



Categorization of indicators for sustainable manufacturing

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ABSTRACT

The manufacturing industry is seeking an open, inclusive, and neutral set of indicators to measure sustainability of manufactured products and manufacturing processes. In these efforts, they find a large number of stand-alone indicator sets. This has caused complications in terms of understanding interrelated terminology and selecting specific indicators for different aspects of sustainability. This paper reviews a set of publicly available indicator sets and provides a categorization of indicators that are quantifiable and clearly related to manufacturing. The indicator categorization work is also intended to establish an integrated sustainability indicator repository as a means to providing a common access for manufacturers, as well as academicians, to learn about current indicators and measures of sustainability. This paper presents a categorization of sustainability indicators, based on mutual similarity, in five dimensions of sustainability: environmental stewardship, economic growth, social well-being, technological advancement, and performance management. Finally, the paper explains how to use this indicator set to assess a company's manufacturing operations.

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1. Introduction

In the recent decade, there has been increased pressure on manufacturing companies to think beyond the economic benefits of their processes and products and consider the environmental and social affects. It has thus become the goal for manufacturers to promote manufacturing processes and manufactured products that minimize environmental impacts while maintaining social and economic benefits. This desire has been extended by many customers, who wish that their products be created in a sustainable manner (MIT Sloan Management Review, 2011). This situation has challenged manufacturing enterprises around the world to stay competitive in the market place by developing and implementing sustainable manufacturing techniques and tools. Manufacturers have started to find sustainability measurement solutions; however, few effective measurement methods are available for assessing the impacts of manufacturing on the environment and society.

At least eleven major indicator sets have been developed to analyze and score sustainability of manufacturing processes. Since the application field of sustainability assessment is wide and new, a number of measures and metrics by means of indicators, indices, and frameworks for analyzing sustainable manufacturing have also been developed. Existence of many indicator sets has

created confusion among manufacturers when they attempt to select an operational set of indicators for assessing sustainability in manufacturing. Specifically, manufacturing enterprises have been challenged to decide which indicators to choose to evaluate their processes and products, and how they should interpret these indicators in making their processes and products sustainable. Sikdar (2003) states that no consensus exists on a reasonable taxonomy of sustainability-related metrics. Similarly, Gaurav et al. (2008) state in a literature review that major sustainability metrics are inconsistently defined and business-specific. For instance, the Organisation for Economic Cooperation and Development (OECD) (OECD CEI, 2003) Core Environmental Indicators (CEI) include 46 indicators to measure the impact of industrial activities on the environment in industrialized countries, while the United Nations (UN) Commission on Sustainable Development identifies 96 indicators (UN-CSD, 2007) to address environment deterioration due to human activities.

To address this challenge, the National Institute of Standards and Technology (NIST) has developed a categorization of sustainability indicators that classifies a large number of indicators into appropriate categories and subcategories. The categorization provides a reasonable structure to integrate inclusively all the possible indicators from which companies can choose to assess sustainability for their products and processes associated with manufacturing. The rest of the paper describes the research and development of the sustainability indicator categorization. Section 2 reviews a collection of publicly available indicator sets. Section 3 provides an analysis of

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indicator properties and criteria used to evaluate indicators. Section 4 presents the methodology to categorize these indicators into a hierarchical indicator map. Section 5 suggests how to apply the right indicators for company-specific sustainability measurement needs, and Section 6 summarizes this work.

2. Indicator sets review

An indicator set is a group of indicators that comprise a holistic view of sustainability. Combining indicators from the more common environmental, economic, and social dimensions and evaluating those indicators together is a practice to measure the sustainability on a much larger scale than individual indicators. Results from the measurement help companies create focus areas for improvement in regards to sustainability.

Interpretability with indicator sets is, however, a key issue because the complexity of the interrelationships of indicators causes a number of contrary conclusions about the level of sustainability and what can be done to improve it (Kibira et al., 2009; Ueda et al., 2009). In contrast to indicator sets, indices provide a more straightforward conclusion on the level of sustainability because they rely on weight-based mathematical methods to aggregate many indicators into a single score. An index aggregates several indicators, e.g., Environmental Vulnerability Index (consists of indicators of hazards, resistance, and damage). With a single score, a sustainability level can be set and used as a metric for performance. In regards to how to improve the sustainability, contrary opinions can be drawn because of the compositions and interpretations of the indicators of an index. Because of these difficulties, a number of indicators, sets, and indices have been developed by organizations in an attempt to match the various levels of decision making for sustainability. Various levels are from the process/product level, company/organization level, and nation/region level, to the global level (OECD, 2007).

Through a literature review, we found the following eleven indicator sets that are publicly available. They include many indicators that can be used to measure sustainability in manufacturing processes. A summary is provided as follows.

1. *Global Report Initiative (GRI)*: the GRI is a voluntary sustainability reporting initiative for organizations. The GRI consists of 70 indicators that are identified within the three main dimensions of sustainability: economy, environment, and society. In reporting, an organization would record and report the actual numbers for chosen individual indicators. Using the report, the organization's sustainability performance according to the GRI or internal entities can be analyzed and tracked. The purpose of such reporting is for evaluation and tracking for decision-making at multiple levels of the organization including: management, operations, and internal or external stakeholders (GRI, 2006; Staniskis and Arbaciauskas, 2009).
2. *Dow Jones Sustainability Indexes (DJSI)*: the DJSI assesses the financial and sustainability performance of the top 10% of the companies in the Dow Jones Global Total Stock Market Index. The results of the index are used as criteria for investors and investment firms. Analysis by media and stakeholders along with a questionnaire for the organization forms the basis of the index. The index evaluates the performance of a company in 12 criteria, covering mainly the economic dimension, but also includes some aspects of the environmental and social dimensions (SAM Indexes, 2007).
3. *2005 Environmental Sustainability Indicators (ESI)*: the 2005 ESI was developed by the Yale Center for Environmental Law & Policy for measuring and evaluating environmental stewardship for regions and countries. The ESI is a single value index that is an aggregate of six policy categories and 21 core factors consisting of 68 indicators. An ESI value for one country is the average of 68 indicators within the 21 factors (ESI, 2005).
4. *Environment Performance Index (EPfi)*: the EPfi, developed at Yale University, complements the ESI by assessing the policy performance of countries in reducing environmental stresses on human health, enhancing ecosystem vitality, and sustaining natural resource management. The focus of the EPfi is in its 19 indicators for which these environmental stresses are measured (EPfi, 2010).
5. *United Nations-Indicators of Sustainable Development (UN-CSD)*: the UN-CSD developed by the United Nations (UN) Commission on Sustainable Development (CSD) assesses the degree of sustainable development of a country or region. The latest version of UN-CSD was finalized in 2006 and contains 96 indicators. The indicators are categorized by 14 themes that account for the economic, social, and environmental health of developing countries (UN-CSD, 2007).
6. *Organisation for Economic Cooperation and Development (OECD) Core Environmental Indicators (CEI)*: the OECD CEI was designed for monitoring environmental conditions for sustainable development of member countries. The OECD CEI includes 46 indicators, which address a range of environmental, social, and economic issues (OECD CEI, 2003).
7. *Ford Product Sustainability Index (Ford PSI)*: the Ford PSI considers sustainable indicators within the environmental, economic and societal dimensions that are specifically relevant to automobile manufacturing and services. Because of the specialization, Ford's PSI has eight indicators: mobility capability, life cycle cost, impact on life cycle global warming, life cycle air quality, sustainable materials, restricted substances, safety, and drive-by-exterior noise (Schmidt and Taylor, 2006).
8. *International Organization for Standardization (ISO) Environment Performance Evaluation (EPE) standard (ISO 14031)*: the ISO 14031 is an international standard containing specifications for organizations to develop their own indicators for environmental performance measurement. In the informative annex of the standard, three categories are relevant to manufacturing: (1) operational performance, (2) management performance, and (3) environmental condition (ISO, 1999).
9. *Environmental Pressure Indicators for European Union (EPri)*: the EPri is a comprehensive list of indicators of the most important human activities that have a negative impact on the environment. The EPri contains 60 indicators that overview the pressure of human activities on the environment in 10 policy fields including air pollution, climate change, loss of bio-diversity, marine and coastal environments, ozone layer depletion, resource depletion, urban environmental problems, waste, water pollution, and water resources (EPri, 1999).
10. *Japan National Institute of Science and Technology Policy (NISTEP)*: the NISTEP report contains indicators that cover the technological advancement due to contributions and personnel skill level of a given organization through education, patents imported or exported, and scientific publications (Japan Science and Technology Agency, 1995).
11. *European Environmental Agency Core Set of Indicators (EEA-CSI)*: the purpose of the EEA-CSI is to provide a set of manageable indicators for reporting. Measurements based on the EEA-CSI provide a means for prioritizing environmental improvements for countries in the EU (EEA-CSI, 2005).

3. Analysis of indicators

An indicator has been defined in several slightly different ways in literature (Heink and Kowarik, 2010; Veleva and Ellenbecker,

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