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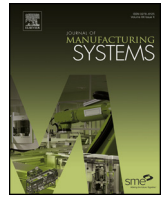
Journal of Manufacturing Systems, 32(4)

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Publication Date

2013-06-01



Technical paper

Understanding life cycle social impacts in manufacturing: A processed-based approach

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ARTICLE INFO

Article history:

Received 6 May 2013

Accepted 15 May 2013

Available online 29 June 2013

Keywords:

Sustainable manufacturing

Sustainable supply chains

Social impacts

Social responsibility

Welding

ABSTRACT

Developing sustainable products and processes is growing in importance due to increasing regulation, consumer interest, access to information, and competitive forces. In order to adequately evaluate the sustainability of products and processes, there is a need to consider the impacts from all three pillars of sustainability – society, environment, and economics. There are substantial challenges to identifying and understanding the social impacts associated with manufacturing activities. This paper provides a framework for characterizing the social impacts of manufacturing throughout the life cycle of a product or process. Social impacts occur on various scales in manufacturing, from the level of a unit process to the level of the enterprise. Additionally, manufacturing activities impact consumers, communities, and larger political/spatial realms. This paper identifies key characteristics of social impacts associated with manufacturing that should be considered to more effectively address the social dimension of sustainability for products and processes. Examples involving a typical manufacturing process – welding – are presented to illustrate the utility of the framework.

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1. Introduction

Interest in achieving sustainable manufacturing systems and production processes is growing. Sustainability was first defined by the Brundtland Commission as meeting “the needs of the present without compromising the ability of future generations to meet their needs” [1]. Its definition has evolved to include three pillars: the environment, society, and the economy, which, when integrated, are sometimes referred to as the “triple bottom line.”

There is public movement toward a triple bottom line approach to measuring corporate success. A recent article published in conjunction with Newsweek’s Green Rankings stated: “Now that environmental leadership has been widely embraced by companies as a competitive advantage, it’s time to redefine sustainability to include social impact. This entails a departure from the traditional cost-cutting model toward a triple-bottom-line approach, embracing economic, environmental, and social performance as measures of corporate success” [2].

Beyond this recent call, manufacturers’ concern about how to manage and achieve sustainability has been driven by steadily increasing costs of energy and resources, risks associated with material availability and use, consumer demands, government

regulations, and interest in reducing the environmental impacts of production. However, although there is a desire to move toward more sustainable practices, substantial hurdles to establish sustainable manufacturing systems persist. As noted in a National Institute of Standards and Technology (NIST) industry workshop report: “Industry is unable to measure economic, social, and environmental consequences of their activities and products accurately during the entire life cycle and across their supplier network” [3].

The economic dimension of sustainability, from the perspective of a single company, is addressed as a matter of course in standard operating practices. Similarly, the environmental impacts associated with decisions at various levels, from unit manufacturing processes to entire enterprise systems [4], are increasingly understood. However, there remains much discussion about the social impacts that should be considered, how they should be measured, and who, within an organization, is responsible for addressing these issues. Additionally, the ability of a company to evaluate the economic, environmental, and social consequences of its activities is limited in part by the knowledge it has about its supply chain.

Although much ambiguity remains, there is a growing call for brand manufacturers to address the social implications of their products throughout the supply chain. Retailers are increasingly requiring their suppliers to provide information about the social impacts associated with manufactured products [5]. Some retailers are making purchasing decisions based upon the information provided [6]. Consumers are able to learn about the social and environmental performance of products on the shelf or in their

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electronic “cart” using rating tools such as GoodGuide [7]. Similarly, consumers are able to evaluate the number of slave laborers involved in the production of the items they own or consume [8].

Some social impacts of a product are closely linked to corporate or enterprise behavior. Corporate policies and practices related to labor and human rights imply social impact [9]. Social risks may be evaluated on a national or regional scale; supply chain concerns may be focused on where products and components are produced without specific information about the facilities where that production is taking place [10]. While attention to social impacts at these levels is certainly important, there are other levels that should be addressed and may be addressed at the level of a facility, process chain or unit process.

Although challenges exist, a systematic approach to identifying and understanding the social impacts of manufacturing is possible. In this paper, the term sustainable manufacturing as used here is first defined and then the definition extended to illustrate the associated social impact aspects and their relationship to manufacturing. A framework for defining and applying metrics for measuring social impacts is proposed. Finally, to illustrate the importance of these considerations we are going to provide a case study focused on welding.

2. Background

Sustainable manufacturing has been 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 are economically sound [11]. Measures of all three pillars of sustainability are necessary in order to judge how a change to a product or production system affects its sustainability. These metrics and associated decision-making tools are critical to enabling an organization to measure its progress toward sustainability and communicate its progress to consumers and others. This work outlines a method to identify the social impacts associated with manufacturing throughout the supply chain.

2.1. Social sustainability in manufacturing

Companies interact with a number of social entities, such as their employees, customers, supply chain partners, communities, and the public as a whole [12]. Based on the initiatives that address social sustainability and the sphere of influence identified by ISO 26000 [13], companies have a responsibility to consider how they impact these social entities at the most basic level, in terms of the physical health and safety of the individuals that compose these groups. Beyond the basic level, however, there also appears to be a desire in other initiatives to consider impacts related to human rights [14], which begin to address concerns such as equity, respect and even the rights to enjoyment of the arts and a share in scientific advancement (Article 27).

These broader social issues may be understood through the hierarchy of needs put forth by Maslow [15], which provides a framework to consider the physiological, emotional, cognitive, and social resources that people require. According to Maslow [15], after an individual has achieved physical health and safety, they will become concerned with love/belonging, esteem, and, finally, self-actualization. Belonging, affection, and love requirements may manifest as the desire to overcome or avoid feelings of loneliness and alienation and could be recast in an organizational context as “affiliation”. The need for esteem is often exemplified by individuals seeking self-respect and respect from others because of their abilities and achievements. Maslow views self-actualization as the process of an individual utilizing an increasing amount of his or her

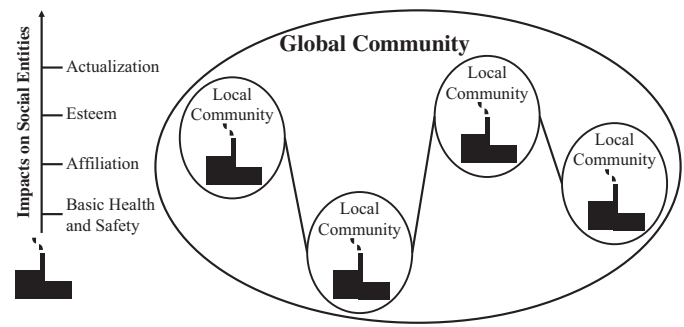


Fig. 1. Manufacturer's supply chain and social impacts.

potential and capabilities “to become more and more what one is, to become everything that one is capable of becoming” [16].

Critics have argued that humans do not seek to fulfill these needs in a perfectly sequential manner [17]. Additionally, alternative methods have been suggested for categorizing different types of social/personal needs (cf., [18]). However, the hierarchy proposed by Maslow does provide a useful means for categorizing needs.

Hutchins et al. [19] have developed a framework for social sustainability metrics by considering Maslow's hierarchy in conjunction with the social groups or entities a manufacturer interacts with throughout its supply chain, as shown in Fig. 1. Each facility in the supply chain employs a number of workers, is situated in a particular community, and may have some effect on the global community through interaction with policy makers, customers and others. A manufacturer could consider how it is impacting each of these social groups or entities based on the need levels suggested by Maslow [15]. In particular, knowing how far along a community is in satisfying the needs in Maslow's hierarchy will provide an indication of where investment should be made.

In some countries, regulations require businesses to consider some of the basic health and safety needs of their employees and customers. However, even in the U.S., there are concerns that even these most basic needs are not adequately addressed. For example, the hazards associated with many chemicals in use are unknown and the mechanisms in place to phase out chemicals of concern have been ineffective [20]. On the other hand, some organizations are already considering the “higher order” needs of customers and members of their supply chain by tracking measures of the relationship (i.e., affiliation) the organization has with these entities [21].

Numerous frameworks, principles, and guidelines provide potential indicators of social impacts. The United Nations Global Compact (UN-GC) [22] and the OECD Guidelines for Multinational Enterprises [23] are two internationally-established, high-level documents that address social impacts amongst other sustainability issues. Programs focused on corporate social responsibility include: ISO 26000: Guidance on Social Responsibility [13] and SA 8000, which is an auditable social certification standard [24].

The guidance provided in these documents is often incorporated into sustainability compliance materials for use in evaluating actors within a value chain. However, the guidance is sometimes interpreted differently depending on the context where it is applied. The Global Social Compliance Program seeks to improve comparability and transparency across the spectrum of compliance systems [25].

Other organizations are approaching the lack of consensus regarding appropriate measures of sustainability by focusing on specific industries or sectors. The Sustainability Accounting Standards Board (SASB) is developing industry-specific key performance indicators related to sustainability [26]. Sector-specific

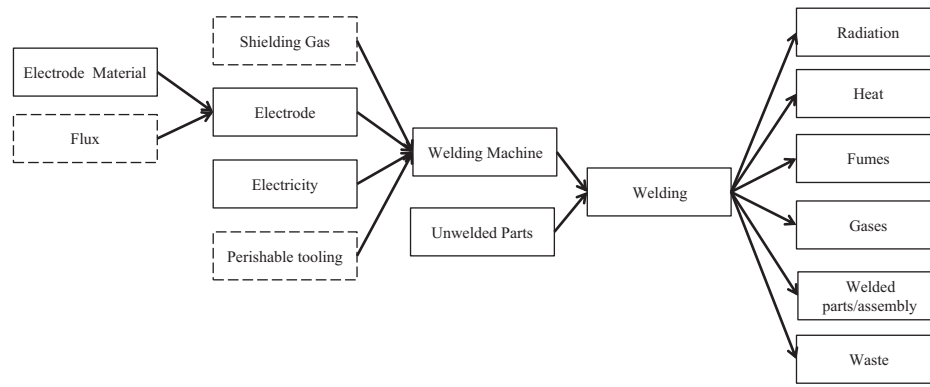


Fig. 2. Simplified inputs/outputs of welding.

organizations such as Sustainable Apparel Coalition [27] and Sustainable Forestry Initiative (SFI) [28] also provide insights into what social impacts may be associated with products and production.

However, many of the socially-oriented indicators contained in these documents described may not be applicable in a manufacturing context. Many efforts have been made to identify measures of social impact that are useful to engineers and manufactures, such as [18,19,29–34].

Due to the broad range of social entities an organization interacts with and the similarly broad range of potential impacts to consider, guidance is needed in terms of the specific metrics that should be used by manufacturers and designers. Often, decision makers must make trade-offs between conflicting goals, whether that be product-level design requirements or corporate-level investment decisions. A structured approach, in terms of which social impacts should be considered in a particular situation or should be given priority, will be useful.

In order to provide context for this discussion of social impacts, welding will be considered as an example of manufacturing activity. Welding is chosen here as it is widely used and has a number of well documented issues associated with worker health and safety. It should be noted that process characteristics, design parameters, and system inputs and outputs all effect people. Although much of the discussion that follows will focus on welding, it is possible to draw parallels to other manufacturing processes.

2.2. Welding

Welding is a ubiquitous process, used in manufacturing facilities worldwide for assembly of structural and other components of products. In the industrialized world welding is usually concentrated in well-controlled manufacturing facilities where fumes and other outputs, including disposal of waste materials, is more regulated and carefully handled. However, in many facilities welding processes are conducted in much less controlled environments, for example, consider ship building activities and repair or demolition in economically developing countries [35].

Welding processes can be divided into two major categories: fusion welding and solid-state welding. Fusion welding can be defined as the melting together and coalescing of materials by means of heat. The thermal energy required for these welding operations is usually supplied by chemical or electrical means. Filler metals, which are metals added to the weld area during welding, may or may not be used. This process constitutes a major category of welding; it comprises consumable- and nonconsumable-electrode arc welding and high-energy-beam welding processes [36].

In arc welding, the heat required is obtained from electrical energy. The process involves either a consumable or a nonconsumable electrode (rod or wire). An arc is produced between the

tip of the electrode and the workpiece to be welded, by the use of an AC or a DC power supply. This arc produces temperatures of about 30,000 °C (54,000 °F) to melt the metal [36]. The “arc welding” category includes several processes, as described below.

Shielded metal-arc welding (SMAW) is one of the oldest, simplest, and most versatile joining processes. About 50% of all industrial and maintenance welding is currently performed by this process [36]. The electric arc is generated by touching the tip of a flux-coated electrode against the workpiece and then withdrawing it quickly to a distance sufficient to maintain the arc. The electrodes are in the shape of a thin, long stick, so this process is commonly known as stick welding. The heat generated melts a portion of the tip of the electrode, of its coating, and of the base metal in the immediate area of the arc. A weld forms after the molten metal, a mixture of the base metal (workpiece), the electrode metal, and substances from the coating on the electrode, solidifies in the weld area. The electrode coating deoxidizes the weld area and provides a shielding gas to protect it from oxygen in the environment [36].

Gas metal-arc welding (GMAW), commonly referred to as MIG (metal inert gas), is an electric arc welding process in which an arc is struck between a consumable wire electrode and a workpiece. The weld area is shielded by an inert atmosphere of argon, helium, carbon dioxide, or other gas mixtures. The consumable bare wire is fed automatically through a nozzle into the weld arc.

Flux-cored arc welding (FCAW) is similar to gas metal-arc welding, with the exception that the electrode is tubular in shape and is filled with flux.

In short, the inputs required for the welding process include electricity, an electrode, and a welding machine. The outputs from the welding process can be characterized as radiation, heat, fumes, gases, and waste. Depending on the specific welding process used, some inputs and outputs vary, as indicated by dashed lines in Fig. 2. Inputs that are not present in all welding processes are indicated with dashed lines. Welding consumables can generate welding slag, fumes, and/or stub ends depending on the type of consumable used. Welding fumes can be hazardous and should be kept away from the welder’s breathing zone.

Fume components contributing to the health hazard are mainly heavy metals and fluorides. One can find reasonable data in the literature on the magnitude of these outputs and their measurable impacts on people.

3. Characterization of social impacts

To support assessment of the triple bottom line in manufacturing decision making, it is necessary to identify and understand social impacts. In this section, a method to characterize social impacts is proposed. This method suggests areas to consider when looking for social impacts associated with products and production

systems. It also seeks to provide guidance regarding which individuals or organizations may be able to affect these social impacts.

The following factors are proposed to characterize social impacts and risks associated with manufacturing:

- scope of activity (SoA) relative to product/process of interest
- scope of activity relative to the source of impact/risk
- stakeholder(s) impacted
- life cycle phase
- source of impact/risk
- type of impact/risk

The scope of activity refers to the level of detail associated with the system of interest. There are two perspectives to consider in terms of scope of production activity. One perspective is from that of the product or process of interest (i.e., the focus of evaluation for potential social impacts). The other perspective is from that of the social impact. Dornfeld et al. [37] introduce the following levels of activity in the context of the need for interoperable systems to realize computer integrated manufacturing: enterprise, factory, line, machine tool, component, and sensor data. In the context of evaluating social impacts there are also data at different scales in different layers of the manufacturing and socio-political system.

The scale of the available data and the boundary around the production activity of interest are useful characteristics of social impacts. Consider an example in which there are concerns about forced labor in the facility where electrode materials are processed. From the perspective of welding, the electrode is at the machine tool level, whereas the labor issue is likely at the facility or enterprise level depending on the context.

A number of stakeholders and stakeholder groups have been suggested by others for consideration in the assessment of social impacts of products and processes. For example, Dreyer et al. [29] suggest that there are only three main stakeholder groups: employees, local community, and society. The UNEP-SETAC Social Life Cycle Assessment Guidelines suggest employees, local community, society (national and global), consumers, and value chain actors [12]. Hutchins et al. [19] propose identifying impacts associated with those suggested by UNEP-SETAC and the addition of stockholders. In this study we will consider employees, local community, society, consumers, and value chain actors.

The life cycle stages that are suggested follow ISO 14040: Life Cycle Assessment – Principles and Framework [38]:

- raw material extraction
- production and use of fuels, electricity, and heat
- primary manufacturing
- manufacture of ancillary materials
- manufacture, maintenance and decommissioning of capital equipment
- distribution/transportation
- use and maintenance of products
- disposal or recovery of used products (including reuse, recycling and energy recovery)

For the purposes of the proposed characterization method, the life cycle stage is identified from the perspective of the product or process being examined.

The source of the social impact or risk is a key characteristic of that issue. Understanding the root cause of a problem is essential in addressing it effectively. For some social impacts, such as the effects of some welding activities on respiratory health, the relationship between manufacturing activity and impact is well understood and may be grounded in the physical sciences. However, the source of other social impacts, such as child labor, are not as clearly defined. Perhaps one way to characterize the source of

this type of impact is “a combination of social, cultural, economic and other factors.” Whenever possible, the source or potential sources of social impacts should be tracked, as that often provides insight into potential solutions.

Finally, at this stage, we propose two elements of type of impact or risk. One element characterizes whether the impact (or risk) has a (potentially) positive or negative effect on the stakeholder of concern. The focus of this work is negative impacts, which may actually imply positive impacts, as avoidance of negative impacts has positive effects. However, there is certainly a need to move from being less bad to being good.

The second element characterizes the “need level” guided by Maslow’s hierarchy and Hutchins et al. [19]. The proposed levels are: fundamental, intermediate, and higher order. Fundamental impacts are those that have a direct effect on the basic health and safety of individuals and/or are related to widely agreed upon human or labor rights. When negative, impacts on fundamental needs are often perceived to be the most egregious. Higher order needs are those that relate to the desire of individuals or organizations for esteem and actualization. Intermediate needs, as the label implies, fall somewhere between. This grouping includes impacts on the basic functioning of organizations (e.g., bankruptcy) and impacts that are highly contentious in terms of being defined as impacts (e.g., impediments on freedom of association).

While the definition of an intermediate impact is not fully developed, its inclusion is important as it acknowledges that the level of impact for some issues is subject to debate. It is hoped that the inclusion of this category of impact will facilitate discussion and be the subject of future research.

4. Characterizing social impacts in a welding process

To illustrate the scenarios in which the factors proposed for characterizing social impacts are linked to manufacturing decision making, consider the individuals and groups involved in the selection, procurement and utilization of a typical consumable in welding, electrode wire for gas metal arc welding.

- Designer – designs the part, influences electrode wire selection with choice of material, part functionality, operating environment, etc.
- Manufacturing engineer – selects appropriate welding process (including electrode wire) to achieve required design specifications
- Procurement department – determines which supplier to purchase the electrode wire from
- Electrode wire manufacturer (supplier or 2nd/3rd tier supplier) – determines electrode composition and where to source materials for their electrode products
- Material processor – establishes working conditions within their facility and decision making relative to community impacts
- Ore extractor – establishes working conditions within their facility and decision making relative to community impacts

All along the procurement chain decisions are made based on cost, regulatory constraints, traditional supplier relationships, etc. These decisions are not unique to welding; most any manufacturing process requires these decisions to be made.

With an understanding of the value chain and an awareness of social impacts of interest, one can generally identify impacts that are associated with value chain actors throughout the life cycle and scope of production activity. Databases such as those provided by the ILO, UN, and Earthster can provide information related to risk of social impacts [10,39,40]. Audit results can be reviewed for facility-specific information.

Table 1
Example of characterized social impact of welding.

Product or process of interest	Welding
Social impact or risk	Increase in risk of mortality from lung cancer
SoA – product/process	Unit process
SoA – impact/risk	Unit process
Stakeholder Impacted	Employee
Life cycle phase	Use
Source of impact/risk	Chromium in welding fumes
Level of impact	Fundamental
Reference	[42]

For example, there are some serious concerns about mining ore for tantalum, gold, tin and tungsten – these are sometimes referred to as ‘conflict minerals’. The profits generated at these mines in the Democratic Republic of Congo (DRC) are often used to fund armed conflicts [41]. There are several impacts or risks that could be associated with the activity “mining ore for gold” in the location “DRC.” Child labor, health and safety, fair labor, corruption, and prevention and mitigation of armed conflicts are some of the potential impacts associated with mining in this area. The risk for corruption is also in the life cycle phase raw material extraction and the SoA-process/product is enterprise; however, the SoA-impact/risk is society.

In Tables 1 and 2, two examples of characterization of social impacts of welding are detailed from information in the literature. Table 1 addresses the potential risk of mortality due to inhalation of fumes and particulates from the welding process if the worker is not properly protected and adequate ventilation provided. This stems from the presence of chromium in the filler metal (electrode wire). Table 2 addresses a different social impact, also related to the constitution of the filler metal, but in this case, the use of nickel and the potential that the source of the nickel is from a region where risk is increased for human and labor rights violations and, hence, promotes risk or impact in material extraction.

These two examples illustrate the temporal and spatial nature of the problem – one affecting workers very early in the supply chain and likely masked by several layers of suppliers and the second affecting a production worker in the fabrication facility actually welding. Manufacturers seeking to employ sustainable production practices will have varying abilities to address the issues raised here.

A careful analysis of the potential impacts, first at a local level and then at increasingly broader levels may yield a clearer indication of those potential sources of impact that the manufacturer can affect. Clearly, it may be very difficult to insure that the source of filler metal constituents fully supports human and labor rights without relying on assurances from the suppliers.

However, it is increasingly evident that the manufacturer employing welding will need to understand some rudimentary

Table 2
Example 2 of characterized social impact of welding.

Product or process of interest	Nickel production
Social impact or risk	Risk of human and labor rights violations
SoA – product/process	Unit process
SoA – impact/risk	Facility or enterprise
Stakeholder impacted	Employee
Life cycle phase	Raw material extraction
Source of impact/risk	Includes Chinese social, cultural, and financial situation
Level of impact	Fundamental
Reference	[43]

aspects of the source and content of the materials used. We propose that where an impact falls on the spectrum between an opportunity and a challenge is a function of the characteristics previously described, specifically:

- scope of activity,
- stakeholder(s) impacted,
- life cycle phase,
- source of impact/risk, and
- impact type.

The type of impact (i.e., positive/negative and need level) provides some insight into its severity or gravity. The scope of activity, from the perspective of both the product or process of interest and the impact, as well as life cycle phase, can provide insight into the decision makers in a position to affect the impact.

Negative impacts that effect fundamental needs especially those within a brand manufacturer, retail, or their close supplier’s facility pose a significant threat to those organizations. Costs associated with the legally required prevention and mitigation of these impacts can be significant and the risk to brand reputation can also be substantial.

What becomes important for manufacturers and engineers is the identification of (i) strategies that mitigate these threats and (ii) decision makers in a position to implement them. For example, in some welding processes filler material is used that does not include integral shielding (e.g., flux) on the material and, hence, some materials issues are avoided. If the supply chain source can verify the filler material is sourced sustainably, then this eliminates the potential impact. In some cases improved material selection is a simple solution.

However, it seems that as impacts shift to intermediate or higher order needs, the scope of activity shifts to higher levels (from the product/process or impact perspective) or further from the point of analysis in the life cycle it becomes difficult to (i) link the impact to the product or process of interest, and (ii) identify the decision maker(s) capable of affecting change.

The risk to human/labor rights associated with the nickel described in Table 2 begins to illustrate these challenges. Because nickel is a commodity and the facility of concern is likely supplying materials to many other facilities it is challenging to determine how much of the impact or risk can be assigned to the welding process of interest and how much influence individual decision makers have. Similarly, because raw material extraction is many steps removed from the welding activity, it may be challenging to verify that the risk is an actual issue and influence change. In this case, the relationship between decision makers is likely weak to nonexistent.

This implies that changes to support improved social sustainability may be initiated outside of an individual brand manufacturer or retailer. For example the Electronic Industry Citizenship Coalition (EICC) and Global e-Sustainability Initiative (GeSI) have partnered to develop a conflict-free smelter program to collectively address the associated problems in the Democratic Republic of Congo.

Manufacturers and engineers can utilize the characterization method described herein and the resulting structure demonstrated in Tables 1 and 2 to construct a prioritization scheme for social impacts that is relevant in their unique circumstance. Some may wish to address those issues in which the scope of activity relative to the impact/risk occurs at the unit process level and is, presumably, more directly under their control. Some may wish to focus on the most fundamental levels of impact. Others may wish to use established statistical methods to weigh and consider several characteristics simultaneously.

5. Conclusion

This paper first defined sustainable manufacturing as a basis for establishing a view of the social impact aspects of sustainability and their relationship to manufacturing. A framework for defining metrics for measuring social impacts and identifying decision makers in a position to affect the metrics was proposed. The framework includes: scope of activity (SoA) relative to product/process of interest and relative to the source of impact/risk, stakeholder(s) impacted, life cycle phase, source of impact/risk, and type of impact/risk. Finally, welding was used as an example to ground the discussion of this characterization scheme, providing two concrete examples of social impacts due to process related effects and material extraction/supply chain effects.

To successfully assess and address the social impacts of production as a means toward achieving sustainable manufacturing it is necessary to:

- clearly identify the domain or scope of the enterprise in which relevant processes occur. That is, define the spatial and temporal dimensions across life cycle stages and the different processes that are involved
- consider whether it is the product or process that is of interest (i.e., the focus of evaluation for potential social impacts)
- employ a clearly defined set of factors to characterize social impacts and risks associated with manufacturing as applied to each process of interest
- investigate the root cause of any identified problems to establish a basis for addressing them based on the impacts
- identify decision makers with the capability to affect positive change or establish organizations with the ability to institute solutions

There are many opportunities for further research related to the social impacts of manufacturing. While this work establishes a framework for characterizing impacts, additional work is needed to clarify definitions of the different aspects of social impacts. Additionally, it may be possible to develop a means for characterizing the overall severity of an impact or the responsibility of an organization to address an impact. Methods for prioritizing potential impacts are needed and should be tested. Finally, to facilitate socially sustainable manufacturing processes, software tools are needed which incorporate the considerations defined above.

Acknowledgements

The authors would like to acknowledge the Sustainable Products and Solutions Program of the Center for Responsible Business and the Sustainable Manufacturing Partnership of the Laboratory for Manufacturing and Sustainability at University of California, Berkeley for support of this research. Additional details can be found at imas.berkeley.edu.

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