

SUSTAINABLE MANUFACTURING TECHNOLOGIES:
ADDITIVE, SUBTRACTIVE, AND HYBRID

SUSTAINABLE ADVANCED MANUFACTURING AND MATERIALS PROCESSING

METHODS AND TECHNOLOGIES



EDITED BY

**SARBJEET KAUSHAL • ISHBIR SINGH
SATNAM SINGH • ANKIT GUPTA**



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Sustainable Advanced Manufacturing and Materials Processing

This book encapsulates and highlights the most recent innovations, breakthroughs, and comparisons of advanced sustainable manufacturing and material processing techniques for high-performance materials applications with a focus on sustainability and using conventional available methods.

Sustainable Advanced Manufacturing and Materials Processing: Methods and Technologies addresses the various sustainable manufacturing and materials processing techniques for advanced materials. It discusses advancements in conventional and non-conventional techniques used in casting, joining, drilling, surface engineering, sintering, and composite manufacturing. The book focuses on a wide range of manufacturing techniques and materials processing technologies along with their benefits, limitations, and sustainability quotient. The conventional and advanced processes are compared in parallel to understand the need for advanced methods in manufacturing technology.

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Sustainable Advanced Manufacturing and Materials Processing

Methods and Technologies

Edited by
Sarbjee Kaushal, Ishbir Singh,
Satnam Singh, and Ankit Gupta



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1 Introduction to Sustainability of Manufacturing and Materials Processing Technologies

Satnam Singh

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1.1 INTRODUCTION

Manufacturing sectors globally are being transformed and upgraded due to strict norms from various government policies. Energy savings and emission reduction (ESER) is a globally adopted strategy by industries to promote sustainability goals (Cai et al., 2019; Herrmann et al., 2014). The global strategy for any manufacturing industry to grow and sustain is to focus on energy-efficient processes, green manufacturing, and low carbon emissions. All sectors are being reformed due to directives from government policies for lower carbon footprints and energy savings. Out of all the sectors, manufacturing plays a crucial role in the economic development of any nation. This sector is now on the radar for transformation from conventional methods to advanced technologies, where sustainability is one of the major parameters. Sustainability should further provide room for clean, green, and low carbon–emission processes. Now the major question arises of how industries are going to innovate and implement various strategies for green transition while addressing sustainability issues. Sustainability issues in the manufacturing area have been a major topic of discussion at the global level, where researchers are considering sustainable manufacturing an effective solution for continuous growth and development (Böhringer & Jochem, 2007). Over the years, lean manufacturing or lean production methods have provided a route for sustainable and cost-effective manufacturing policies. A lot of literature is available on the application of lean practices for sustainable development in the core area of manufacturing where a lot of methods, modeling, analysis, and

frameworks have been reported (Martínez León & Calvo-Amodio, 2017; Abualfaraa et al., 2020). Lean practices have been used in almost all sectors, including automobiles, foundries, hospitality, supply chains, education, and so on (Hallam & Contreras, 2018; Comm & Mathaisel, 2005; Arumugam et al., 2022).

However, sustainability is still a very broad term that needs to be analyzed at the root level for any manufacturing process. Further, there can be multiple parameters that can contribute to the sustainability of any manufacturing/material processing technology. These parameters need to be selected carefully to understand their impact on the overall sustainability of processes, and mathematical models can be developed to understand this in a better way. Lucato et al. (2018) reported a mathematical model for understanding the sustainability of a computer numerical control lathe machining process considering three major dimensions: environmental issues, economic performance, and social gains. Such a study can be associated with every process to understand the sustainability index of manufacturing processes. There are still limitations to applying parametric analysis on all the available manufacturing and materials processing technologies and find the sustainability index. Many ideas and initiatives have been developed to study sustainability over the years, but some limitations still exist, such as:

- The sustainability framework is different for different sectors and cannot be universally applied.
- Lean practices/frameworks work for the industry as whole but cannot be segregated for the manufacturing process alone.
- Measurement for sustainability is carried out on various parameters and may consider environmental, economic, and social parameters separate variables, or they may be integrated with one another.
- The concept may be too complicated to apply for the industry to evaluate all its processes.
- Developed frameworks may provide data that may be difficult to implement to achieve the objectives of sustainable development.

Hence this chapter proposes a simple mathematical model to evaluate the manufacturing process based on simple measurable parameters to identify the sustainability index. The parameters selected for this model are general and can be identified easily and used per requirements.

1.2 PROPOSED MODEL FOR SUSTAINABILITY INDEX

Manufacturing processes have various measurable parameters that can easily be determined by the industries. Some of these parameters are shown in Figure 1.1.

The parameters are common in nature and can be associated with any manufacturing/materials processing technology. These parameters are based on four common points:

- Parameters determining the economic performance of processes
- Parameters affecting the environment
- Parameters affecting process capabilities
- Safety parameters

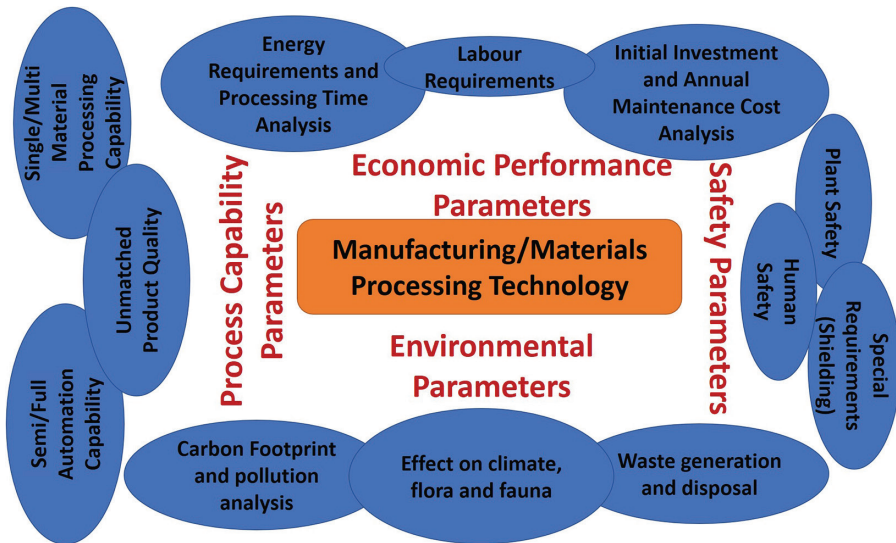


FIGURE 1.1 Common measurable parameters associated with any manufacturing process.

These four common parameters can further be divided into subparameters; for example, the economic performance of any process can be directly measured by the energy consumption in processing/manufacturing. This is directly related to time consumed to manufacture a product. Further, the economy of a process can also be related to the initial investment made and annual maintenance cost for the process. The life cycle of the equipment used in the process is also an important parameter. On similar lines, environmental safety can be linked to carbon emissions, pollution, and effects on flora and fauna. Capability parameters may be linked to the capability of a process to handle multi-material systems, the extent to which the process can be automated, and whether the quality of products produced by the process is unmatched and cannot be obtained by other process. Safety parameters may be linked to special requirements (shielding due to explosive nature or radiation, etc.), human safety, and plant safety. All these parameters can be ranked from 1 to 5 based on available benchmarking data or a user-designed matrix. Based on the selected parameters and subparameters, Equation 1 can be used to design the sustainability index value.

$$SI = f(P_1, P_2, P_3, \dots, P_n) \quad (1)$$

where SI is the sustainability index value, P is a parameter associated with the selected manufacturing process, and f is a function of parameter scores that can be based on the relative scores obtained by comparison with conventional system (see Tables 1.1 and 1.2). To understand the process, let us consider a case study of a microwave materials processing process and some parameters.

Let the SI value be between 1 and 5, where 1 is the lowest sustainability index value, which indicates the process is not sustainable and will not be able to survive,

TABLE 1.1**Parameters Selected for Sustainability Index for Microwave Sintering Process**

S. No.	Parameter Category	Parameter Selected	Range	Relevance in Comparison to Conventional Sintering Process	Score	Justification
1	Economic considerations	Energy required	1–5	The microwave sintering process is a well-established route for ceramics with very high energy savings and lower processing times.	5	More than 90% savings in energy in comparison to conventional heating system (Singh et al., 2015)
2		Processing time			5	Lower processing time by factor of 10 (Singh et al., 2015)
3		Initial cost and annual maintenance cost			4	Cost is comparable to conventional furnaces but highly cost effective in comparison to advanced technologies such as laser sintering processes (Pathania et al., 2015)
4	Process capabilities	Product quality	1–5	Microwave heating does not promote high grain growth due to lower processing time and also suppresses defects.	4	High-quality products with the fewest defects are reported in the literature (Singh et al., 2015)
5		Material system		Microwave heating can be used for ceramics, metallic powders, plastics, glass, and so on.	4	Versatile and can be used for all types except bulk metals
6		Automation		Difficult to automate, as research is ongoing in this area. Lower volume in comparison to conventional furnaces.	3	No work focusing on fully automatic materials processing systems has been carried out, but it can be achieved
7	Safety	Human safety	1–5	Highly safe process and threat until direct exposure of tissues.	4	There are only safety issues if a microwave radiation leak occurs, but commercial systems are well designed
8		Plant safety		No threat to plant, as microwave systems are safe with proper shielding, in comparison to conventional processes, which need shielding from radiation leaks.	3	Need shielding from microwave leaks (Singh et al., 2015)

TABLE 1.2**Parameter wise Calculation of Scores for Microwave Sintering Process**

S. No.	Parameter Category	Parameter Selected	Individual Score	Average Category Score	Overall Process Score	Sustainability Index Value
1	Economic considerations	Energy required	5	4.67	11.84	3.95
2		Processing time	5			
3		Initial cost and annual maintenance cost	4			
4	Process capabilities	Product quality	4	3.67		
5		Material system	4			
6		Automation	3			
7	Safety	Human safety	4	3.5		
8		Plant safety	3			

whereas a value of 5 is the highest value and represents the process being highly sustainable per the selected parameters. Table 1.1 shows the various parameters, their relevance, and the ranges for the calculation of the sustainability index for the microwave sintering process of ceramics.

The scores from the range of values are selected based on the user experience and comparisons between the selected parameters of conventional and microwave sintering processes. The benefits of microwave heating in terms of energy savings and lower processing time are known globally and hence can get a full score. Similarly, other parameters are scored on the basis of available literature and user experience. The calculation of final scores for the parameter category is shown here:

$$\begin{aligned}
 \text{Average Score}_{(\text{Economic Consideration})} &= (\text{Score } \sum_{i=1}^n P_i) / n \\
 &= (5 + 5 + 4) / 3 \\
 &= 14 / 3 = 4.67
 \end{aligned}$$

$$\begin{aligned}
 \text{Average Score}_{(\text{Process Capabilities})} &= (\text{Score } \sum_{i=1}^n P_i) / n \\
 &= (4 + 4 + 3) / 3 \\
 &= 11 / 3 = 3.67
 \end{aligned}$$

$$\begin{aligned}
 \text{Average Score}_{(\text{Process Capabilities})} &= (\text{Score } \sum_{i=1}^n P_i) / n \\
 &= (4 + 3) / 2 \\
 &= 7 / 2 = 3.5
 \end{aligned}$$

$$\begin{aligned}
 \text{Overall Sustainability Index Value} &= \text{Average scores} / n = (4.67 + 3.67 + 3.5) / 3 \\
 &= 11.84 / 3 = 3.95 < 2.5 \text{ (minimum score to qualify)}
 \end{aligned}$$

For the present case, the sustainability index value of the microwave sintering process is close to 4, which shows the process is highly sustainable. This is based on the simple method of weighted averages but can provide significant information regarding process sustainability. Scores can also be collected through surveys from experienced user groups for better predictions on sustainability index values. The different parameter categories can be added per the requirements, and various parameters affecting the overall manufacturing process can be used to track its performance. For any process to qualify as sustainable, it should score at least 2.5 out of 5 considering all the major parameters and comparisons to conventional process values. This score can also provide insights on areas of improvement for the particular process and critical areas hampering the sustainability of process. Table 1.2 summarizes the scores of various parameter categories and the sustainability index.

This case study reveals that the sustainability of a process is based on the sustainability of many parameters, which needs to be addressed before actually calculating the sustainability for any process. Benchmarking needs to be done against the parameter values so that a real picture of the process can be obtained. Figure 1.2 shows a methodology chart for calculating the sustainability value for any process.

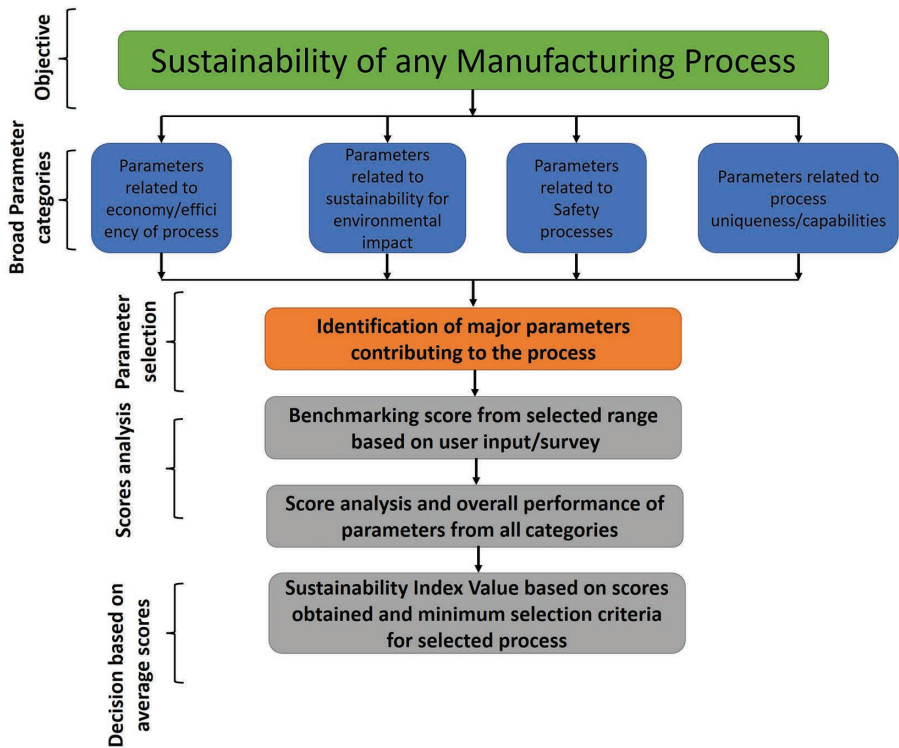


FIGURE 1.2 Proposed methodology for calculating the sustainability index value.

1.3 CONCLUSION

There is a global need for sustainable manufacturing processes that can help industries grow further. Sustainability itself is a wide term that can include many parameters for process sustainability. The frameworks available in the literature are too complex to work on and implement. The present work reports a simple method to analyze any manufacturing process/material processing technology for sustainability. The method involves five steps to find the sustainability index:

- First, identify the major parameter categories for any process that directly affects sustainability.
- For every category, list the major parameters.
- Compare these parameters to conventional available processes or get input from specialist user groups through surveys.
- Provide a general score based on the inputs received. Calculate the average score for each parameter category.
- Calculate the total average score of all categories to find the sustainability index value. A minimum target is to be set at, say, 2.5 (50%) on average for all parameter categories, and if the sustainability index value is more than 2.5, the process can be considered sustainable.

Further, the data from this analysis can highlight the category in which the process is underperforming or sustainability is hampered. This method can provide a simple way to gain insights on the sustainability issues of any manufacturing process.

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