performs better; or, even benchmark, among companies taking KPIs indicators for evaluation.
- In the case studies, KPIs were most applied to assess the results of actions designed to improve systems performance.
- The prediction or estimation of indicators were also an important topic within the literature, enabling the use of KPIs as inputs on conditions based maintenance systems.
- A few papers have explored the tradeoffs between different maintenance KPIs, such as the rate of unexpected failures and the remaining useful life of components.

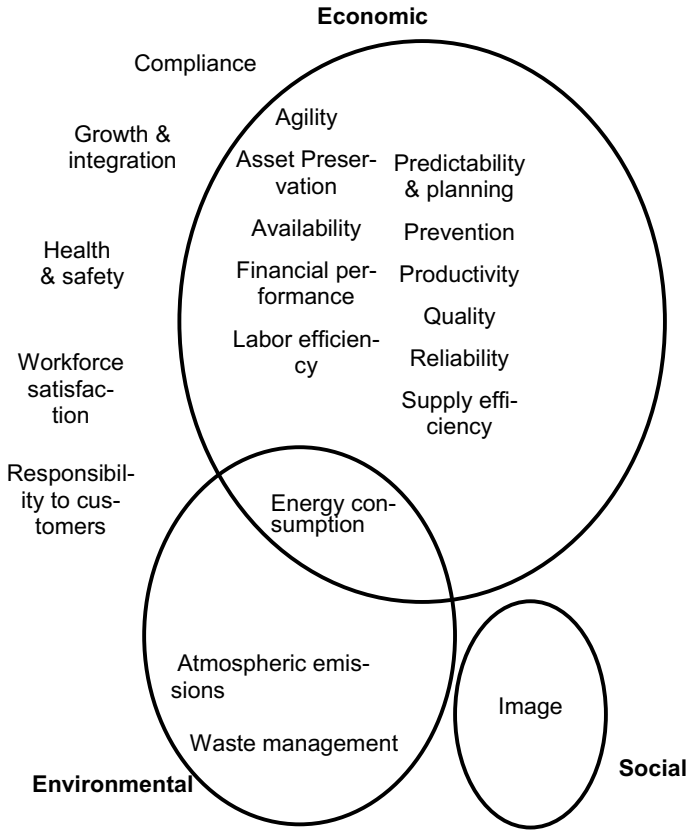


Fig. 3 Relationship between maintenance objectives and sustainability dimensions

Some objectives and aspects are repeated on each dimension. It happens because such objectives increase overall maintenance performance, leading to better performance on three dimensions of sustainability. It should lead to a false impression of balance between the three dimensions of sustainability (Fig. 3).

3.2 Exploratory Survey

The previous section has risen a doubt about the importance attributed by maintenance to sustainability dimensions. In order to elucidate this questioning, a survey was applied to maintenance experts collecting their perceptions about how much maintenance KPIS cover sustainability dimensions. Such survey returned 92 answers, from people spread in 23 countries in Africa, Asia, Europe, Latin America, Middle East and North America.

The professionals were also asked if their companies where they have worked used indicators related to each sustainability dimension and which KPIs were used. The results demonstrate that 68.5% of the respondents could affirm that economic KPIs were used in their companies, while for the environmental and social dimensions the results were 42% and 30%, respectively.

Table 1 (See Appendix) shows the KPIs mentioned on the survey and those most found out in the literature, both categorized according to the maintenance objectives and dimensions. Despite the differences on objective selection, all the objectives from literature had at least one related KPI mentioned on the survey. But still there are some gaps on the literature and companies' KPIs. The objectives that would benefit the most for having more KPIs are asset preservation, atmospheric emissions, energy consumption and workforce satisfaction.

3.3 Survey for Mapping Maintenance KPIs Linked to Sustainability

A second questionnaire composed by two questions was applied to elucidate the links between sustainability dimensions, maintenance objectives and KPIs. The first question asked the respondents to check if there was a relationship between each objective-dimension pair. Table 2 demonstrates the percentage of positive answers, while Fig. 1 illustrates which objectives were considered significantly related to each sustainability dimension, assuming a level of significance of 5%.

The results in Fig. 1 show that most of the maintenance objectives relates exclusively to the economic dimension. Also, the only objected that have been considered for multiple dimensions were energy consumption, which relates to the economic and environmental dimensions at the same time. Besides, five objectives do not relate to any of the dimensions. Such results evidence that professionals are less prone to link objectives to dimensions. These results were unexpected and show that professionals tend to disregard the relation between objectives and dimensions when the impacts from achieving the objectives are indirect.

The second question of the survey aimed to assess the most adequate KPIs to measure the performance for each objective. After analyzing the answers, it resulted in 25 indicators that need to be taken into account when measuring the sustainability of the maintenance process: 22 of these KPIs are related exclusively to the economic dimension. 2 are related to the environmental dimensions and one is related to both of them. We noticed that there are no indicators for the social dimension. Table 3 presents the indicators and objectives considered for each dimension after the statistical analysis.

In general, the results in Table 2 demonstrate a higher level of prioritization of the economic dimension if compared to the results from the first survey or from the literature review. Part of this difference is due to the choice of objectives related to sustainability dimensions. All the five objectives that were not related to any of

Table 1 Main KPIS in literature and companies

Dimension	Objective	KPIS from literature	KPIS from companies
Economic	Agility	Mean time to repair; time to answer; average delay on jobs; % of jobs on hold; % of jobs completed on time; % of failures not corrected on the first contact	Mean time to repair, mean response time, backlog aging
Economic	Asset preservation	Maintenance cost/replacement value	Asset health index, maintenance cost per asset cost, average component lifespan
Environmental	Atmospheric emissions	Greenhouse gas emissions	Carbon footprint, plant pollutant emissions
Economic	Availability	Availability; OEE; unplanned downtime; downtime caused by spare parts delay	OEE, availability, total downtime
Environmental, economic and social	Compliance	Predicted requirements/Total requirements monitored by society; number of non-conformities	n° of environmental aspects and impacts
Environmental, economic	Energy consumption	Energy efficiency index	Water and electricity consumption per unit, fuel consumption, efficiency
Economic	Financial performance	Profit loss from failure; unexplored lifetime; Maintenance cost per unit; % of costs from corrective maintenance; % of costs from personnel; % of costs from spare parts; maintenance value; Indirect economy; total maintenance costs	Maintenance cost per unit, % of costs from workforce, % of costs from installations, % of cost from corrective maintenance, maintenance cost as % of Total Cost of Production, opportunity costs
Economic, Social	Growth and integration	Training hours per employee per year; improvement suggestions received in a year	Training hours, number of new initiatives

(continued)

Table 1 (continued)

Dimension	Objective	KPIs from literature	KPIs from companies
Environmental, economic and social	Health and safety	Mean time to respond emergencies; % of harmful residues; mean time to discover failures on security system; number of non-conformities on health and safety standards; potentially harmful failures; insurance costs; % of critically analyzed systems; loss of working hours due to accidents; n° of accidents/no of incidents	Criticality equipment analysis, pollution incidents, frequency of accidents
Environmental, economic and social	Image	Complaints from local communities; market share; awards	Number of social projects with involvement, frequency of community complaints
Economic and social	Labor efficiency	Manpower availability; % of extra hours; actual working hours/planned working hours; labor productivity; % of manpower from third-party solutions; actual working hours/available working hours	Man hours per order, % of extra-hours
Environmental, economic and social	Predictability and planning	Planned manpower/total available manpower; % of completed jobs	Cost adherence to planned, schedule completion, backlog size
Environmental, economic and social	Prevention	% of manpower allocated on corrective, preventive and proactive activities; preventive maintenance orders/total maintenance orders; % of failures on items that should have been inspected	% of reactive and preventive jobs

(continued)

Table 1 (continued)

Dimension	Objective	KPIs from literature	KPIs from companies
Economic	Productivity	OEE; produced volume; actual production/Maximum theoretic production	OEE, total output, productivity loss
Economic	Quality	OEE; Success rate on work orders; rejected production/actual production; repetitive failures/total failures; % of work orders related to rework	OEE, % of orders from rework
Economic	Reliability	Mean time between failures or mean time to failure; failure frequency; % of equipment failing before the expected	MTBF, failure frequency, MTTR
Economic and social	Responsibility to customers	Recall events caused by maintenance; consumers complaint	Compliance with contract requirements, Stress level, satisfaction
Economic	Supply efficiency	Components unavailability; stock turnover; stock value/stock replacement value; supplier performance index; amount of emergency purchasing orders; utilization of items in contract	Stock turnover, stock value
Environmental, economic and social	Waste management	Scrap volume; % of recycled residues; % of incinerated residues; lubricant consumption	residues generation, recycling of wastes, savings from recycling initiatives
Economic and social	Workforce satisfaction	Absenteeism rate; employee satisfaction grades	Team stress level, satisfaction survey, turnover, absenteeism

sustainability dimensions were part of the social dimension on the initial analyses. Another noteworthy aspect about the objective selection is that most of objectives related to the economic dimension and a second or third dimension were then considered as exclusively regarded as an economic objective, the lack of KPIs related to the image objective has caused the final list of KPIs to ignore the social dimension completely. This scenario highlights the importance of developing indicators related to the image of companies in order to measure its impact on the social dimension.

Table 2 Relationship between objectives and dimensions

Objective	Code	Economic (%)	Environmental (%)	Social (%)
Agility	O1	86	7	24
Asset preservation	O2	86	34	14
Atmospheric emissions	O3	21	100	28
Availability	O4	79	14	24
Compliance	O5	52	55	41
Energy consumption	O6	72	69	21
Financial performance	O7	93	7	7
Growth and integration	O8	62	28	55
Health and safety	O9	62	55	52
Image	O10	38	28	72
Labor efficiency	O11	90	10	24
Predictability and planning	O12	97	28	17
Prevention	O13	83	52	34
Productivity	O14	90	21	17
Quality	O15	76	31	38
Reliability	O16	83	31	34
Responsibility to customers	O17	59	31	66
Supply efficiency	O18	83	31	17
Waste management	O19	24	100	28
Workforce satisfaction	O20	55	28	66

4 Conclusion

The results from the research demonstrated there is a lack of maintenance KPIs that covers the environmental and social dimensions of sustainability. Also, it was evidenced the unbalance of maintenance KPIs in covering the three dimensions of sustainability, once the KPIs and objectives analyzed mainly cover the economic dimension of sustainability implying in a scarcity of such indicators in covering environmental and social aspects of maintenance operations.

It is also noteworthy that maintenance professionals surveyed often disregarded the indirect impact that some objectives have on multiple sustainability dimensions. For this reason, objectives like health and safety, growth and integration, and compliance were not considered to impact any of the sustainability dimensions. Also, objectives like prevention and predictability and planning were considered related only to the economic dimension. A possible reason for this behavior is that achieving these objectives would lead to indirect impact on sustainability dimensions, rather than direct impact.

This research is into an evident gap: the scarcity of knowledge that link maintenance to sustainability. The results should support managers and researchers,

Table 3 List of maintenance KPIS linked sustainability

TBL Dimension	Objective	KPI
Economic	Agility	Average response time (beginning of repair)
	Reliability	Mean time between interventions
		Failure frequency
	Financial performance	Maintenance cost per unit
		Maintenance value
		Total maintenance costs
	Availability	Availability (Available time/Total time)
	Labor efficiency	Labor productivity
		Actual working hours/planned working hours
	Supply efficiency	Stock turnover
		Components unavailability
	Asset preservation	Actual lifespan/Projected lifespan
		Equipment lifespan/Warranty period
	Prevention	% of dedication to corrective, preventive and proactive maintenance
		% of failures on items that should have been inspected
Predictability and planning	% of jobs completed	
	Actual costs/Planned costs	
	% of working hours used on unplanned orders	
Productivity	OEE	
Quality	% of work orders related to rework	
	Rejected production/actual production	
	Success rate on work orders	
Environmental and Economic	Energy consumption	Energy efficiency
Environmental	Atmospheric emissions	Emission of poisonous pollutants
	Waste management	% of recycled residues
Social	Image	–

supporting them in reviewing maintenance indicators in order to produce operations more sustainable.

There is a lack of adequate maintenance indicators related to company image, which could imply in reducing organizations reputation. For this reason, it is recommended for future researches the development of KPIs able to measure the impacts of maintenance on companies' image. It may even be viable for this objective to incorporate others not related to sustainability dimensions, such as workforce satisfaction, responsibility to customers and Growth and integration.

The present work may serve also as a first step towards the practical application of the KPIs, in order to compare the performance of companies' maintenance systems. Other recommendations for future researches are the allocation of weights to the KPIs in order to identify which of KPIs are more relevant to companies.

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Appendix

See Table 1.

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