

Chapter 2

Evaluation of Manufacturing Systems

Abstract The proper functioning of manufacturing systems can be ensured by conducting evaluations in terms of quality, productivity, leanness, flexibility, and reliability, among others. Then, after such evaluations, it is important to apply methods and strategies to improve the aforementioned aspects. In this chapter, we define the concept of evaluation and discuss its different stages. Also, we discuss the three aspects upon which manufacturing systems have been assessed through the years.

2.1 Evaluation Theory

Evaluation is a developing discipline, so there is not a rigorous definition of it. So far, there is no answer to the question “What does evaluation really mean?” (Guba and Lincoln 1989; Säfsten 2002), although many definitions of the term reflect some degrees of multidisciplinary and multifunctionality.

Some authors argue that evaluating implies examining and judging a system in terms of its relative value, performance quality, degree of effectivity, and anticipated costs, among a few (Åberg 1997; Säfsten 2002). The same authors also point out that an evaluation is a multifunctional, rational task including three aspects: knowledge, valuing, and the use of results. Knowledge involves handling and understanding the object of evaluation (e.g., manufacturing systems), whereas valuing refers to making a judgment on that object (Åberg 1997). It is argued that valuing is at the core of any evaluation, and results can be valued only by comparing them with other results (Säfsten 2002). Finally, the use of such results depends on the evaluation purpose.

An evaluation is also considered to be a methodological task involving simply the collection of performance data, their combination with a weighted set of goal scales to produce numerical or comparative assessment, and the justification of (a) data collection instruments, (b) weights, and (c) goals selection (Scriven 1967; Säfsten 2002). Also, according to Säfsten (2002), evaluation refers to a systematic and methodical process for researching and assessing in light of certain criteria or it

can also be the result of such a process. Additional conceptualizations for the term evaluation are introduced in Table 2.1.

Evaluations have goals, purposes, and functions that differ across users and change over time (Karlsson 1999). Experts claim that the purpose of evaluating a system is to determine its real characteristics and make sure it achieves its goals (summative evaluation) or to identify potential areas of opportunity (formative evaluation) (Scriven 1967; Blanchard and Fabrycky 1998; Säfsten 2002). Also, House (2010) argues that the goal of an evaluation is to produce a value judgment of an object. Although a judgment does not necessarily lead to a decision to act in a certain way, it can be the starting point for making changes and developments.

- Purposes of evaluating a manufacturing system include (Säfsten 2002):
- Find out how good a manufacturing system is.
 - Identify/evaluate possible changes/improvements.
 - Identify whether a manufacturing system meets the formulated specifications.
 - Compare alternative solutions.

The evaluation process usually comprises the following three stages (Scriven 1991):

- Identification of relevant effectiveness and efficacy standards (evaluation criteria).
- Investigation on the performance of the evaluand (object of evaluation) concerning chosen criteria.

Integration or synthesis of partial results to achieve a general evaluation.

Despite the vast amount of research dealing with the different aspects of manufacturing systems evaluation, many companies still struggle to perform accurate assessments. According to (Öhrström 1997), many of such struggles are derived from the following problems:

- Lack of resources, especially time.
- Unicity of the systems.
- Lack of concepts to be compared during the system’s design process.

Table 2.1 Definition of evaluation

Author	Definition
Jerkedal (2001)	Evaluation means describing and assessing a program
Scriven (1991)	Evaluation is the process of determining the merit or worth of things. An evaluation is a product of that process
Nydén (1992)	Evaluation is a systematic and methodological judgment of a phenomenon in light of certain criteria
Vedung (2009)	Evaluation, in politics and public administration, aims at carefully surveying and judging the implementation and results of public measures
Stufflebeam and Shinkfield (2012)	Evaluation is the systematic assessment of the worth and merit of an object

The worth of something depends on many factors, such as the person to whom it should have value, the perspective, and the context (Karlsson 1999). Westlander (Westlander 1999) suggests the normative point as an appropriate start for an evaluation. At the normative point, people know whether the results of an evaluation are good or bad. Ideally, a value judgment must be as objective as possible, yet Karlsson (1999) points out that no judgment is objective, since human beings (Karlsson 1999) create them.

A judgment can also be generated according to reference points or measures. Likewise, the result of an evaluation must be viewed from two perspectives (Säfssten 2002):

- In terms of its desirable qualities.
- In terms of its real use.

Every evaluation must be useful to a given audience, must generate new knowledge, and has to be theoretically appealing (Robson 1993). When an evaluation is not viewed as a potential means of learning, good solutions may be discarded (Karlsson 1999).

2.2 Focus on Manufacturing Systems Evaluation

Many evaluation approaches attempt to unify the numerous criteria for the evaluation of manufacturing systems. These criteria are discussed below.

2.2.1 *Productivity*

Productivity is a key to measuring the economic performance and competitiveness of a company. In the context of labor, productivity refers to the relationship between outputs (goods and services) and inputs (time, workers, materials, etc.) or resources (Sanchez and Madrid 2007; Syverson 2011; Bernal et al. 2015). Therefore, productivity can be a synonym for production efficiency (Syverson 2011). In this sense, Eq. (2.1) presents a common formula to measure the productivity of manufacturing systems (Sampere et al. 2008; Bernal et al. 2015).

$$\text{Productivity} = \frac{\text{Produced units}}{\text{Utilized resources}} \quad (2.1)$$

Syverson (2011) argues that productivity can be measured from different perspectives. For instance, single factor productivity measures units of output produced per unit of a particular input. On the other hand, total factor productivity (TFP) refers to the variation of output that cannot be explained by the amount of inputs used in the production (Comin 2010). TFP levels are estimated based on the

efficiency and intensity of inputs. Time, for instance, is one of the most popular resources used to measure productivity.

In manufacturing systems, productivity can also be positively influenced by quality improvements, costs and inventory reduction, better material handling (Bernal et al. 2015), the integration of new technology (Sanchez and Madrid 2007), resource intensity, (Syverson 2011), training, organizational innovation, (Antonioli et al. 2010), and ergonomic practices (Hendrick and Kleiner 2016; Mossa et al. 2016). In turn, productivity changes can affect the employment level. For instance, as demand increases, productivity increases, which in turn creates more jobs (Matsuyama 2008). Finally, productivity also affects exports, as the most productive manufacturers manage to penetrate foreign markets (Cuevas 2008). Therefore, productivity plays a crucial role in the competitiveness of those manufacturing companies seeking to be part of international trades (Casanueva and Rodríguez 2009).

2.2.2 *Flexibility*

Lately, flexibility has gained relevance in manufacturing systems evaluation. According to Manyoma (2011), flexibility in manufacturing is defined as the ability of a manufacturing system to successfully adapt to changes in its environment and to customer and process needs with little penalty in time, effort, quality, costs, and performance. Manufacturing flexibility can be of different types. For instance, Chrysosolouris (2013) proposes a categorization of three types of flexibility: operation flexibility, product flexibility, and capacity flexibility, whereas authors such as Manyoma (2011) propose a larger classification. The author recognizes six types of manufacturing flexibility:

1. Volume flexibility: The ability of a manufacturing system to alter (increase or decrease) its productivity levels according to changes in demand.
2. Product flexibility: This is composed of three subtypes:
 - Variety flexibility
 - Design flexibility
 - Modification flexibility

Variety flexibility describes a system's ability to produce specific units of a given product, whereas design flexibility refers to the number of units and variety of products that can be introduced in a normal production scheme, considering time and costs. Finally, modification flexibility describes the number of alterations to a product design under a given time period.

3. Machines, equipment, and tools flexibility: The different types of operations that a machine can perform or the ease to profitably switch from the processing of a component or part to the processing of another different component or part.

4. **Material handling flexibility:** The ability of a system to effectively move and deliver materials within the manufacturing facility. Also, it is viewed as the number of routes connecting the manufacturing stations and the variety of materials that can be transported along these roads.
5. **Routing flexibility:** It is strongly interrelated with materials handling flexibility. It refers to the different routes that can be used to produce a product within a manufacturing facility.
6. **Workforce flexibility:** The ability of a system to adapt its human resources by profitably increasing or decreasing them and managing their skills, tasks, and alternative responsibilities. The number and the types of tasks that an employee can perform are at the core of workforce flexibility.

Experts claim that flexibility can be measured through different perspectives, yet the most common form of measuring flexibility is through volume and variety (Bengtsson and Olhager 2002; Francas et al. 2011; Manyoma 2011). Volume flexibility can be measured using the cost curve. A U-shaped cost curve with a flat and long bottom denotes flexibility and implies that costs remain low over a wide range of output levels (Manyoma 2011). On the other hand, product variety can be measured by looking at the different types of products that a company can manufacture. The number of different products (N) provides a strict numerical value representing the final number of products manufactured by an organization. On the other hand, (H) refers to product heterogeneity and provides a more comprehensive view on product flexibility.

Flexibility in terms of product volume and variety can be estimated using Eq. (2.2) (Manyoma 2011):

$$\text{PFLX} = \sum_{c_1=1}^C \sum_{c_2=1}^C (\gamma_{c_1,c_2} \text{DP}_{c_1,c_2}), \quad c_1 \neq c_2 \quad (2.2)$$

where

PFLX product variety flexibility ranging from 0 to 1, being $\text{PFLX} = 1$, the maximum flexibility.

c_i different products to be manufactured, for $i = 1, 2, \dots, C$.

γ_{c_1,c_2} number of times a change from batch c_1 to batch c_2 occurs in the production sequence, in such a way that $\sum_{c_1} \sum_{c_2} (\gamma_{c_1,c_2}) = 1$.

DP_{c_1,c_2} difference between two products, c_1 and c_2 , where c_2 is the biggest product.

DP_{c_1,c_2} takes values ranging from 0 to 1. When products do not have components in common (i.e., products are totally different), $\text{DP}_{c_1,c_2} = 1$. On the other hand, as the similarity between components increases, DP_{c_1,c_2} becomes closer to 0.

Flexibility in manufacturing systems is becoming increasingly important, as companies have to adapt to sudden market changes, shorter product life cycles, increasing product variety, shorter delivery times, and higher quality standards

(Gerwin 1989, 1993; Benjaafar 1994, 1995). Therefore, flexible production control practices can help companies reach their desired success (Gupta and Buzacott 1989; Benjaafar 1994, 1995). In fact, in the manufacturing industry, flexibility is a key competitive strategy (Manyoma 2011).

2.2.3 *Leanness*

Leanness refers to the application of lean manufacturing practices (Bayou and de Korvin 2008; Vinodh and Chintha 2011). Current manufacturing companies implement lean manufacturing as a competitive strategy to increase efficacy, improve product quality, and reduce process time cycles through the elimination of waste or muda. Muda refers to those activities that do not add any value to a product.

Studies have demonstrated that manufacturing practices have a positive impact on the organizational performance of manufacturing systems (Belekoukias et al. 2014). Like in productivity and flexibility, experts have proposed methodologies to evaluate manufacturing systems from a lean perspective (Karlsson and Ahlström 1996; Vinodh and Chintha 2011). For instance, Bayou and de Korvin (2008) developed a systematic, long-term measure of leanness using a fuzzy logic methodology, since leanness is a matter of degree. The measure is also relative, dynamic, objective, integrative, and comprehensive.

From a similar perspective, Vinodh and Chintha (2011) proposed a lean assessment model using a multigrade fuzzy approach to obtain the leanness index of a company after introducing assessment data. An index of leanness allows for the identification of areas for leanness improvement in a given company. Finally, Soriano-Meier and Forrester (2002) developed another model to measure the degree of leanness of manufacturing companies. In their proposal, authors identified ten variables:

- Elimination of waste
- Continuous improvement
- Zero defects
- Just-in-time deliveries
- Pull of raw materials
- Multifunctional teams
- Decentralization
- Integration of functions
- Vertical information systems
- Managerial commitment

To measure these variables, authors designed two questionnaires. The first one is aimed at production managers and seeks to measure the extent to which manufacturing companies implement lean manufacturing practices. This questionnaire measures two dependent variables: (1) the degree of adoption of manufacturing

practices and (2) the degree of leanness. Both variables are measured according to data gathered on the first nine independent latent variables. To measure the degree of adoption of manufacturing practices (first dependent variable), participants must rate the extent to which their companies adopt different lean manufacturing principles (first nine variables) using a scale, ranging from 1 (no adoption) to 7 (full adoption). Once data are gathered, the mean value is estimated. This value represents the degree of adoption of lean practices in a given company (first dependent latent variable). As for the degree of leanness (second dependent latent variable), it is calculated by estimating the mean of the nine independent variables proposed by (Karlsson and Ahlström 1996).

The second questionnaire is aimed at general executives and measures managerial commitment to lean manufacturing. This questionnaire assesses two dependent variables—just-in-time (JIT) deliveries commitment and total quality management (TQM) commitment—through four independent variables using a seven-point Likert scale. As in the previous questionnaire, the values of the dependent latent variables are obtained by calculating an average score.

Other models, surveys, and tools have similarly been developed to assess the degree of leanness of manufacturing systems (Doolen and Hacker 2005; Elnadi and Shehab 2014; Wong et al. 2014; Azadeh et al. 2015; Susilawati et al. 2015; Ali and Deif 2016; Vidyadhar et al. 2016; Narayanamurthy and Gurumurthy 2016). However, our literature review revealed that studies on leanness evaluation are less common than those addressing lean manufacturing implementation. Still, current methodologies for leanness assessment are of wide range and vary from a simple qualitative checklist to complex quantitative mathematical models (Narayanamurthy and Gurumurthy 2016). Nevertheless, most of these methodologies use fuzzy logic, given the level of subjectivity of lean manufacturing variables.

In conclusion, the assessment of leanness performance is an ongoing research field that constantly proposes novel methodologies to evaluate the degree of leanness of manufacturing systems. This increasing trend in the study of lean manufacturing demonstrates the crucial role of lean manufacturing practices as competitive strategies.

2.2.4 *Quality*

The concept of quality in manufacturing work systems has considerably evolved. Some experts conceive it as the total characteristic of a product or service that satisfies the needs of customers, whereas some others argue that quality is what satisfies customer needs and desires but also exceeds customer expectations. From both points of view, customer is a key element to defining quality. On the other hand, on an organizational scale, quality can be better understood through the concept of quality systems. A quality system refers to the organizational configuration, measurements, processes, and capital that ensure quality management. To Colledani et al. (2014), manufacturing work systems have to constantly

overcome challenges to operate their processes and deliver high-quality products. Such challenges have contributed to a new quality paradigm, known as production quality.

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Macroergonomics for Manufacturing Systems

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