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# Defining sustainable manufacturing using a concept of attractor as a metaphor

Anastasiia Moldavska[a,*], Kristian Martinsen[a]

[a]Department of Manufacturing and Civil Engineering, Norwegian University of Science and Technology (NTNU), 2821 Gjøvik, Norway

* Corresponding author. Tel.: +4 796 830 938. *E-mail address:* anastasiia.moldavska@ntnu.no

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**Abstract**

Sustainability assessment (SA) is a decision support tool that should guide decision makers toward sustainability. A lack of the operational definition of sustainable manufacturing (SM) is one of the challenges that researchers face when developing SA tools for manufacturing. Existing definitions do not provide an explicit list of criteria for SM that affects the choice of indicators for assessment, and thus the reliability and accuracy of the assessment result. The observed lack of common sustainability criteria that can be used when one develops a SA tool for manufacturing organization is the main motivation for this research. In this paper, one of the ideas of complexity theory—attractor—has been used as a metaphor to define SM with the comprehensive list of criteria for SM.

*Keywords:* Sustainability criteria; Trajectory attractor; Criteria for sustainable manufacturing

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## 1. Introduction

Both researchers and industry have discussed what sustainability means in a manufacturing context for last two decades. However, this is still a subject of interpretations depending on the type of industry and research focus. Researchers state that there is no common and unified understanding of what SM is [1-6]. The variety of interpretations and the lack of a practical definition of can constrain the transition to SM [7].

Research done by Moldavska and Welo [8] shows that short definitions of SM include both sustainability-related features and criteria of actual sustainability performance, and fall short on covering a full range of issues associated with SM. Moreover, many of the analyzed definitions do not properly address important aspects of recent thinking about sustainability, such as (1) sustainability is a process, not a destination, (2) sustainability is an attribute of the system, not an end goal, and (3) sustainable system is the one that is continuously in a state of 'becoming'. A conceptual shift in thinking about 'sustainable' as an adjective instead of 'sustainability' as a noun results in seeing sustainability as an attribute of the products, systems, and practices, and not as an end goal [9]. Moreover, Backstrøm et al. [10] argue that for a system to be sustainable, it should be continuously in a state of 'becoming', and a definition of sustainability must take into account time as a key factor. Similarly, Nooteboom [11] suggests to view sustainability as a strange attractor and argues that since sustainable development cannot be precisely defined, it has to be an outcome of a search process that never ends.

The lack of the operational definition is one of the biggest challenges that researchers face, particularly, practitioners in the field of SA. Meins and Schneider [12] argue that definition of SM applied by the practitioners in SA is crucial and influence the assessment of the organizational sustainability. Thus, the lack of operational definition results in a variety of challenges with SA.

One of the challenges with SA as a means to support decision makers toward sustainability and to indicate how organizations contribute to sustainable development is that most of the assessment frameworks do not distinguish

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between extent of implementation of sustainability-related features and actual sustainability performance of the organization [12]. This is supported by Ihlen and Roper [13] who argue that steps toward sustainability should not be presented as actually having reached sustainability. Ihlen and Roper analyzed sustainability reports published by 30 world's largest corporations and identified that organizations present attempts to operationalize sustainability e.g., environmental management system, design for X, sustainability strategy, as an indicator of sustainability performance. Thus, there is a risk that organization that possesses sustainability practices or sustainability-oriented instruments can be claimed to contribute to sustainability. This drawback of SA is caused by the lack of clear differentiation between sustainability-oriented practices and criteria of actual sustainability performance in the definitions of SM.

Moreover, researchers and practitioners in SA face a challenge to develop SA tools that address both organizational context and general criteria for SM. Since every organization has different structure, culture, and produces different products, a standard set of sustainability indicators can be ineffective and either overlook some important issues or focus on irrelevant ones. On the other side, the use of completely different sets of indicators by each particular organization can lead to measuring what matters most to an individual organization while missing the full picture of SM. This drawback of SA is caused by the lack of a standard list of criteria for SM, which can be used as a foundation for development of indicators for different organizations. Sustainability criteria provide the framework for managing a system such as manufacturing organization, while indicators are the measure of performance and are used to infer the status of a criterion [14]. A criterion can be understood as a prioritized aspect SM strives for, e.g., minimizing the use of toxic materials, and indicator as a measurement that can indicate the state of the criteria, e.g., % of toxic materials used per unit of product. Hallstedt [15] argue that the problem is that sustainability criteria used today may be chosen because they are common or well-known, e.g., reduction of GHG emissions by x%. Such approach does not provide a complete picture of SM. However, attention to indicators prevails over the criteria for SM by the developers of SA tools. Hence, there is a need for a comprehensive set of criteria that will describe SM without regard to type of industry or organizational context.

The use of complexity science to understand dynamic systems in terms of networks of relationships is being increasingly used in sustainability analysis [16]. The use of complexity theory's ideas to study SM might help to overcome the shortcoming of the current approaches to both assessment and transition to SM [7].

The objective of this paper is to provide an operational definition of SM that includes an explicit list of criteria for SM and that can be used to guide corporate SA in manufacturing. This is accomplished using a trajectory attractor as a metaphor to define and understand SM concept.

The reminder of this paper is structured as follows. Section 2 introduces the trajectory attractor as a metaphor for SM. In Section 3 we define SM using trajectory attractor concept and discuss advantages that such definition provides. Finally, concluding remarks are presented.

## 2. Attractor as a metaphor for sustainable manufacturing

An attractor is one of the concepts of complexity science that has been used to study the behavior of complex socio-economic systems for more than a decade. The concept of attractor was used in the context of transition management of complex societal systems [17], to analyze resilience of socio-ecological systems [18], to define and understand sustainable work systems [10, 19], and to view sustainability as a global attractor [20].

The concept of an attractor was initially used to describe the behavior of non-linear systems such as hydrodynamic, chemical, etc. The behavior of any dynamic system can be represented by a state-space model:

$$X(t)=[x_1(t),x_2(t),\dots, x_n (t)] \in R^n,$$

where $x_n (t)$, state variables, define the status of the system at any given time $t$. State variables can be defined as the dynamically changing quantities that describe a system. The space of the state variables is called a phase space. The change of the state variables is defined by the system's equations. Depending on the initial conditions of the system, the system's equations will form a phase portrait of the system in the phase space. If the system has N state variables, then its phase space will be of dimension N [21]. An attractor can be defined as a region of a N-dimensional phase space to which a system settles as $t \to \infty$ [22]. Detailed theoretical background on the attractor can be found in Milnor's "On the concept of attractor" [23].

In mathematical terms, an attractor is a system limit, where the "limit function" defines where the system tends to be—i.e., the set of values incorporated by the system. However, even though the limits are known, it is not possible to know where exactly within the phase space the system is located. It should be noted that the attractor is not a goal of the system or a force of attraction. Instead, it depicts where the system is headed based on its rules of motion [24], and a level of the system's performance will follow the attractor [19]. It can be seen as "a complex behavior pattern to which system is attracted" [10].

Dynamic systems can be characterized by (1) a single equilibrium—a point attractor, (2) a multiple equilibrium—a periodic point, (3) a repeating cycle of values—a periodic attractor, (4) unpredictable paths—a strange attractor, or (5) continuous changes of a state of the system in time—a trajectory attractor [20, 25]. A damped pendulum can illustrate the concept of the point attractor and an orbit of a planet illustrates a periodic attractor. A simplified illustration of a trajectory attractor can be a ski slope, i.e. each skier follows slightly different path but tends to be around the middle of the slope. The movement of the skier is defined by the dimensions of the slope, which represent state variables. Figure 1 illustrates a point attractor, a periodic attractor, and a trajectory attractor for a system with two state variables, x1(t) and x2(t), which define the phase space.