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CHARACTERIZING SUSTAINABILITY FOR MANUFACTURING PERFORMANCE ASSESSMENT

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ABSTRACT

Manufacturing industries lack the measurement science and the needed information base to measure and effectively compare performance of manufacturing processes, resources and associated services with respect to sustainability. The current use of ad-hoc methods and tools to assess and describe sustainability of manufactured products do not account for manufacturing processes explicitly and hence results in inaccurate and ambiguous comparisons. Further, there are no formal methods for acquiring and exchanging information that help establish a consolidated sustainability information base. Our goal is to develop the needed measurement science and methodology that will enable manufacturers to evaluate sustainability performance of fundamental manufacturing processes ensuring reliable and consistent comparisons. In this paper, we propose and discuss a methodology for sustainability characterization to bridge the measurement science and the needed information base for sustainable manufacturing. This will set the stage for manufacturers to objectively assess and compare different manufacturing processes for sustainability.

Keywords: sustainable manufacturing, manufacturing performance, characterization, assessment methodology

1. INTRODUCTION

Sustainable manufacturing is defined as the creation of manufactured products that use processes that minimize negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound [1]. According to the National Association of Manufacturers (NAM), the industrial sector accounts for 31% of all the energy consumed in the United States. Manufacturing alone accounts for 65% of the industrial sector's energy consumption [2]. With manufacturers looking towards cleaner energy sources and improving their energy efficiency due to an increasing energy price tag, a model for sustainable manufacturing among industries has become important.

Performance measurement in general identifies the gaps between the current and desired performance, and provides indication of the progress made towards closing the gaps. Related performance indicators reduce and organize huge data into formats that are easier for understanding, analyzing and comparing purposes. Companies then use such indicators to set targets and monitor their performance. Traditionally, manufacturing related performance indicators provided information on the productivity and throughput, cost, quality, material, etc.

Performance measurements for sustainable manufacturing should include performance indicators and corresponding metrics. The challenge, however, is in identifying the sustainability performance indicators which directly relate to manufacturing metrics; e.g., energy utilization versus productivity. A number of indicators have been proposed in the past for sustainability performance measurement [3]. Some are commonly used in the industry. Addressed as key performance indicators (KPIs), they are used to evaluate the success of a particular activity or operation with respect to sustainability [4]. For instance, one of the commonly used performance indicator for injection molding process is energy per unit of mass and the corresponding metric is kWh per kg (or MJ per kg) of injection molded parts.

To remain globally competitive, manufacturers must increase the flexibility, speed of production systems and their supplier networks, while also reducing environmental impacts, material and energy requirements [5]. These changes require a transformation from manufacturing practices based on experience and best practices towards science-based modeling, decision making, and production. This paper presents a methodology for sustainability characterization to bridge the measurement science and the needed information base for sustainable manufacturing to help U.S. manufacturers make this transformation.

The paper is organized as follows. Section 2 presents how process characterization is an inherent part of performance measurement. This section also outlines the challenges in developing the required measurement science for sustainability of manufacturing processes. Section 3 presents a background review on sustainability indicators, process information models followed by a brief review of the relevant software tools for sustainability. Section 4 presents the methodology development for sustainability characterization for manufacturing processes. Section 5 concludes the paper with our proposed scope of work towards sustainability characterization.

2. MANUFACTURING PERFORMANCE ASSESSMENT

In this section, we present how process characterization is an inherent part of performance measurement and discuss how process characterization can be used for developing the science-based performance measurement for sustainability. We also briefly present the challenges in developing the required measurement science for sustainable manufacturing.

2.1. Process characterization vs. Performance measurement

Process characterization activity typically identifies key inputs and outputs of a process, collects data on their behavior over the entire operating range, estimates the steady-state behavior at optimal operating conditions and builds models describing the parameter relationships across the operating range. The result of process characterization activity is a set of mathematical process models that can be used to monitor and improve the process [6]. Figure 1 shows an example of a process as a system boundary along with possible inputs and outputs [7].

Manufacturing process characterization can be useful when: bringing a new process or tool into use, bringing a tool or process back up after scheduled/unscheduled maintenance, comparing tools or processes, checking process health, troubleshooting a bad process, or in our case, determining the sustainability performance.

Performance measurement is complementary to process characterization, with feedback control for improved results. We believe that production process characterization (PPC) [7] can be used as a promising methodology for sustainable manufacturing; the challenge however is in developing the measurement science.

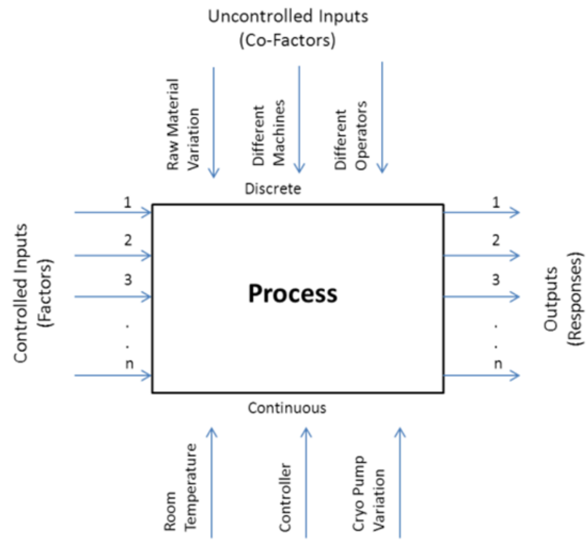

Figure 1 Boundaries of a process under study **[7]**

2.2. Challenges in developing the measurement science

The major obstacle in developing absolute measures for sustainability is the absence of a well-defined approach to first characterize sustainability for manufacturing. Characterizing sustainability will help manufacturing industries to improve productivity through ways of improvement in process control and in turn better resource management. Different manufacturing processes and resources have different or overlapping capabilities with varying efficiencies. It is well understood that the currently available Life Cycle Assessment (LCA) tools like GaBi [8] and SimaPro [9], use Life Cycle Inventory (LCI) databases which are typically limited only to primary material production (e.g., sheets, foils) and recycling processes [10]. General approximations made today for sustainability ignore the manufacturing- process-related LCI and hence result in inaccurate planning for cross comparisons and decision making.

Developing the measurement science for sustainability at various system levels (e.g., resources vs. facility, facility vs.

factory, and factory vs. supply chain) can help manufacturing industries for enhanced manufacturing resource management.
The following are the corresponding challenges to develop the measurement science:

- uncertainties in manufacturing environment
- dramatic changes in customer requirements
- innovation in production technology
- uncertainties in internal operating environment
- inadequate traditional approach to overcome uncertainties
- inadequate and unstructured information
- inadequate decision models
- undefined scope and boundaries within manufacturing unit processes
- multiple unverified proposed measurement methodologies

Note that sustainability, like quality, is in the eyes of the beholder. The meaning of sustainability varies, depending on the sector, category and region. Sustainability performance measurement for a manufacturing process can be used as a means of representing an aspect of quality. One analogy is the way the *impact factor* of journal citations has become an accepted standard of quality. For sustainable manufacturing, a similar metric that delivers the impact and caters to an unbiased comparison is lacking. We propose to develop a science-based performance measurement for sustainable manufacturing building upon the traditional production process characterization methods [7].

3. BACKGROUND REVIEW

This section presents a background review on sustainable manufacturing indicators and manufacturing process models followed by a brief review of the relevant software tools for sustainability to help understand the requirements for developing the needed measurement science.

3.1. Indicators for Sustainable Manufacturing

Reportedly, there are a number of indicators for sustainability, which include indicators based on environmental stewardship, economic growth, social well-being, technological advancement and performance management [11]. Researchers have been working to define and use indicators specifically for sustainable manufacturing. In this section, we first discuss such earlier efforts, followed by a discussion on the key indicators for sustainable manufacturing.

Chengcheng *et al.* [12] suggested that a comprehensive system is needed to implement sustainability indicators in manufacturing companies. They shortlisted a number of indicators used for sustainability measurement and attempted to evaluate those based on the criteria of relevance, analytical soundness and measurability. Joung *et al.* [13] proposed a sustainable manufacturing measurement infrastructure. They defined the sustainability measurement process as a sequence of operations, with the necessary instruments and for determining the value of an indicator. Laurent *et al.* [14] investigated the suitability of CO_2 emissions (or carbon footprint) as a performance indicator for product or production activities. Their focus was to identify potential correlations between the Carbon Foot Print (CFP) and other types of environmental impacts like Human Toxicity Impacts (HTI). The overall environmental impact was investigated based on the life cycle assessment of several materials based on importance; e.g., metals vs. plastics.

In addition to the earlier efforts, there have been efforts by multiple organizations to define and adopt sustainable manufacturing indicators. An effort by the National Institute of Standards and Technology (NIST) was the Sustainable Manufacturing Indicator Repository (SMIR) [15]. SMIR extensively captures indicators for sustainable manufacturing and addresses a range of sustainability issues. From an extensive review of publicly available indicator sets, the SMIR is categorized on five dimensions: environmental stewardship, economic growth, social well-being, technological advancement, and performance management. More recently, the Organization of Economic Co-operation and Development (OECD) has published a Sustainable Manufacturing Toolkit [3] which defines 18 indicators for sustainable manufacturing in three categories namely: inputs, operations and products. Inputs include non-renewable material intensity, restricted substances material intensity and recycled-reused contents. Operations include water intensity, energy intensity, renewable proportion of energy, greenhouse gas intensity, residual gas, air release intensity, water release intensity and proportion of natural land. Besides these, there are seven indicators for products namely recycled/reused content, recyclability, renewable material content, non-renewable material intensity, restricted substances content, energy computation and greenhouse gas emissions intensity.

We identified that some indicators do affect the performance of other indicators. For example, energy intensity affects indicators like the greenhouse gas intensity or renewable proportion of energy. In the following section, we discuss such key indicators that help to improve manufacturing from the sustainability point of view. Manufacturing industries use these indicators when reporting sustainability [16].

3.1.1. Key Sustainable Manufacturing Indicators

a. Energy Indicator

Conserving and using energy optimally is crucial in manufacturing. According to the OECD [3] any energy production, whether non-renewable or renewable, depletes non-renewable resources (including habitats, fossil fuels and uranium), generates GHG (greenhouse gases) or both. Energy intensity (EI) in Mega joule (MJ) is calculated for production processes and overheads (see Equation 1 [3]). We use the OECD indicators for demonstration purposes. OECD suggests that the energy intensity of the inputs can be included by extending the accounting boundary.

$$EI = ((Energy\ consumed\ in\ production\ processes + Energy\ consumed\ in\ overhead)) / (Normalization\ factor)$$

--- (1)

Depending on the production process, energy computations will have to be made. There may be multiple methods to calculate energy consumed. For example, if we consider material removal by machining processes, energy can be computed theoretically based on the material removed during the process (removed volume) and the specific energy of the material. Energy can also be obtained directly from an energy meter reading. We must note here that there will be uncertainties and heuristics associated with the type of energy computation methodology and hence it is important to consider these when we characterize manufacturing processes to handle such uncertainties.

b. Carbon dioxide

The calculation of the CO_2 emissions is dependent on the electricity generation. According to EPA on an average, electricity sources emit 0.5925 kg of CO_2 per kWh. CO_2 emissions per kWh for a particular state may vary greatly in accordance with the amount of clean energy in the energy supply. For example for Maryland CO_2 emissions are 1,338 lb/MWh (0.608 kg/kWh) while for District of Colombia it is 2,782 lb/MWh (1.2644 kg/kWh) [17]. Equation 2 [3] represents the Green House Gas (GHG) intensity of the facility including production processes and overhead (energy-related emissions and business travel) in tons of CO_2 equivalent.

$$GHG\ Intensity = \frac{\begin{pmatrix} GHGs\ released\ in\ energy\ consumption\ for\ production + \\ GHGs\ released\ in\ energy\ consumption\ for\ overhead + \\ GHGs\ released\ by\ transport\ used\ for\ business\ travel + \\ Additional\ GHGs\ released\ from\ production\ process \end{pmatrix}}{Normalization\ factor}$$

--- (2)

Unit of the indicator: tCO2e/normalization factor

c. Waste

Waste minimization involves efforts to minimize resource and energy use during manufacture. When fewer materials are used, then lesser waste is produced. Waste minimization usually requires knowledge of the production process, cradle-to-grave analysis (the tracking of materials from their extraction to their return to earth) and detailed knowledge of the composition of the waste.

d. Water

Depending on the production process, water is often consumed for cooling, heating or washing. The OECD indicator calculates only the intensity of total water intake of the overhead and production process (Equation 3 [4]).

$$WI = \frac{(Total\ water\ intake)}{Normalization\ factor}$$

--- (3)

e. Emissions

OECD notes that it is important for a production facility to also track releases of its individual air pollutants of concern, e.g., NOx, SOx, persistent organic pollutants (POPs), volatile organic compounds (VOCs), hazardous air pollutants, particulate matter, and/or other pollutants that are priorities for the state, region, locality and public interest groups. Equation 4 [3] represents the intensity of the weight in tons of all releases to air during the reference year. Although it might be difficult or insignificant to track, OECD recommends tracking the releases to air from overhead as well as production processes.

$$Intensity\ of\ pollutant\ releases\ to\ air = \frac{(Weight\ of\ releases\ to\ air)}{Normalization\ factor}$$

--- (4)

More information on Equations 1-4 is available at the OECD website [3].

Depending on the industry and sector, key manufacturing performance indicators need to be determined. The overall problem however is the underlying measurement science and procedures in place to measure those indicators. Currently manufacturing industries lack the measurement science and the needed information base to measure and effectively compare environmental performance of manufacturing processes, resources and associated services with respect to sustainability. Moreover, there are no formal methods for acquiring and exchanging sustainability-related information for manufacturing. The next section discusses the needed relationships between general manufacturing process information and sustainability-related information.

3.2. Manufacturing Process Models

To understand sustainability performance of manufacturing processes, engineers will need well-defined manufacturing process models. Sustainability performance is broadly dependent on all information related to manufacturing processes namely resource, tooling, materials and energy. A manufacturing process model must define relationships between sustainability performance and information related to manufacturing processes. Previous manufacturing process models mainly focused on what information is related to manufacturing processes yet do not explicitly show how manufacturing process information is related to the sustainability performance.

Subsequent sections provide an analysis and discussion of the previous manufacturing process models to identify the needed relationships between manufacturing process information and sustainability performance.

3.2.1. Classification of Process Models

Process models can be classified into language level and model level according to the information abstraction levels. At the language level, a process model defines fundamental entities and their relationships. IDEF0 (Integration Definition for Function Modeling) [18], BPMN (Business Process Modeling Notation) [19], and PSL (Process Specification Language) [20] are examples of process models at the language level. Engineers use process modeling languages to build process models.

Process models at the model level can either be activity models or information models. Activity models describe dataflow and precedency of manufacturing processes. The Systems Integration for Manufacturing Applications (SIMA) reference architecture – part 1 [21] earlier defined reference activity models for product development. The SIMA activity model comprehensively explains processes and dataflow (i.e., inputs, outputs, reference and control flows) in product development using IDEF0.

Table 1 Process models classification

Modeling languages	General modeling languages	XML, UML, EXPRESS, KIF, OWL
	Process-specific modeling languages	IDEF0, BPMN, PSL
Manufacturing process models	Activity models	SIMA reference architecture- Part1
	Information models (Class level)	CMSD, ISO 15531-1 Manufacturing management data exchange (MANDATE)
	Information models (Property level)	Injection modeling process analysis CO2PE - unit manufacturing process analysis

Information models of manufacturing processes define entities and their relationships. The dataflow in activity models can be entities in information models. Table 1 summarizes the process model classification.

Information models of manufacturing processes can be further classified into the class level and the property level. Information model in the class level focus on classes and their relationships to represent information related to manufacturing processes. For example, a class diagram in the core manufacturing simulation data (CMSD) [22] can be one of the information models in the class level. Information models in the property level define mathematical models of properties of classes related to manufacturing processes. Thiriez [23] extensively analyzed injection modeling process and provided an information model of injection modeling process. The information model shows how properties of material, mold, machine and process contribute to the total energy use in an injection modeling process.

For example, from Figure 2 A213 (select processes) activity, engineers make a decision on selecting manufacturing processes to realize a product model. Product models, Bill of Materials (BOMs), market data, equipment and material information are the inputs for the decision. Here, process models are used as references for the decision. The inputs can be changed if a new product model is introduced, but the references do not change. Engineers select the best manufacturing process which satisfies time, cost and resource constraints. Sustainability performance of manufacturing processes can potentially be introduced as a new constraint for the process selection activity [24].

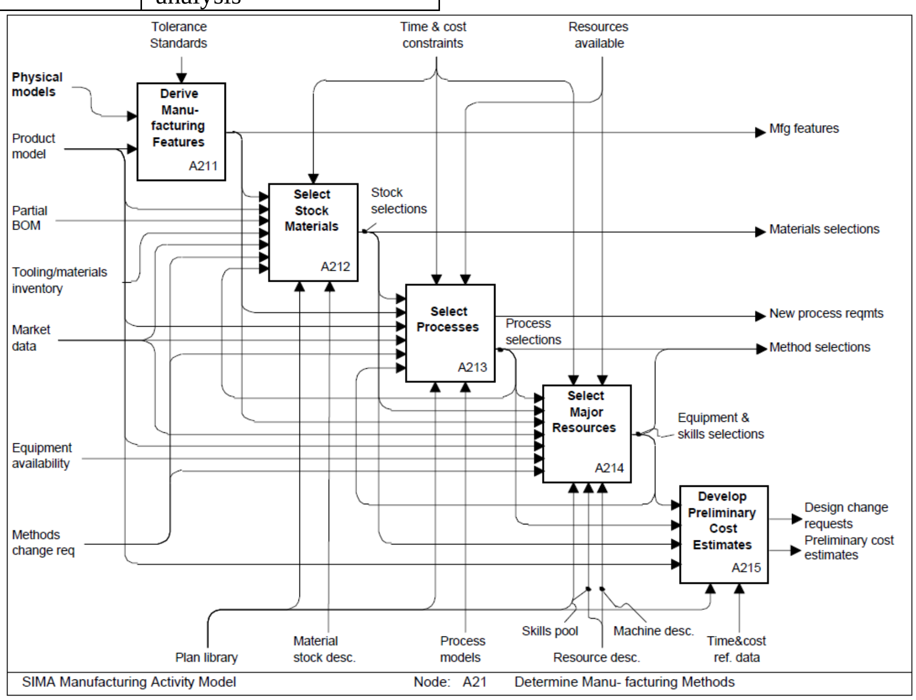

Figure 2 SIMA model: A21 Activity Model- Determine manufacturing methods

3.2.2. *Reference information model*

Some manufacturing process standards define information models including manufacturing process class definitions and its relationships to other classes. The CMSD standard for example, defines a manufacturing process class as shown in Figure 3. The process class in CMSD defines what information is necessary for process planning and simulation. The process class has attributes, which are relationships to other classes, such as produced part, consumed part, required resource, machine program, setup and operation time, cost and material information.

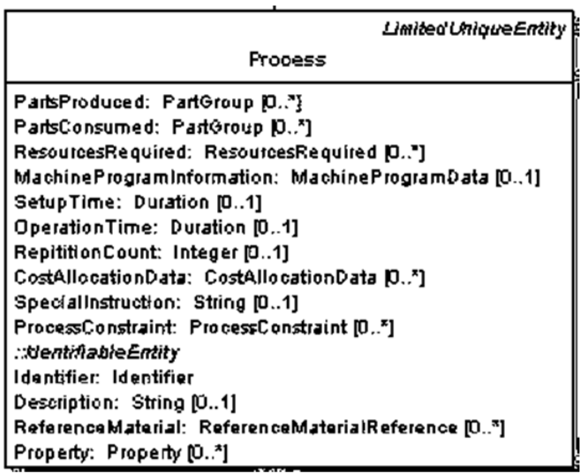

Figure 3 Process class defined in the CMSD

Although a process class shows what information is related to manufacturing processes, it does not express how the information influences the performance of manufacturing processes. Thiriez [23] analyzed an injection molding process and developed a process model with property level detail. The process model explains how to calculate the required energy to produce a kilogram part using an injection molding process with a given material type and mold shape. Since an injection modeling process consists of several operations, the total energy required for an injection molding process is a sum of the energy for all those operations.

One of the goals of the CO2PE [25] effort is to develop a methodology that allows providing data in a format useful for inclusion in LCI databases. The effort includes developing the unit process model at the property level. There are also standards like the ISO 14048: Environmental management- life cycle assessment- data documentation format [26] and commercial data formats like the [27] and [28] for the LCI data. The objective was to define data formats to exchange LCI data among Life Cycle Assessment (LCA) tools. These data formats are useful to know what manufacturing processes performance needs to be captured in a process model; however, they do not explicitly explain what information influences the performance of manufacturing processes in the property level detail.

Having reviewed the previous manufacturing process models at various abstraction levels, it is clear that one generic process model cannot satisfy different usages of the process model. However, we believe that reference process models represented as a function between inputs and performance indicators in the process selection activity can be very useful (See figure 4). The function represents what information is related to manufacturing process performance. If the function is defined with property level details and each unit manufacturing process has such a function, then the function can be used as a reference model for process selection activities.

$$C = f(P, D, M, R)$$

C : performance indicators of manufacturing processes (i.e., throughput, cost, energy and material use)
f : reference manufacturing model function
P : product models including bills-of-materials, geometry and tolerance
D : demand
M : selected material information
R : resources including machines and tools

Figure 4 Function between manufacturing process information and performance

Besides developing information models, it is important to consider the portability and robustness of such information models to implement solutions to support sustainable manufacturing. The next section reviews selected software tools that supports sustainability analysis.

3.3. Software tools

The software tools used for determining sustainability help reduce the time taken for sustainability assessment. The tools generally rely on different LCI databases. A summary of different software used for sustainability assessment is presented in Table 2.

From the review of the various environmental assessment software tools, it was observed that measurement of impact assessment for a product was based on the LCI database provided by different organizations. The major deficiency in these LCI databases is that, details up to the level of individual manufacturing processes are not included. These databases provide LCI information which is based on the BOM. Furthermore, the information is region specific and the scientific basis of the LCI is unknown. For example, although LCI information is available for cast or rolled steel process, there is no information related to the numerous operations being performed on the sheet such as punching, blanking, shearing and bending etc. Presently available software tools, which depend on LCI databases, are therefore incomplete when it comes to performance measurement for sustainability. We evaluated several LCA based software tools [8, 9, 29, 30-32] and found that manufacturing process specific LCI is not available.

Table 2 Summary of different software tools for sustainability assessment

Sofware	Databases	Impact Assessment Methods	Major functions
GaBi [8]	USLCI, Ecoinvent, GaBi database	CML 96/2001/2007, Ecoindicator 95/99, EDIP 97/2003, TRACI, IO2+ and others	Impact assessment
SimaPro [9]	Ecoinvent, USLCI, ELCD, US Input-Output, EU & Danish Input & Output, Dutch Input –Output, LCA Food, Industry Data, IVAM, Japanese input-output	ReCiPe, Eco-indicator 99, USEtox, IPCC 2007, EPD, Impact 2002+, CML-IA, Traci 2, BEES, Ecological Footprint EDIP 2003, Ecological scarcity 2006, EPS 2000, Greenhouse	Impact assessment
DFMA [29]	No separate database	Waste from Electronic and Electrical Equipment (WEEE) Restriction of Hazardous Substances (RoHS)	Impact assessment during conceptual stage of design
Eco Material Advisor [30-31]	Cloud hosted Material Universe	CO_2 footprint, energy usage, water usage, and RoHS	Selection of environmental compliance material
Other PLM Tool[32]	Integrate with internal database of the company	CO_2 footprint, energy usage	Environmental impact of design alternatives

4. METHODOLOGY DEVELOPMENT

Manufacturing industries need a systems approach to realize sustainability across the enterprise, bridge the information gap and deliver business growth [33]. From the above sections it is clear that the research and development of solution enabling measurement science, methodologies for knowledge management and sustainability assessment technologies are crucial to ensure sustainability in manufacturing.

Manufacturing industries are challenged to remain globally competitive, improve productivity, and reduce environmental impacts and energy requirements. This requires the development of fundamental measurements, standards, and knowledge base. The US manufacturing industry currently lacks the measurement science to measure and effectively compare the performance of unit manufacturing processes with respect to sustainability.

Besides the lack of measurement science, manufacturing industries also lack the needed information base to measure and effectively compare environmental performance of manufacturing processes, resources and services with respect to sustainability. The current use of ad-hoc methods to informally describe sustainability of manufacturing processes results in inaccurate and ambiguous comparisons of these processes.

Further, there are no formal methods for acquiring and exchanging information that help establish a consolidated sustainability information base. Information management is crucial for sustainable manufacturing through a consolidated information base about the manufacturing processes, facilities and impact and accessible information models.

The subsequent section introduces a sustainability characterization methodology that bridges the measurement science and manufacturing knowledge base for sustainable manufacturing.

4.1. Sustainability characterization methodology

The new technical idea is the sustainability characterization through unit manufacturing processes for performance modeling and assessment of manufacturing systems. Sustainability characterization will create the information crucial in the decision making related to sustainability. Such information includes, but not limited to energy, emissions, pollutants, waste and scrap, alternative materials, cycle times and productivity. A set of common computable metrics (carbon emissions, material waste, toxicity, etc.) as discussed in the previous sections will be identified. The metrics will use the sustainability characterized information for decisions comparing within and across manufacturing processes for carbon foot printing, energy auditing besides others.

The lack of measurement science will be addressed by developing a science-based assessment methodology and structured information, based on the fundamental sustainability characterization of unit manufacturing processes (UMP). UMPs are those individual operations (e.g., casting, machining, and surface treatment) that transform raw material and add value to the work piece as it becomes a final product [34].

The measurement science activities for the sustainability characterization methodology will be comprised of (1) definitions of key performance indicators and common computable sustainability metrics; (2) formal information model that defines the analytics for computing the manufacturing process sustainability; and (3) manufacturing process-specific data sets that instantiate the information models and enable execution of computable metrics. Figure 5 illustrates the components of the sustainability characterization methodology. Such sustainability characterization will support the required evaluation of sustainability performance by allowing science-based rigorous assessment of manufacturing processes.

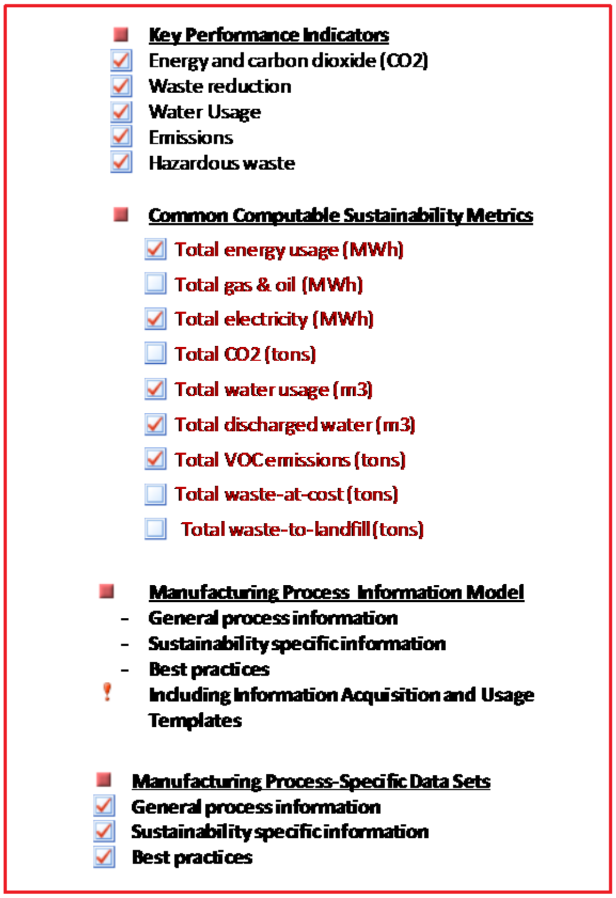

Figure 5 Sustainability characterization components

To illustrate the usefulness of sustainability characterization, Figures 6 and 7 provide the logical model and an example using the injection molding process respectively. One of the challenges is to extract the key information of manufacturing processes from all the relevant data available in the form of text documents, hand books, catalogs, etc. Relevant work on the unit process life cycle inventory (uplci) [35] is pursued at the Wichita State University. Their uplci profile is for a high production manufacturing operation, defined as the use of processes that generally have high automation and are at the medium to high throughput production compared to all other machines/equipment that perform a similar operation. Besides this, the National Renewable Energy Laboratory (NREL) (36) and its partners have created a U.S. Life Cycle Inventory (LCI) Database to help life cycle assessment (LCA) practitioners answer questions about environmental impact.

As mentioned in Section 3, a major challenge is identifying and representing key information as unit manufacturing information models. Once represented the models are capable of providing the computing functionality for sustainability to provide the necessary decision support. Note that this effort can facilitate the development of a structured information base by making available a Standard Reference Data for Unit Manufacturing Process (SRDUMP) consistent with NIST's Standard Reference Materials (SRM) [37] and Standard Reference Data (SRD) [38] efforts.

5. CONCLUSIONS

This paper emphasizes the role on sustainability characterization to facilitate measurement science and methodology development to evaluate the sustainability performance of manufacturing processes.

The authors first presented how process characterization is an inherent part of performance measurement and highlighted the challenges in developing the needed measurement science for sustainability characterization. The authors then presented a related background review on sustainability indicators, manufacturing process information models and relevant software tools for sustainability assessment. Finally the paper proposed the sustainability characterization methodology.

To develop a science-based methodology for sustainability characterization, major tasks under this project are planned along four phases. Phase one involves the tasks related to the fundamental sustainability characterization. Research activities involve requirements gathering, sustainability characterization methodology development, science-based measurement procedures and process data representation for UMPs. Phase two involves the tasks aligned with performance modeling of manufacturing processes using information generated through sustainability characterization. Research activities involve the development of sustainability focused manufacturing process analytical models to compute sustainability performance of UMPs. Phase three involves the tasks that lead to the standard on sustainability assessment methodology for identified processes and the SRDUMP. Phase four involves the verification and validation of the methodology and standards created.

DISCLAIMER

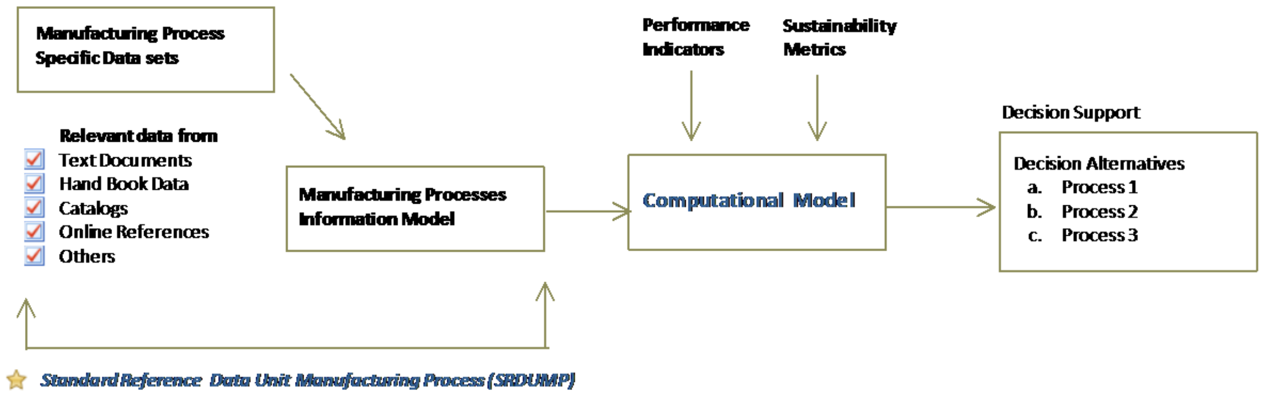

Figure 6 Logical model for sustainability characterization

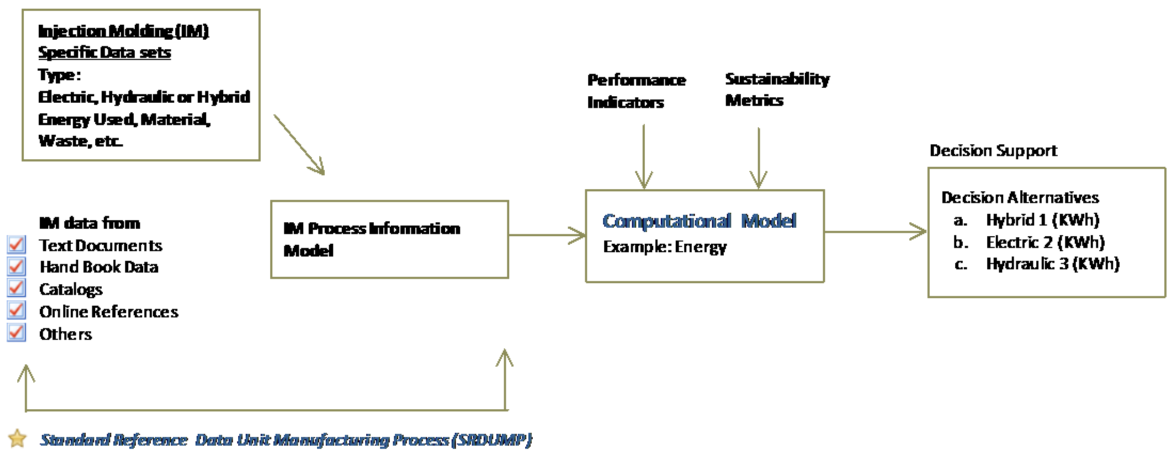

Figure 7 Example demonstrating the logical model

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