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Macroergonomics for Manufacturing Systems

An Evaluation Approach

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To God, who never lets me down.
To my parents, who always support me.
To my nephews, as they encourage me to face any challenge that I encounter.
To the Autonomous University of Ciudad Juárez, CONACYT, and the Technological Institute of Tijuana for the economic support and the shared knowledge.
To my colleagues and coauthors for their invaluable contributions and support through the reviewing process of the book.
To all my friends who, in one way or another, offer me unconditional support and friendship.
Arturo Realyvásquez-Vargas

I dedicate this book to my husband, Martin, and my three sons: Erick, Alexis, and Ethan. You are my sturdiest motivation and the best reason why I try to be a better human being in all aspects. I am so proud of you, and I thank God for your presence every day and every moment of my life.
I also dedicate this book to my students, coauthors, and colleagues; it is a great

pleasure to share and explore our potential and achieve ambitious goals together.

Aide Aracely Maldonado-Macias

To God for everything.
To my children, Mariana Odette and Jorge Andrés, who are the reason I live.
To my wife Ana Blanca, my parents, and other relatives for their unconditional support.
To my friends and those who are my brothers, not by birth but by right (you know who you are). Thank you for your support and guidance.

Jorge Luis García-Alcaraz

Foreword

Macroergonomics is a branch of ergonomics that approaches work system analysis, design, and evaluation; its main goal is to harmonize such systems at micro- and macroergonomic levels. Macroergonomics emerged in the late 1970s as a response to insufficient and often obsolete microergonomic results. The pioneers of this subdiscipline were American and British scientists.

Nowadays, macroergonomics provides specific work tools and methods for system design and analysis. Three well-known macroergonomic methods are participative ergonomics (PE), macroergonomic analysis and design (MEAD), and macroergonomic analysis of structure (MAS). PE relies on employee participation to analyze and design work systems, whereas MEAD provides ten steps to work system design and evaluation from a sociotechnical perspective. On the other hand, MAS combines empirical analytic models to analyze the impact of the three main sociotechnical system components—i.e., technology and tools, people or human resources, and environment—on a fourth component—the work system—and to determine the basic design or an effective work system. Other macroergonomic methods include focus groups, cognitive walk-through, Kansei engineering, and antropotechnology, among others.

The key term in ergonomics and all its branches is compatibility. Two objects are compatible with each other when their characteristics complement one another to reach a common goal. In ergonomics, and especially in macroergonomics, compatibility is defined as the ability of the different work system components and elements to complement the capabilities and limitations of employees, thus allowing such workers to reach the goals and objectives established by the company. Unfortunately, none of the current macroergonomic methods can measure work system macroergonomic compatibility, and this is a limitation to the consolidation of ergonomics as a science and discipline. Therefore, as a means to overcome this limitation, this book proposes a macroergonomic compatibility index for work systems, namely manufacturing work systems.

This book is divided into three parts. Part 1, Macroergonomics for Manufacturing Work Systems, encompasses Chaps. 1–4. Chapter 1 defines the concept of manufacturing system and its main components, whereas Chap. 2 introduces the evaluation theory, discusses its diverse definitions, and presents the four main approaches to manufacturing system evaluation: productivity, flexibility, leanness, and quality. On the other hand, Chap. 3 discusses the most popular macroergonomic evaluation methods for work systems. More specifically, the macroergonomic evaluation methods are compared with microergonomic approaches and discuss their main advantages, disadvantages, and applications.

Chapters 4 and 5 introduce the reader to the most studied macroergonomic factors and elements. Specifically, Chap. 4 addresses the concepts of system-human compatibility, symvatology, and macroergonomic compatibility. On the other hand, Chap. 5 introduces relevant models and presents the literature review results reporting the frequency of appearance of each studied macroergonomic element. As for Chap. 6, it offers a comprehensive literature review regarding the impact of the macroergonomic elements and factors on manufacturing work systems. Such review first addresses the macroergonomic factors and then the macroergonomic elements.

Chapters 7–10 propose and analyze hypothetical causal models of the effects of the macroergonomic factors (and their elements) on work system performance as measured by customers, production processes, and organizational performance. The data used to validate such models were collected in the Mexican manufacturing industry using the Macroergonomic Compatibility Questionnaire (MCQ). As results, this research found that the macroergonomic elements and factors have a positive impact on customers, production processes, and organizational performance. Such findings validated our assumption that the macroergonomic compatibility construct has a positive impact on manufacturing companies.

Chapter 11 discusses fuzzy logic theory as an essential tool for developing the macroergonomic compatibility index and addresses different fuzzy logic-based manufacturing system evaluation approaches. On the other hand, Chap. 12 proposes and explains our index generation methodology and its result, the macroergonomic compatibility index (MCI), discusses dimensional analysis as another multi-attribute and multi-criteria tool that is essential to our proposal, and provides details regarding the MCQ and its rating scale. Finally, Chap. 13 analyzes three case studies wherein the MCI was implemented. The three case studies correspond to manufacturing companies located in Ciudad Juárez, Mexico. In most of the cases, low macroergonomic compatibility levels were found, thereby suggesting that the companies need to implement ergonomic practices in facilities, processes, and equipment.

I sincerely believe that this book provides an efficient solution to the problems of work systems. Its particular value, however, lies in the macroergonomic compatibility index which was developed in the theory and applied in the industrial practice. Therefore, I recognize it to be very useful to students, researchers in academia, and professional engineers working in these areas. Moreover, it does not only move the present state of the art, but also illustrates the rich stream of future research that is required. I hope that you will not only enjoy this book but that it will also help you in your work and give you new insights.

Poznań
August 2017

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Preface

Macroergonomics dates back to 1982 in Seattle, WA, USA. A group of concerned physical ergonomics researchers concluded that increasing the physical aspects of the job was important but not enough to improve human conditions in labor settings. Thus, to improve work conditions, a new approach was necessary for evaluating the organizational context. Under this scenario, the notion of Organizational Design and Management (ODAM) emerged as an attempt to consider the organizational structure in ergonomic evaluations. Then, years later, ODAM gave birth to macroergonomics, a subdiscipline or branch of ergonomics. Since then, macroergonomics has become popular. Originally, macroergonomics addressed work and job positions from an organizational approach, yet now it has evolved and extends beyond these aspects. Nowadays, it is also interested in manufacturing systems, healthcare systems, safety systems, and sustainable systems, among others.

This book proposes a macroergonomic approach to evaluating manufacturing systems, which is why both terms—macroergonomics and manufacturing systems—must be clearly established from the beginning. That said, experts such as Hendrick (1995), Hendrick and Kleiner (2002), Carayon (2012) view macroergonomics as a branch of ergonomics that is both a top-down and a bottom-up approach to sociotechnical systems. Macroergonomics encompasses organizational structures, policies, and processes that support the design of work systems and interfaces, such as the human–work, human–machine, human–software, and human–environment interfaces. Its fundamental purpose is to make sure that work systems are fully harmonized and compatible with their sociotechnical characteristics to achieve synergic improvements within a broad range of organizational effectiveness criteria (e.g., safety and health, comfort, productivity) (Carayon 2012; Zink 2014).

Nowadays, macroergonomics helps organizations and companies meet international standards and norms such as the International Standard Organization (ISO) 14000 and the Occupational Safety and Health Administration (OSHA). Such norms consider ergonomic aspects of the work system at organizational level. For instance, ISO 14000 demands organizations to maintain a favorable environment to satisfy not only its needs, but also customer necessities and environmental norms. Likewise, ISO helps meet diverse international regulations that provide companies with a certain degree of competitiveness (Clementes 1997; Samaras and Horst 2005).

This book views manufacturing systems as an interactive combination at any level of complexity among people, materials, tools, machines, software, facilities, and processes that are designed to work together and meet a common goal (Chapanis 1996). However, manufacturing systems can also be conceived as a combination of smaller systems, known as subsystems; any changes made to one of such subsystems or parts can affect other parts or the complete manufacturing system (Haro and Kleiner 2008).

To remain competitive, work systems have to be evaluated under different approaches, including productivity, quality, efficiency, flexibility, reliability, and even leanness. Despite the many contributions to the field, the ergonomic evaluation approach is still incomplete. Experts have proposed methods for microergonomic evaluations that generate a microergonomic compatibility index to measure the risk level of tasks or workstations. However, at macroergonomic level, none of the current proposals addresses or discusses an index generation methodology for the macroergonomic assessment of work systems, especially of manufacturing systems. The goal of this work is thus to further develop the concept of macroergonomic compatibility and propose an appropriate index for organizational performance evaluation in work systems. The index relies on employee perceptions to assess the extent to which macroergonomic practices are implemented in a given work system.

The methodology here presented was implemented and validated in the Mexican manufacturing industry. This book aims at business people, ergonomists, healthcare professionals, and company managers and supervisors from all over the world who acknowledge ergonomics as one of the most promising areas to be explored to increase the efficiency, safety, productivity, and competitiveness of manufacturing work systems. Similarly, this book is a useful handbook for graduate and undergraduate students, as it explores a broad range of concepts to better understand what is meant by manufacturing work system elements and factors and why they are important in macroergonomic evaluations.

Throughout its 13 chapters, this book conceptualizes and develops macroergonomics for manufacturing work systems. It also establishes the work system factors and elements that are necessary for performing successful macroergonomic evaluations on manufacturing work systems. Similarly, this book discusses how the index generator methodology, as well as the index itself, was validated through case studies. Such case studies demonstrate how the macroergonomic factors are key elements to achieving the desired organizational performance and reveal to what extent these factors impact on the performance of manufacturing work systems. We believe that this book is the most suitable way of disseminating and sharing with the world a novel index generator methodology for manufacturing system evaluation under an emerging, yet increasingly popular macroergonomic perspective. We hope that readers view our work as an interesting, plausible, and useful contribution to improving the ergonomic conditions of modern manufacturing work systems.

Ciudad Juárez, Mexico

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Jorge Luis García-Alcaraz

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Part I

Macroergonomics in Manufacturing Systems

Chapter 1
Conceptualization of Manufacturing Systems

Abstract In this chapter, we define the term "manufacturing" to later conceptualize manufacturing systems. In addition, we describe the components of manufacturing systems to introduce the terms that will be used throughout the book.

1.1 Concepts

Manufacturing can be defined as the application of mechanical, physical, and chemical processes to modify the geometry, properties, and/or appearance of starting materials to make parts or products (Rao 2007). The ability to make such modifications efficiently implies designing, implementing, and utilizing specific manufacturing systems that determine the success of a given company. To understand the notion of manufacturing systems, the following paragraphs provide and discuss some of their most popular definitions.

According to Suh (1995, 1997), a manufacturing system can be defined as a subset of engineering systems in general for which specific methodologies have been developed and implemented for different departments. Later, Suh et al. (1998) added that each one of these departments could be considered as a subset of the entire manufacturing company. Also, manufacturing systems can be seen as the distribution and operation of machines, tools, materials, personnel, and information to create a value-added product (physical products, information, or services) whose success and cost will be measured by tangible parameters (Cochran 1994; Cochran et al. 2002a; Wu 2012; Chryssolouris 2013). In turn, Chapanis (1996) defined the manufacturing system as an interactive combination, at any level of complexity, of people, materials, tools, machines, software, facilities, and procedures designed to work together for a common purpose.

One key characteristic of manufacturing work systems is that they can be a combination of much smaller systems, known as subsystems. Therefore, alterations at any level of the system can affect other parts, or even the complete system (Haro and Kleiner 2008). From the aforementioned definitions, we can recognize both similarities and differences. For instance, all the authors approach a manufacturing system as a systemic component, a part of a much larger system, known as

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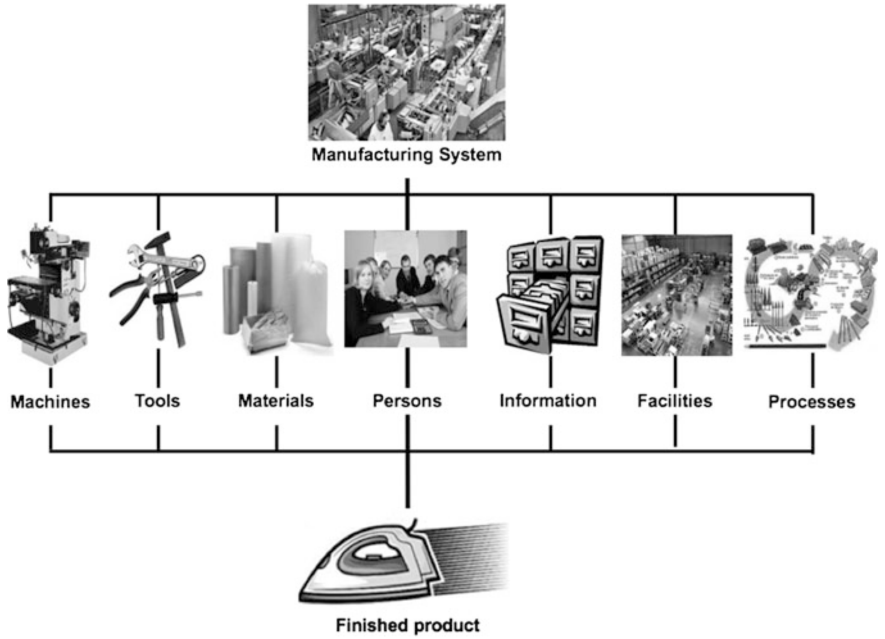

Fig. 1.1 Purpose and components of a manufacturing system

production system or company. Even though not every definition states the purpose of manufacturing systems, they all emphasize in the creation of a value-added product. Figure 1.1 depicts the purpose of manufacturing systems as well as their components as conceived by the definitions.

1.2 Elements of a Production System

Approaching a manufacturing system as Suh et al. (1998) does, in other words, as a subsystem within a manufacturing company, implies that we recognize that manufacturing companies are formed of people, things, and information. People organize themselves to complete different tasks on marketing, design, procurement, inventory control, supervision, machining, management, services, safety, and health, among others. As for things, they refer to the factory itself, including machines, materials, transportation equipment, computational equipment, warehouses, and suppliers, to mention but a few. Finally, the information component is related to standards in terms of marketing, product design, manufacturing systems and operations, manufacturing processes, supply chain, and management. From a similar perspective, Cochran et al. (2000, 2002b) argue that manufacturing systems are constituted by machines, tools, materials, people, and information. All these elements form a manufacturing company, whose design is considered a complex task.

1.2.1 Machines

A machine is an object composed of a set of elements, whose practical purpose is to replace or increase human force, thereby minimizing the effort required to perform some job, always following a same mechanism and yielding the same result (Smith 2004; García 2011; Landín 2011a). However, it is important to mention that some machines are utilized in environments that put individuals at risk or force them to abnormally maximize their efforts.

1.2.2 Tools

The Cambridge Dictionary (2017) defines a tool as an instrument, generally made of iron or steel, that we use with our hands to make or repair something. On the other hand, Millar et al. (2002) defines a tool as a piece of equipment used with our hands to do a particular activity. In a manufacturing system, tools and machines—the latter also referred to as technology—perform particular tasks under specific requirements that people cannot meet by themselves. Some of these requirements include force, precision, deductive reasoning, storage and processing of big data, and multitasking. Also, tools and machines are capable of working for long hours and in environments that may be hostile to people (Mondelo et al. 2004). Because of such capabilities, technology and tools have played a crucial role in the development and evolution of manufacturing systems. Today, they represent an invaluable asset for the competitiveness of modern industries across the globe that strive to maintain high quality and performance (Maldonado et al. 2012).

1.2.3 Raw Materials

Raw materials[1] are any basic materials used in the primary production or manufacturing of a good (Landín 2011b). Raw materials can be classified into different categories, although the most commonly accepted taxonomy includes four groups: (1) metals, (2) ceramics, (3) polymers, and (4) compounds, the latter being a combination of the first three (Rodríguez et al. 2006). Nowadays, competitive manufacturing takes as its basis the appropriate selection of raw materials that are to be converted into products, structures, and useful devices (Asthana et al. 2006).

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[1] A raw material is any material directly extracted from nature.

1.2.4 People

Human resources are a key element in work systems; thus, they cannot be separated from manufacturing systems. According to Holden et al. (2013), in manufacturing work systems, every person performing a task is considered a human resource. According to Crutchfield (2014), human resources represent a unique, sustainable advantage to companies, because unlike any other element, they cannot be easily substituted. Crutchfield (2014) also points out that managers, government officials, and researchers in the social sciences recognize the importance of the human capital to the competitiveness and economic growth of a company within a globalized market.

1.2.5 Information

Information refers to any set of discrete elementary symbols that exist within a source and can be transferred from one point to another. From an etymological perspective, information means to give form (systematic articulation, codification) to a set of data to communicate meaning (Monsalve 2003). To manufacturing companies, information is a tool that allows them to reach goals through adequate processes of compilation, management, and use of such data. Also, information supports collective decision-making and encourages the generation of collective and organizational knowledge (Martínez 2011).

1.2.6 Facilities

Facilities can be conceived as the layout of the physical equipment within a plant (Groover 1997). Layout design has an impact on productivity, profitability, product quality and costs, and the supply/demand balance. Finally, a manufacturing process can be described as the set of successive and interrelated operations and activities programmed through the use of tools, machines, or equipment to transform materials into tangible and useful goods (Eraso 2008). As can be observed, all the components are essential for manufacturing systems to achieve their goal: to create a finished, consumer product.

1.3 Manufacturing Systems Design

A vast number of theories address the design and operation of manufacturing systems and attempt to rationalize the design process. Some of the most notorious works on this matter include (Ham et al. 1985; Black 1991; Sohlenius 1998;

Suh et al. 1998; Cochran et al. 2002b; Gurumurthy and Kodali 2010). However, as in other fields of knowledge, manufacturing systems design in companies and industrial firms is grounded on empirical knowledge and simulation algorithms. The fact that technological development leads the design of these systems has left scientific knowledge, namely discoveries and theories, considerably behind (Suh et al. 1998).

Manufacturing systems design and operation has effects on productivity, return on investment (ROI), and competitiveness. Therefore, companies increase investments and obtain more benefits as a result of improving both manufacturing design/operation and product design. These reasons must motivate the scientific community to regain interest in and understanding of manufacturing systems, and therefore, to contribute to the well-being of companies, individuals, and countries.

A broad range of methodologies propose to increase the efficiency of manufacturing companies by improving information management. Some of these methodologies can be consulted in (Marca and McGowan 1993; Gurumurthy and Kodali 2010). Likewise, lean manufacturing, also known as the Toyota production system, has reached a noticeable impact on the thinking and work of engineers and manufacturing systems. Lean manufacturing seeks to meet particular quality, costs, and productivity standards (Mehrabi et al. 2000; Won et al. 2001; Houshmand and Jamshidnezhad 2006; Gurumurthy and Kodali 2010).

Manufacturing systems can be classified into many types. Four of the most common criteria used for their categorization are listed below (Anonymous 2011):

1. Types of operations performed: Manufacturing systems can perform: (a) processing operations on work units, and/or (b) assembly operations to combine individual parts.
2. Number of work stations and layout: Manufacturing systems can have (a) one work station or (b) more than one workstation. As for layout, manufacturing systems having more than one workstation can be categorized into (b1) fixed routing and (b2) variable routing.
3. Automation level: Manufacturing systems can be of three types: (a) manually operated, (b) automatically operated, or (c) hybrid. Hybrid manufacturing systems combine the characteristics of manually operated and automatically operated systems.
4. Part or product variety: Manufacturing systems can be: (a) single models, (b) batch models, or (c) mixed models. In the single-model case, there is no part or product variety; therefore, the system does not need to be flexible. On the other hand, batch-model systems require being flexible, since there is typical hard product variety. As for the mixed-model case, there is soft-product variety, and the system needs little flexibility.

To respond to competitive environments and sudden changes in technological processes, companies must rely on manufacturing systems that are capable of integrating functions easily and rapidly (Mehrabi et al. 2000). These requirements have led to the generation of manufacturing systems that are able to:

1. Launch new products in short time periods and adjust their production capacity to market demands.
2. Achieve rapid integration of new functions and technological processes in existing systems.
3. Adapt easily to changing production based on market exigencies.

In other words, manufacturing systems must be rapidly designed and capable of generating novel products. Also, they must be able to adjust their production capacities to the sudden and unforeseen market exigencies and integrate new technologies to generate a variety of products.

1.4 Manufacturing Systems Paradigms

According to Mehrabi et al. (2000), the main paradigms of manufacturing systems are:

- *Mass production systems*: focus on product cost reduction.
- *Lean manufacturing*: emphasizes on the continuous improvement of product quality and waste reduction.
- *Flexible manufacturing systems (FMS)*: allow the production of a wide range of products within the same system.

FMS have achieved limited success, although they are said to pursue an important goal. These systems are often high-priced, include more functions than necessary, and utilize inappropriate software systems. Unfortunately, the development of a specific software application decreases the system's utilization. Also, because FMS can be little reliable and more prone to quick obsolescence, a new paradigm has emerged, transforming these systems into *Reconfigurable Manufacturing Systems*. RMS are created by incorporating basic hardware and software modules, which can be replaced more rapidly and reliably.

RMS also provide appropriate functionality and capacity when necessary to reduce the time when launching a new system and reconfiguring preexisting ones. Likewise, RMS allow for rapid modifications in the manufacturing process and faster integration of new technologies and functions into the current system.

Manufacturing systems are a fundamental part of the global economy, since they promote and stimulate the other economic sectors by generating a variety of jobs, either manual or automated. In turn, jobs contribute to a better quality of life across the different social sectors. In other words, manufacturing systems generate wealth for the society (Koren 2010).

1.5 Conclusions

As the manufacturing components, their conceptions, and their evolution into different paradigms demonstrate, the human factor is a crucial element of manufacturing systems. Human resources interact with the other elements, and they are important and versatile because they are irreplaceable. Therefore, for a manufacturing system to function properly, companies must guarantee the appropriate interaction between their human resources and the remaining components of the system, since people actually coordinate these components. Even in the most modern manufacturing paradigms, the role of people contributes to the importance of such paradigms.

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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 multidisciplinarity 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

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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 (Säfsten 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).

$$\text{Productivity} = \frac{\text{Produced units}}{\text{Utilized resources}} \tag{2.1}$$

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, Chryssolouris (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):

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

where

PFLX	product variety flexibility ranging from 0 to 1, being PFLX = 1, the maximum flexibility.
c_i	different products to be manufactured, for $i = 1, 2, \ldots, C$.
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 $\sum_{c_1}\sum_{c_2}\left(\sum_{c_1,c_2}\right) = 1$.
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), $\mathrm{DP}_{c_1,c_2} = 1$. 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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Chapter 3
Macroergonomic Methods for Manufacturing Systems Evaluation

Abstract In this chapter, we present the most popular macroergonomic methods for the evaluation of work systems. More specifically, macroergonomic approaches and microergonomic perspectives are compared. Some of these methods have been adapted from more popular methodologies aimed at studying the organization and behavior of variables and factors. For every method, a brief description is offered to discuss its major advantages, drawbacks, and implementation areas. Also, whereas the majority of the methods presented below are composed of a series of instruments for data collection, others represent more comprehensive methodologies aimed at analyzing sociotechnical systems and organizational structures in terms of the technological and person subsystems and external environmental aspects. All these methods have contributed to the development and rapid growth of macroergonomics as a subdiscipline of ergonomics.

3.1 Macroergonomics in Manufacturing Systems

The contributions of ergonomics and macroergonomics to manufacturing systems take as their basis the analysis and design, or redesign, of the different elements of system: tasks, technology, and environment with which human factors interact. The goal of analyzing and designing these elements is to detect potential risk factors to the health, safety, and performance of employees.

Ergonomics operates along with product development and processes, as it belongs to a systematic development framework rigorously structured and applied in systems engineering. This framework allows for maximizing the advantages of ergonomics during the whole product life cycle or process (Chapanis 1996; Samaras and Horst 2005). Figure 3.1 depicts the systems engineering domain—requirements engineering, compliance engineering, and reliability engineering—and the range of activities—economics, ergonomics, software and hardware—that are part of ergonomics (microergonomics).

The role of ergonomic considerations is similar to the role of hardware and software considerations when formulating requirements and complying with

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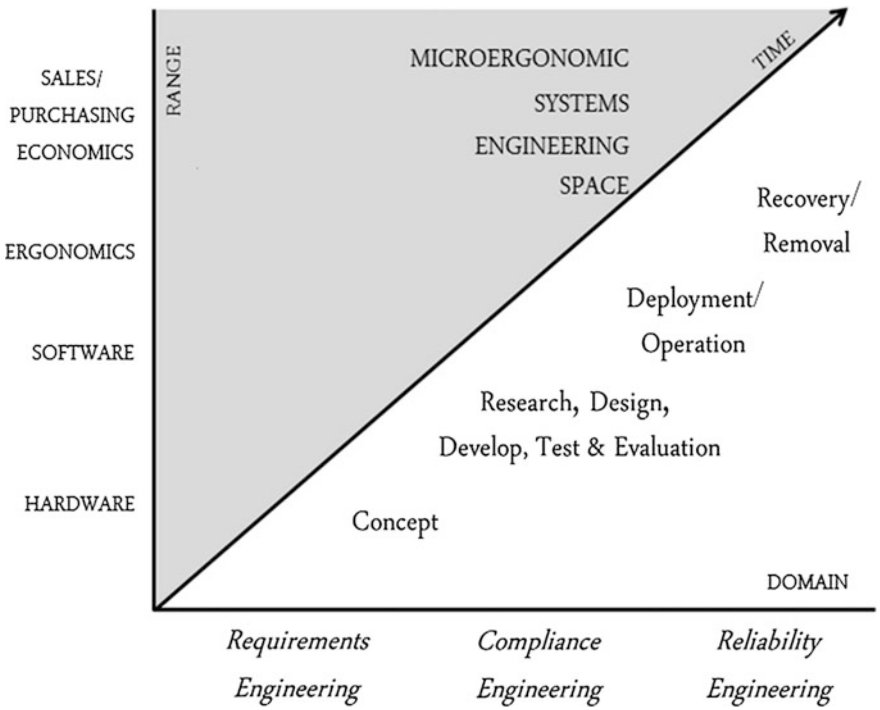

Fig. 3.1 Microergonomic space of systems engineering. Adapted from: Samaras and Horst (2005)

appropriate regulations and norms and in reliability engineering. In requirements engineering, the first step is to identify system users' needs. Then, we must assess such needs and translate them into requirements for manufacturing systems. Finally, such requirements become engineering specifications, which are at the core of ergonomic practices (Samaras and Horst 2005). In this sense, Table 3.1 introduces the application of ergonomics in systems engineering and its benefits.

So far, we have discussed the contribution of ergonomics in engineering sciences from a microergonomic perspective. To introduce the macroergonomic approach, Fig. 3.2 shows that the range of activities changes from sales/purchasing (s/p) economics, ergonomics, and software and hardware to finance, personnel, operations, and management. However, both the domains and time remain the same (Samaras and Horst 2005). The new activities in the macroergonomic approach to manufacturing systems evaluation highlight the elements that are key to an organizational change.

The macroergonomic approach to manufacturing systems starts with the identification and analysis of user needs and the formulation of goals for the work system, always considering ergonomic elements from the beginning. These ergonomic elements are transformed into requirements that, along with restrictions, have

Table 3.1 Application of ergonomics in systems engineering and its benefits

Systems engineering (microergonomics)			
Domain	Stages	Role of ergonomics	Benefits
Requirements engineering	Define the needs of manufacturing system users	Ensure the system design meets user needs	Good product performance, reliable results, competitiveness, motivated workers
	Convert user needs into design specifications	Use anthropometric tables, design interfaces, assess tasks, assess environmental conditions, assist in the product design process	
	Implement the product	Evaluate product usability, redesign work, develop work aids, formulate recommendations on environmental and organizational factors	Increased productivity and user satisfaction
Compliance engineering	Comply with the necessary laws, norms, and regulations	Identify, interpret, design the product	Norms compliance
Reliability engineering	Increase system reliability	Apply analytic and laboratory techniques potentially risky usage errors	Maximized user safety
	Minimize risk factors	Analyze tasks and functions	Man–machine interface optimization

Source Prepared by the authors

to meet the organizational needs and goals. Later on, the requirements are converted into organizational design specifications at the administrative, operational, and financial levels and for human factors.

Once the specifications have been verified along and compared with the requirements, we must start implementing the work structure and its processes. Once the specifications correspond to the requirements, we can start implementing the work structure and its processes. When the implementation responds to the system's specifications, and such specifications in turn meet the requirements, a new work and process structure is created. Finally, similar to microergonomics, macroergonomics applied in systems engineering to address organizational aspects improves the decision-making process, making it better structured, and more systematic and transparent.

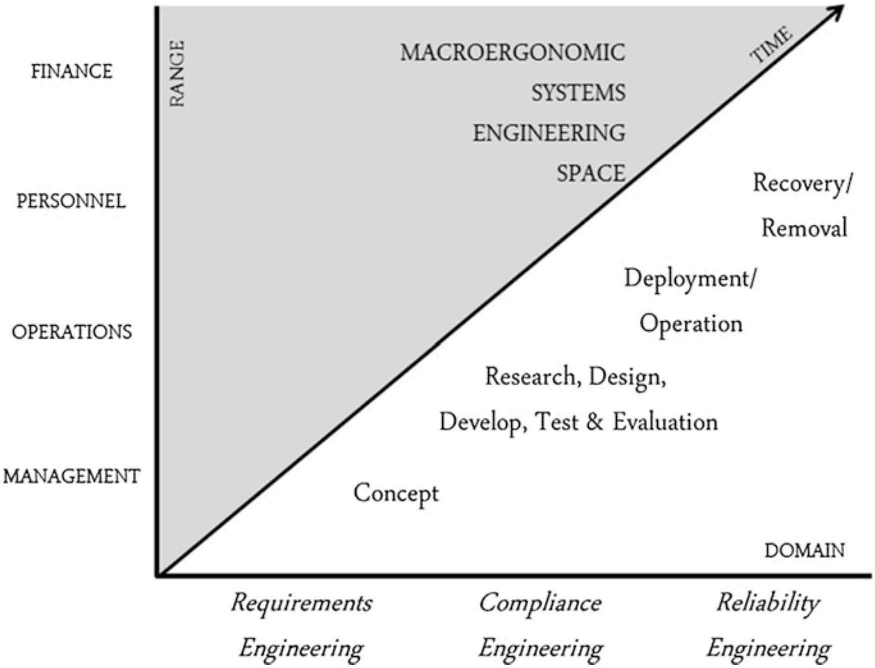

Fig. 3.2 Macroergonomic space of engineering systems. Adapted from: Samaras and Horst (2005)

3.2 Qualitative Methods

3.2.1 *The Macroergonomic Organizational Questionnaire Survey (MOQS)*

The Macroergonomic Organizational Questionnaire Survey (MOQS) identifies symptoms of design problems in work systems and provides improvement suggestions. MOQSs are used to collect information on various aspects of the work system (Carayon and Smith 2000), including tasks, organizational conditions, environmental aspects, tools and technologies, individual characteristics, working life quality, physical and psychological stress, physical and psychological health, performance, and attitudes.

When designing MOQS, it is important to clearly define the concepts to be studied and explore the range of questions that can be asked to measure them. Likewise, we must pay attention to the degree of objectivity/subjectivity of the measurements (i.e., the degree to which cognitive and emotional processing influences answers to the questions) (Carayon and Hoonakker 2001). Finally, bear in mind that, rather than simply being a pre-existing questionnaire, already designed, validated, and available, a MOQS is a methodology to develop, manage, and administer a macroergonomic questionnaire.

Before developing a questionnaire survey, we must clearly define its purpose. Likewise, (Carayon and Hoonakker 2001) propose five stages for developing a questionnaire survey:

1. Conceptualization
2. Operationalization
3. Sources of questionnaire
4. Constructing the questionnaire
5. Pre-testing the questionnaire

To read more about each stage, our readers can consult the work of (Carayon and Hoonakker 2001).

One of the most salient advantages of MOQSs is their ability to collect voluminous amounts of data at a relatively low cost in a relatively short period of time (Sinclair 1995). Also, MOQSs offer structured data that can be easily measured, analyzed, and compared. However, as drawbacks, the development of these macroergonomic questionnaires may be challenging in terms of defining its goal, and thus defining the concepts to be measured. Similarly, researchers may struggle to find the most appropriate way of asking a question, which is why experts recommend to conduct a pre-test. Finally, other disadvantages include a limited space to both formulate and respond to the questions.

As for reliability, MOQSs have reached desired reliability standards in many studies, such as in Cook et al. (1981). Moreover, Carayon and Smith (2000) validated a MOQ using the results obtained in their research. From a macroergonomic approach to manufacturing systems evaluation, we can therefore list the following elements necessary to develop a macroergonomic questionnaire survey and collect the necessary data:

- Define the variables to be evaluated
- Formulate several questions for each concept to obtain a valid and reliable survey
- Pre-test the survey to identify errors
- Define a scale to measure the items
- Define different ways of administering the survey
- Define the potential sample and the administration period

Table 3.2 summarizes the advantages and disadvantages of the other macroergonomic methods for collecting qualitative data.

Table 3.2 Advantages and disadvantages of qualitative macroergonomic methods

Method	Advantages	Disadvantages
Interview	Facilitates data gathering Identifies survey design errors Increases likelihood of honesty in data Allows the researcher to gain access to the personal experiences of participants Reveals which macroergonomic interventions are effective for the redesign of manufacturing systems Identifies macroergonomic and microergonomic design errors	Maybe expensive and time-consuming Main cause bias Are open to the subjective coding and interpretation of data Results may be difficult to summarize
High integration of technology, organization, and people (HITOP)	Quickly introduces new technology into the market Ends manufacturing training and paperwork before the company launches a new product Offers realistic expectations regarding technology Improves technology quality, design, and distribution through the simultaneous design of organization and processes Improves processes before starting the manufacturing of a new product	Lacks basic knowledge of the best practices If the researcher captures incorrect data in the forms, the error is incorrigible
TOP modeling	Allows companies to identify the necessary organizational changes while considering new process technologies Contains an extensive knowledge base of the best organizational design practices Identifies gaps in organizational changes according to new technologies Analyzes gaps to prioritize the solution of the most important Identifies the lack of consensus among team members regarding the current manufacturing system design in light of joint business Takes into account certain factors, such as work descriptions, during the design of new technologies Encourages manufacturing systems to challenge their current status Provides a quick analysis on the use of the system	Does not provide a fast solution for incorrectly designed systems or a redesign plan Does not provide a catalyst for change If the organization's current status is incorrectly described, the obtained results would be meaningless It provides only one of the several starting elements of a complex decision-making process Does not precisely describe how to make modifications

(continued)

Table 3.2 (continued)

Method	Advantages	Disadvantages
Anthropotechnology	Focuses on work, i.e., the activities of the person factor Detects serious abnormalities that can be easily treated Increases the likelihood that imported technologies would fit the country's culture and could be successfully implemented	It is a low method Does not provide descriptions as results Implementing expert knowledge can increase the cost and duration of the project

3.3 Quantitative Methods

3.3.1 Macroergonomic Analysis of Structure (MAS)

The macroergonomic analysis of structure (MAS) was developed by Hendrick to evaluate the structure of work systems in terms of their compatibility with their sociotechnical characteristics. Among these characteristics, MAS includes aspects of technology, humans, and the external environment of companies. MAS integrates models which are empirically designed. These models evaluate the characteristics of one of the factors of a manufacturing system—technology, human resources, and external environment—in terms of their implications in manufacturing systems design. By connecting the values of each variable, the model suggests an optimal level of organizational complexity, formalization, and centralization. Comparing MAS results with the actual organizational structure allows companies to identify deficiencies, propose potential solutions, and reach an optimal performance of the work system.

The MAS proceeding includes the following steps:

1. Structural dimensions of a work system.
2. Analysis of the sociotechnical system.
3. Integration of separate evaluations.

These stages are thoroughly discussed in Stanton et al. (2005).

Similarly, applying MAS in a work system has the following advantages:

1. Allows the ergonomist or organizational design expert to take into account the impact of sociotechnical characteristics on the optimal design of a work system.
2. Helps identify the system's dysfunctional discrepancies by comparing MAS results with the actual work design structure.
3. MAS results can help correct discrepancies.

However, implementing MAS may also have the following disadvantages

1. Conducting organizational evaluations requires training and expertise.
2. Determining the amount of a key sociotechnical variable that is either present or absent in the system is not a simple quantitative process. It requires the subjective judgment, based on knowledge and expertise.

3.3.2 Macroergonomic Analysis and Design (MEAD)

The macroergonomic analysis and design is a methodology for the evaluation of work design processes. MEAD takes as its basis the sociotechnical systems theory (STS) and ergonomics. There are ten steps in the MEAD methodology as follows:

1. Scanning the environmental and organizational design subsystem
2. Defining the production system type and performance expectations
3. Defining unit operations and work process
4. Identifying variances
5. Creating the variance matrix
6. Creating the key variance control table and role network
7. Performing function allocation and joint design
8. Understanding roles and responsibilities perceptions
9. Designing/redesigning support systems and interfaces
10. Implementing, iterating, and improving

Each step is thoroughly discussed in Stanton et al. (2005).

MEAD is a systematic and comprehensive approach that reflects the macroergonomic principles and offers a wide range of benefits. It combines organizational analysis with ergonomic analysis, and unlike microergonomic approaches, MEAD addresses bigger environmental and organizational issues. However, as any other macroergonomic method, it has some drawbacks. Because it is such a comprehensive methodology, its implementation may be time-consuming. Ideally, a training course or workshop on macroergonomics should precede MEAD application (Stanton et al. 2005). Also, MEAD can be manually implemented, but some aspects may need to be applied using technology. Finally, analysts can perform a qualitative evaluation, or she/he can conduct statistical analysis on data, such as a variance analysis.

Table 3.3 summarizes the advantages and disadvantages of the other quantitative macroergonomic methods.

Table 3.3 Advantages and disadvantages of quantitative macroergonomic methods

Method	Advantages	Disadvantages
Laboratory experiment	Allows the ergonomist to manipulate multiple variables of interest The ergonomist can observe and register the impact of these variables on individual, group, and organizational performance indicators It responds to causality questions It is a systematic process The use of groups and teams is realistic	It requires a valid set of measures Generalization into the real world is often questioned Sometimes it is difficult to control unknown and confusing variables The process may be slow and time-consuming It is difficult to control variability within groups or teams
Field experiment	The researcher controls dependent variables of interest Gathers real information on the work system's functioning More efficient than the laboratory experiment in terms of timing and costs	The researcher can introduce unknown variables influencing the effects of change The way changes are made may determine an intervention's success or failure Companies may consider that using unexperienced employees increases costs
Computer-integrated manufacturing, organization, and people (CIMOP) system design	Simplifies the evaluation of computer-integrated manufacturing (CIM) Allows ergonomists to select and include specific design factors (DFs) in the evaluation criteria Helps decide whether a CIM project must be implemented or improved Can determine the uncertainty of subjective, qualitative, or imprecise DFs	It does not offer any solution to design problems It does not provide any quick solution for the improvement of a system Only compares the status of each DF with a predefined level

3.4 Mixed Methods

3.4.1 Participative Ergonomics (PE)

Participative ergonomics is an adaptation of participative management and was developed for both micro- and macroergonomic interventions. When PE is used to evaluate a work system, employees work in conjunction with an ergonomist, who performs as the facilitator and specialist. One of the main advantages of this approach is that employees eventually are able to detect more easily the symptoms of a problem and identify the most appropriate macroergonomic intervention to be implemented.

Employees who take part in PE are more likely to support changes in the work system, even if the adopted approaches do not always match their opinions. Also, a participative approach effectively encourages an ergonomic culture and promotes solid performance and safety improvements that occur from macroergonomic interventions. EP may not be the most common method used in macroergonomic interventions; however, it usually accompanies other methods. Moreover, its application in ergonomic design and analysis is endless (Stanton et al. 2005). Finally, PE can be viewed as a method that involves employee participation in ergonomic analysis and design.

As Hendrick and Kleiner (2001) claim, when participation implies ergonomic design and analysis, employee participation constitutes participative ergonomics, which in turn comprises three approaches: parallel suggestion involvement (consultative participation), job involvement (substantive participation), and high involvement. Each one of these approaches is thoroughly addressed in Stanton et al. (2005).

- As for the advantages of EP, no other method involves employee participation in such an effective way. Every participative method offers a series of advantages; some of them are unique, whereas others are common among several EP approaches.
- Using EP techniques in ergonomic design and analysis interventions and design implementations leads to a greater sense of “ownership” of the solution among team members and employees affected by the treated problem. This feeling in turn increases work satisfaction and commitment regarding work changes.
- Employees become experts in what they do. They know best their work environment, acquire the necessary knowledge, and develop the necessary skills to perform their jobs better than anyone. Employees are also in a better position to identify and analyze problems. Therefore, they are able to both evaluate ergonomic solutions and propose effective ones that are easily accepted among group members.
- Implementing a PE approach generally leads to more appropriate ergonomic solutions if compared to macroergonomic interventions that do not rely on employee participation.
- Involvement in ergonomic design and the implementation process can lead to faster and more meaningful learning of the system or a new procedure, which in turn can significantly improve employee performance and reduce costs incurred from training.
- The participation process can have a systemic effect beyond its original focus and dimensions, thereby causing an impact on other parts of the organization, either through the content or the process of participation strategies.
- Regarding the disadvantages of PE, we can list the following:

- Any kind of participation at any level (micro or macro) may be difficult to encourage among employees and managers.
- The organizational structure can limit the degree of employee participation, or even worse, prevent the creation of a participative culture.
- PE intervention programs for work systems require high managerial commitment, which may be difficult to reach. As for high-participation programs, managerial commitment is a key component. Companies must adopt an organizational philosophy to encourage active participation.
- Ergonomic design and analysis interventions/programs that are planned and developed in a more participative way may be more expensive, due to the time and effort dedicated to them.

Table 3.4 summarizes the advantages and disadvantages of other mixed macroergonomic methods, according to our literature review. For more information regarding these methods, please consult Stanton et al. (2005).

The main disadvantage of current mixed macroergonomic methods is the lack of an index to evaluate the macroergonomic compatibility of manufacturing systems.

Table 3.4 Advantages and disadvantages of mixed macroergonomic methods

Method	Advantage	Disadvantage
Focus groups	Can help interview small groups of people simultaneously Provides a safe and comfortable environment to participants Can help simulate changes in a work system Facilitates the development of ergonomic interventions The researcher can observe the interaction process among the participants Comments from one participant can encourage opinions from other participants The researcher collects data on the attitudes, ideas, and concerns of the participants It is a low-cost data gathering method, if compared to interviews	The neutral level of interaction limits the amount of collected behavioral data The presence of the researcher may affect the behavior of participants The group's culture may prevent people from providing individual answers, which can lead to group thoughts and opinions Some participant(s) may predominate more than others
Fieldwork	Collects real data on the work system's functioning through systematic and direct observation Can identify design deficiencies of work systems Facilitates the implementation of macroergonomic strategies to correct design deficiencies	May be a time-consuming and expensive process, since the researcher must wait for the results to come up naturally The researcher may need to conduct several observations under different conditions before identifying the real

(continued)

Table 3.4 (continued)

Method	Advantage	Disadvantage
	The researcher may discover causal relationships of identify correlations among variables that suggest causality of the work system Results can be generally used in a practical way	causal variables and removing the strange ones
Fieldwork	Collects real data on the functioning of a work system through direct and systematic observation Helps identify the system's design deficiencies Facilitates the implementation of macroergonomic strategies to correct design deficiencies The researcher can discover causal relationships or identify correlations among variables that suggest causality in the work system Highly reliable in terms of the practical application of results	May be a time-consuming and expensive process, since the researcher must wait for the results to come up naturally The researcher may need to conduct several observations under different conditions before identifying the real causal variables and removing the strange ones
Cognitive path	The evaluator takes the place of the user to identify design problems Identifies real, meaningful problems Evaluates and improves the usability of conceptual designs in work systems Is an analytic process Involves expert as evaluators The cost and resources demand are relatively low It effectively captures usability problems	Problems may not be consistent with user reports Cannot be used in isolation, as it must be combined with other methods Time exigencies may be high, depending on specificity Low consistency among evaluators and when compared with usability tests
Kansei engineering	Takes into account the customer's Kansei Develops a new product based on the customer's Kansei Increases customer satisfaction Helps suggest the future trend of a new product domain Improves the design sense of the designer group	The customer's Kansei may be difficult to capture Kansei engineers are necessary to have sophisticated knowledge of and understanding on the statistical methodology Kansei engineers are necessary to be able to read the design sense of the number calculated from the statistical analysis There are no reliable statistical tools to treat the nonlinear characteristics of the Kansei

(continued)

Table 3.4 (continued)

Method	Advantage	Disadvantage
System analysis techniques (SAT)	Helps understand the causal factors at both the micro- and the macroergonomic levels Helps design a range of intervention alternatives for the solution of work system problems at both micro- and macroergonomic levels Helps to analyze the advantages and disadvantages of every solution at the micro- and the macroergonomic levels. Provides a robust analytic method that can be implemented in a variety of work environments and for work systems problems Offers decision-makers a systematic viewpoint of the work system's problem and its solutions through flow charts and matrices for every SAT step	May be difficult to obtain a disciplinary point of view to create a tree problem and formulate the solution alternatives for the work system It is difficult to find reliable and valid advantages/disadvantages (cost/benefit) and effectivity data for every alternative solution to construct the decision criteria table Applying the SAT exhaustively and creating graphs may be time-consuming

3.5 Conclusions

This chapter presents a broad range of methods for evaluating work systems. The microergonomic–macroergonomic comparison allows us to appreciate the ergonomics' potential to improve not only job positions but also the complete organizational development throughout the whole product or process life cycle. Both microergonomic and macroergonomic approaches help detect potential health, employee safety, and work performance risk factors. Qualitative methods have proved to be reliable and valid tools to study work systems. Through interviews, questionnaires, and semi-structured surveys, these methods can gather rich data on the compatibility of work systems with people. On the other hand, quantitative methods propose evaluating work systems with respect to multiple macroergonomic factors, such as technology, people, and the external environment. Quantitative methods are more structured than qualitative methods and offer an assessment of the characteristics of a work system to identify its deficiencies and help to correct them. Finally, mixed methods offer appealing advantages, such as active employee participation when detecting problem symptoms and identifying potential macroergonomic interventions. The variety of mixed methods has offered valuable instruments for work systems design and evaluation. However, although micro- and macroergonomic approaches are embedded in a systemic approach to work, they are unable to offer an appropriate indicator or index to measure macroergonomic factors and elements, quantify them systematically, and evaluate the work system's compliance with macroergonomic aspects and practices.

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Chapter 4
Macroergonomic Compatibility Concept for Manufacturing Systems

Abstract This chapter offers a definition of macroergonomic compatibility concept. For this, firstly, it mentions the different macroergonomic factors and elements existing in literature. Then, the chapter presents the history, goals, and definition of symvatology, a subdiscipline of ergonomics and science of artifact–human interaction. Finally, the chapter provides a definition of macroergonomic compatibility.

4.1 Macroergonomic Factors and Elements for Work Systems Design

We took the model of Carayon et al. (2006) as a starting point to define the factors and elements affecting the macroergonomic compatibility of manufacturing systems. According to Carayon and Smith (2000), a work system is composed of five factors: person, tasks, tools and technology, environment, and organization. These factors are consistent to those proposed by Carayon et al. (2006).

Hyer et al. (1999) proposed a model for the design of a work cell from a sociotechnical perspective. The proposal took as its basis the sociotechnical principles, and the work cell design considered important macroergonomic elements, such as employee skills, teamwork, communication, supervision styles, evaluation performance, and employee rewards. As for the tasks factor, Hyer et al. (1999) suggested such macroergonomic factors as task variety, use of skills, and employee involvement in decision-making. On the other hand, the authors proposed the layout of physical elements as an important macroergonomic element of the environment factor.

Carayon and Smith (2000) divided work factors into more specific categories. According to them, the person factor comprises macroergonomic elements such as employee physical and psychological characteristics, knowledge and skills, motivation, and needs. Regarding organizational elements, the authors claim that organizational changes and opportunities for professional development have a strong influence on employee motivation, stress, and performance. On the other hand, for the technology factor, Carayon and Smith (2000) argue that technology

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misuses may affect motivation and performance and increase occupational stress, whereas a correct use of it can bring positive results at both individual levels and organizational levels.

As far as the tasks factor is concerned, Carayon and Smith (2000) mention that macroergonomic elements such as high daily workloads combined with little empowerment contribute to high stress levels and the occurrence of musculoskeletal complaints (MCs). To prevent these problems, authors recommend to avoid job repetitiveness by providing employees with a variety of tasks that make them feel challenged and allow them to test, use, and improve their professional skills and job techniques.

Environment is the last macroergonomic factor according to the model of Carayon et al. (2006). Carayon and Smith (2000) claim that the work environment comprises elements of noise, lighting, temperature, and workstation layout. These elements must be taken into account during the design and evaluation of any manufacturing system, as they influence energy consumption, heat exchange, employee responses to occupational stress, and employee irritability.

Clegg (2000) proposed a description of the sociotechnical principles for work systems design. These principles rely on a macroergonomic perspective. Even though they do not mention macroergonomic elements explicitly, they do so implicitly. One of these sociotechnical principles frames the evaluation as a key component of work systems design and a requisite for learning. From this sociotechnical view, the evaluation must contain social, technical, and operational criteria, yet companies rarely conduct such systematic evaluations to compare their investments with their original corporate goals.

To Clegg (2000), there are four macroergonomic elements: person, organization, technology and tools, and tasks. For the person factor, the author considers macroergonomic elements such as employee and company motivation and needs. He also mentions employee education, knowledge, skills, and psychological characteristics. As for the Organization factor, Clegg (2000) highlights macroergonomic elements of teamwork, organizational culture, supervision and management styles, employee performance evaluation, and employee rewards.

Karwowski (2001) points out that contemporary ergonomics deals with work systems design problems and their evaluation. To address both aspects, Karwowski (2001) considers that it is important to take into account three macroergonomic factors: humans, organization, and environment. For the human factor, the author highlights employee psychological and physical characteristics, as well as education, knowledge, and skills as important macroergonomic elements to be considered when designing and evaluating work systems. Regarding the Organization factor, Karwowski (2001) is in overall consistent with Carayon et al. (2006). The author argues that organizational elements comprise collaboration, coordination, and communication, as well as organization, work schedules, supervision and management styles, and performance evaluation. In terms of environment, both Carayon et al. (2006) and Karwowski (2001) consider the same macroergonomic elements for work systems evaluation: noise, lighting, temperature, distribution, and workstation layout.

From a slightly different view, Erensal and Albayrak (2004) proposed the hierarchical decomposition of macroergonomic factors. The first level of this approach includes individual, organizational, and conditional factors. In turn, these are divided into more specific elements at the second level, and they are similar to the person, organization, and environment factors proposed by Carayon et al. (2006). Also, the individual factor comprises employee knowledge, job techniques, motivation, and psychological characteristics, while the organizational factor is formed by organizational culture and collaboration. Finally, the conditional factor (environment) comprises workstation layout and employee safety. All these factors and elements must be a part of work systems ergonomic design and evaluation (Erensal and Albayrak 2004).

Sluga et al. (2005) proposed a conceptual framework for collaborative product design and operations for manufacturing work systems. The authors state that, in current situations, teamwork among suppliers, buyers, and customers is essential. Teamwork requires collaboration and communication. In turn, effective communication relies on communication technologies, since they allow suppliers and manufacturers to inform each other of the tasks they perform. Even though this approach goes beyond the employee level, we acknowledge that the characteristics of a company are derived from the characteristics of its employees. For this reason, Sluga et al. (2005) believe that teamwork, employee communication, and information technologies are key elements in manufacturing work systems.

Kleiner (2006) considers that work system macroergonomic evaluation must involve factors such as people, organization, technology and tasks, and environment. Notice that the author combines technology with tasks in a single factor, which he calls the technical subsystem. This subsystem refers to the way tasks are performed. Kleiner (2006) provides a description for each of the aforementioned factors, and such descriptions are consistent with what Carayon et al. (2006) propose regarding the five main macroergonomic factors for work systems design and evaluation.

Holden et al. (2008) introduced a set of principles for change management at the organizational level for manufacturing companies. These principles take into account the person factor, including employee education, knowledge, skills, and motivation. In fact, authors claim that motivation helps employees accept changes that companies undergo in their work systems to reach successful macroergonomic implementations. As for the Organization factor, Holden et al. (2008) discuss organizational culture, teamwork, employee coordination, communication, and social relationships, and supervision and management styles. In addition, the authors argue that employees need to perform meaningful tasks, so they could use their professional skills and acquire new knowledge. Finally, Holden et al. (2008) consider that technology and the environment play significant roles in the successful implementation of macroergonomic practices.

Sittig and Singh (2010) proposed a sociotechnical model to study information technologies within complex work systems in the medical industry. The model has eight dimensions, and three of them include the person factor, the organization factor, and the technology factor. For the person factor, the model studies elements such as employee education, knowledge, and skills, whereas the organizational factor comprises communication and organizational culture. Finally, the technology factor focuses on information technologies, namely computational technology (hardware and software) and its multiple devices.

Similar to Kleiner (2006), Koyuncu et al. (2011) do not provide a detailed decomposition of the five macroergonomic factors, yet they mention some elements that they consider a key to design and evaluate work systems. Some of these elements include employee education, knowledge, skills and psychological characteristics, and task variety. Likewise, Koyuncu et al. (2011) claim that to evaluate overall work system performance, it is important to emphasize on macroergonomic factors people, technology, and environment.

In their work, Armutlulu and Noyan (2011) proposed a multilevel structural equations model integrating individual and organizational elements to assess the relationship between job satisfaction and organizational commitment. With this model, the authors found out that job satisfaction is causally antecedent to organizational commitment at both employee and branch levels. To develop this model, Armutlulu and Noyan (2011) considered elements such as supervision styles, teamwork and communication, employee incentives (payments), and organizational commitment (organizational culture).

Chui et al. (2012) studied the pharmaceutical industry in terms of the barriers preventing pharmacists to offer cognitive pharmaceutical services (CPS). The goal of the research was to identify and describe work pharmacy characteristics that pharmacists changed to provide CPS. According to these authors, a system approach can help to better understand the barriers and facilitators to providing CPS. Chui et al. (2012) relied on the model of Carayon et al. (2006) to assess work system factors and elements and study how these factors and elements affect customer service processes. The macroergonomic factors and elements studied by Chui et al. (2012) were consistent with those presented by Carayon et al. (2006), since they used their model.

Our literature review also revealed that Carayon (2012) is consistent with Carayon et al. (2006) regarding most of the macroergonomic elements. However, the former mainly differs in elements such as employee motivation and needs, social relationships, supervision and management styles, and workstation layout.

Marras and Hancock (2014) analyzed human–system interaction. In their analysis, the authors argued that, historically, employee physical and cognitive aspects have usually been studied separately from each other, which is why they proposed to study them together. Similarly, in this analysis, Marras and Hancock (2014) broke down the physical and cognitive features of humans, as well as their interactions and integration. Also, for these authors, human motivation, physical characteristics, and social relationships are key aspects to the analysis of human–system interaction. As for the tasks factor, Marras and Hancock (2014) believe that companies should consider task variety and must pay attention to how challenging or how demanding these tasks are. As for the environment factor, the authors argue that lighting conditions, noise, and temperature are important to take into account.

Authors Karsh et al. (2014) introduced the term mesoergonomics and defined it as an open systems approach to ergonomic theory. The mesoergonomic approach studies the relationships between variables in at least two different levels. To define these variables, the authors used the model proposed by Karsh et al. (2006), which takes into account macroergonomic elements of the person factor, such as employee education, knowledge, skills, motivation, needs, and physical characteristics. As for the Organization factor, the model of Karsh et al. (2006) includes organizational and safety culture, social relationships, performance evaluation, and rewards. Regarding the tasks factor, the model assesses task content, task challenge, and workload. Finally, for the environment factor, the model considers almost all of the elements proposed by Carayon et al. (2006), except for workstation layout.

As can be inferred, the model of Carayon et al. (2006), if excluding processes and results (Fig. 4.1), can evaluate work systems ergonomic compatibility, since it comprises the main elements addressed in the literature.

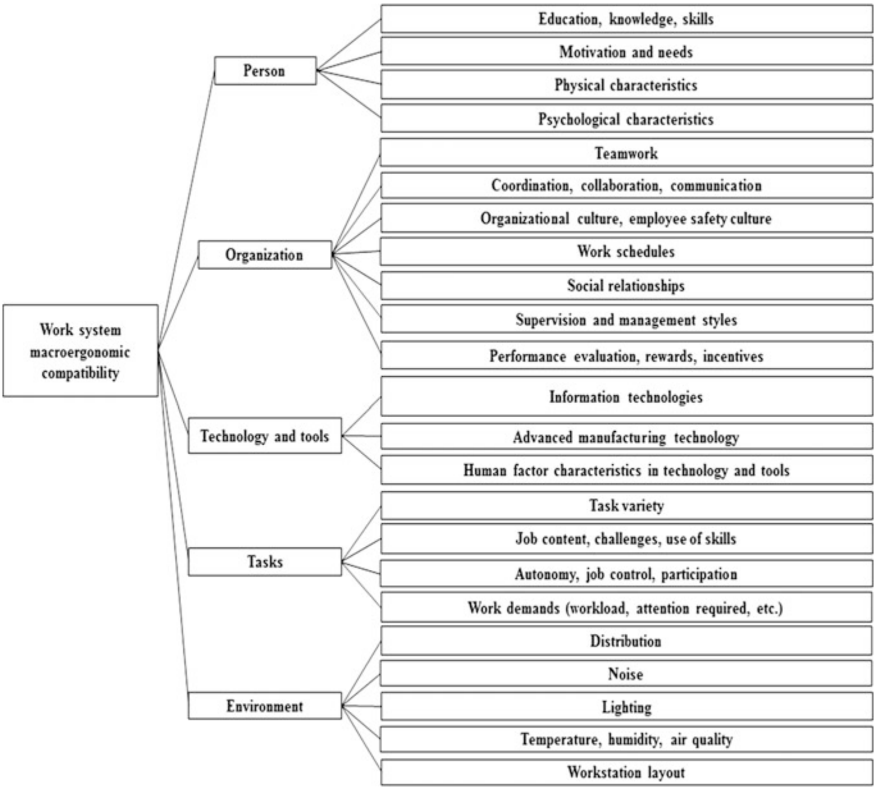

Fig. 4.1 Decomposition of processes and results. Preliminary variables for manufacturing systems evaluation. *Source* Adapted from Carayon et al. (2006)

4.2 Artifact-Human Compatibility: Symvatology

Karwowski (2001) proposed the term symvatology when combining two Greek words: *symvatotis* (compatibility) and *logos* (logic or over-reasoning). The author views symvatology as a subdiscipline of ergonomics and proposed it as a science of artifact–human interaction (system). The goals of symvatology are to discover artifact–human compatibility laws, propose artifact-human compatibility theories, and develop a quantitative matrix for measuring this compatibility.

Symvatology refers to the systematic study—including the theory, analysis, design, implementation, and application—of interaction processes that define, transform, and control the compatibility of artifact-human (systems) relationships. An artifact system can be defined as a set of all artifacts (i.e., objects made by human labor), the natural elements of the environment, and their interaction occurring in time and space afforded by nature. On the other hand, a human system refers to a human being or a set of human beings with all the characteristics (physical, perceptive, cognitive, emotional, etc.) relevant to artifact–human interaction.

Human–artifact compatibility must be taken into account at any level: physical, perceptive, cognitive, emotional, social, organizational, managerial, environmental, and political. This requires a form of measuring the raw materials and products that characterize the set of the human–system interactions (Karwowski 1991, in Karwowski 2005). The objective of quantifying artifact–human compatibility cannot be achieved if we fail to understand its nature.

Symvatology observes, identifies, describes, conducts empirical research, and provides theoretical explications regarding the nature of the artifact–human compatibility. Also, symvatology should encourage the progress of ergonomics by proposing a compatibility design methodology and compatibility design between artificial systems (technology) and human beings.

Karwowski and Jamaldin (1995), cited in Karwowski (2006), view the artifact–human system as a system built from a human subsystem, an artifact subsystem, an environment subsystem, and the interactions among them overtime. In this framework, compatibility is a natural phenomenon affected by the artifact–human structure, its inherent complexity, and its entropy or the incompatibility levels of the elements of the system.

Compatibility should be studied in relation to complexity. That said, transitioning from high to low complexity does not necessarily imply that companies are reaching a higher degree of compatibility. In fact, in most artifact–human relationships, system compatibility improvement can only be achieved at the expense of increasing its complexity. However, ideally, companies should be able to reach high artifact–human compatibility levels under low complexity levels.

Ergonomic incompatibility (EI) is defined as the degradation of an artifact–human system, reflecting the system's measurable deficiency and human losses. The complexity-incompatibility principle can be stated as follows: As artifact–human system complexity increases, the incompatibility among the system's elements also increments. Such incompatibility manifests during the ergonomic interactions of these elements at all system levels and leads to greater ergonomic entropy (ergonomic incompatibility level between the system and its elements) of the system. As a result, companies have fewer opportunities to implement effective ergonomic interventions.

Using this complexity-incompatibility principle, Karwowski and Jamaldin (1996) and Norman (1989), cited in Karwowski (2006), affirm that the technology paradox demonstrates that adding functionality to an artifact implies increasing the artifact's complexity. This paradox manifests in the struggles that people encounter when interacting not only with technology in general, but also with a consumer product. One of the reasons why people feel frustrated when interacting with technology is because technology systems having more features and functionality also lack enough feedback. That said, technology complexity cannot be prevented, yet it can be minimized though effective technology designs.

Finally, Karwowski and Jamaldin (1995), cited in Karwowski (2006), proposed the requisite complexity law, which states that only design complexity can minimize system complexity. In other words, only added complexity, expressed by system compatibility requirements, can be used to reduce system entropy (i.e., reduce overall artifact–human system incompatibility).

4.3 Macroergonomic Compatibility

Macroergonomic compatibility refers to the ability of technology elements, organizational constraints, tasks, and the environment to integrate (adapt) and operate with the person factor in an efficient, agreeable, and orderly way within a work system. Symvatology as a science studies ergonomic compatibility. The term was first introduced by Karwowski (2001) after combining two Greek works: *syvatotis* (compatibility) and *logos* (study of something). Karwowski (2001) pointed out at the need for symvatology as a corroborative science to develop solid ergonomic bases.

Symvatology is the systematic study—including the theory, analysis, design, implementation, and application—of the interaction processes that define, transform, and control compatibility relationships between system elements and people. Its goal is to discover the human laws, theorize about human compatibility, and develop a quantitative matrix to measure this compatibility (Karwowski 2005).

To improve the well-being and performance of the people and the work system, human–system compatibility must be assessed at all levels, including the physical, perceptual, cognitive, emotional, social, organizational, environmental, and political levels. To do this, we need an effective method to measure the input and output variables that characterize the set of human–system interactions (Karwowski 1991, cited in Karwowski 2005; Karwowski and Jamaldin 1995, cited in Karwowski 2005). However, the goal of quantifying human–system compatibility can only be attained if we understand the nature of such compatibility. Symvatology observes, identifies, describes, conducts empirical research, and proposes theoretical explanations regarding natural phenomena occurring in human–system compatibility. On the other hand, ergonomics seeks to enhance the human and system well-being, including their codependent performance (Karwowski 2005). As Hancock (1997), cited in Karwowski (2006), claims, we must guarantee the well-being of humans while enhancing the system to make appropriate use of its life.

Karwowski et al. (1988), cited in the work of Karwowski (2006), proposed to represent human–system interaction as a construct containing a human subsystem (people), an artifact subsystem, and the set of interactions occurring among the elements of these subsystems overtime. In this context, compatibility is a dynamic, natural phenomenon affected by the artifact–human system structure, its inherent complexity, and its entropy or the level of incompatibility among system elements.

System compatibility must be considered in relation to system complexity. In the most optimal state of system design, the artifact–human system reaches high compatibility and low complexity levels. However, the transition from high to low system complexity levels does not always guarantee or lead to higher system compatibility. In fact, in most artifact–human systems, system compatibility is improved as system complexity increases (Karwowski 2005).

Lack of complexity, which is defined as the degradation of the artifact–human system, is reflected on the system's measurable inefficiency and the associated human losses (Karwowski et al. 1988, cited in Karwowski 2006). To express the intrinsic relationship between system complexity and system compatibility, Karwowski et al. (1988), cited in Karwowski (2006), proposed the complexity-incompatibility principle, which states as follows: As artifact–human system complexity increases, the incompatibility among the system's elements through their ergonomic interactions at all system levels also increases, thereby leading to greater system entropy (non-reducible) and diminishing the potential of making effective ergonomic interventions.

Karwowski (1995), cited in Karwowski (2006), explained the complexity-incompatibility paradigm using the example of an office chair design. Similarly, Karwowski (1992), cited in Karwowski (2006), discussed it in the context of organizational design. It is important to mention that the complexity-incompatibility principle reflects the natural phenomena that other researchers in the field of ergonomics have described in terms of the difficulties and struggles encountered by people with consumer products and technology in general. For instance, according to Norman (1988), cited in Karwowski (2005), the technology paradox demonstrates that adding functionality to an artifact usually increases its complexity. Moreover, it has been claimed that added complexity may cause frustration and increased difficulty when people interact with system elements. Finally, Norman (1988) also noted that although increased complexity could not be avoided when adding functionality to system elements, it could be minimized with good designs that follow natural mapping between the elements of a system.

Considering the requisite variety law, proposed by Ashby (1964), Karwowski (1995), cited in Karwowski (2006), proposed the so-called requisite compatibility law. This law states that only design complexity can reduce system complexity. In other words, only the added complexity of the regulator (R = re/design), expressed by system compatibility requirements, can be used to reduce system entropy, also known as the overall artifact–human system incompatibility.

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Part II
Macroergonomic Compatibility Factors

Chapter 5
Macroergonomic Compatibility Factors for Manufacturing Systems

Abstract Measuring ergonomic compatibility has been a concern to many academics, industrialists, and health systems due to the economic implications involved. The goal of this chapter is to describe the most important factors that have been used to develop compatibility indices and to analyze the trends and methods that are most used for index generation, as well as their advantages and benefits.

5.1 Macroergonomic Factors for Manufacturing Systems

The Cambridge Dictionary (2017) defines a factor as a fact or situation that influences the result of something, while *macroergonomic* refers to an ergonomic event that happens at organizational level or affects the whole company (Realyvásquez et al. 2016c). Therefore, a macroergonomic factor can be seen as a variable affecting the performance of a company at all hierarchical levels from an ergonomic point of view. Recently, several authors have developed and proposed macroergonomic models with different macroergonomic factors (Carayon et al. 2006; Karwowski 2006b; Kleiner 2006; Realyvásquez et al. 2016c) and even simpler components, known as macroergonomic elements (Carayon et al. 2006; Holden et al. 2013; Realyvásquez et al. 2015, 2016b, d).

The main goal of macroergonomic models is to analyze the companies departing from the macroergonomic factors to improve the design/redesign of work systems (e.g., manufacturing systems). This goal is achieved when macroergonomic factors are optimized, since they improve organizational performance, productivity, product quality, as well as employee health, comfort, and safety (Beevis and Slade 2003; Dul et al. 2012; Realyvásquez et al. 2016c). Macroergonomic practices are hence a source of competitiveness for companies across all the industrial sectors (Realyvásquez et al. 2016a, c). One important characteristic of macroergonomic factors is that they are interdependent. Thus, changes made in any of them affect the others (Realyvásquez et al. 2016c; Wilson 2014). These changes are made to improve the macroergonomic compatibility of the manufacturing system.

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5.2 Identifying Macroergonomic Factors

To determine the macroergonomic factors to be studied, a comprehensive literature review was conducted among the databases Science Direct, EBSCO, Google Scholar, PubMed/MEDLINE, Taylor & Francis, Wiley Online Library, and SAGE. The review was performed using key words such as work system design, sociotechnical systems, macroergonomics, and organizational elements.

5.2.1 Carayon's Model

Authors (Carayon et al. 2006) developed the Systems Engineering Initiative for Patient Safety (SEIPS) Model. The model integrates five macroergonomic factors that, with some adaptations, can be considered for work system design. Such factors include the Person (or human resources), Organizational conditions, Tasks, Technologies and Tools, and Environment, which are in turn broken down into much simpler aspects called macroergonomic elements. On the other hand, Carayon and Smith (2000) argued that any work system consists of the following five factors: (1) individuals (people), (2) tasks, (3) technology and tools, (4) physical environment, and (5) organization. The authors divided macroergonomic factors into more specific categories. For instance, the Person factor takes into account employee-related elements such as physical and psychological characteristics, skills and knowledge, and motivation and needs. As for the organizational elements, these influence employee motivation, stress, and performance.

As for the Technology factor, Carayon and Smith (2000) point out that technology misuse can cause problems such as motivation loss, stress, and poor performance, whereas the correct use of the technology and tools can bring more favorable results at individual and organizational levels. Another factor to consider when trying to improve the ergonomic compatibility of manufacturing systems is the Tasks factor. According to Carayon and Smith (2000), elements such as high work demands combined with little employee empowerment can produce high levels of stress and musculoskeletal disorders (MSDs). To prevent these problems, the authors suggest avoiding repetitive tasks, both physical and mental, by engaging in a variety of tasks that challenge workers and enable them to use and improve their abilities and skills. Finally, the Environment factor includes physical elements such as noise, lightning, temperature, and workstation layout. These elements must be taken into account in the ergonomic design and evaluation of manufacturing systems, as they influence energy consumption, heat exchange, worker responses to stress, and performance.

5.2.2 Hyer's Model

Hyer et al. (1999) proposed a sociotechnical model for work cell design. The model considered macroergonomic human elements such as employee skills, teamwork, and communication and supervision styles, performance evaluation, and employee rewards. As for the task factor, Hyer et al. (1999) recommended taking into account macroergonomic elements such as task variety, use of skills, and employee involvement in decision-making. For the environmental factor, the authors only mention the cell's layout.

From a similar perspective, Clegg (2000) describes the sociotechnical principles for work system design. These principles reflect a macroergonomic perspective. Although macroergonomic elements are explicitly omitted in these principles, they are implicitly included. One of these principles indicates that evaluation is an essential aspect of work system's design and a prerequisite for learning. From the sociotechnical perspective, work system evaluation must contain social, technical, and operational criteria. However, companies rarely make systematic evaluations to compare their investments with their original goals. Some of the macroergonomic factors addressed by Clegg (2000) include people (human resources), organization, technology and tools, and tasks. For the Person factor, the author considers employee motivation and employee and corporate needs, as well as employee education, knowledge, and psychological characteristics. For the organizational factor, Clegg (2000) highlights elements such as teamwork, organizational culture, management and supervision styles, employee performance evaluation, and rewards.

According to Karwowski (2001), contemporary ergonomics deals with work system design and evaluation problems. To address these problems, the author points out that companies must consider the importance of macroergonomic factors such as human resources, organizational aspects, and the environment. As for human factors, the author claims that it is important to consider employee psychological and physical characteristics, education, knowledge, and skills. In terms of or organizational elements, coordination and communication, the organizational culture, work schedules, supervision and management styles, and performance evaluations should be at the core of manufacturing system design and evaluation. Finally, the Environment factor has to include elements such as lighting, noise, temperature, and workstation layout.

Authors Erensal and Albayrak (2004) propose a hierarchical decomposition of the three macroergonomic factors—the person, organization, and environmental conditions—that, to them, are essential to design and evaluate work systems from an ergonomic approach. The Person factor should include employee education, knowledge, and skills, employee motivation and needs, and employee psychological characteristics. On the other hand, organizational elements range from organizational culture to employee collaboration. Finally, environmental conditions have to be assessed in terms of workstation layout to enhance employee work conditions and comfort.

Sluga et al. (2005) proposed a conceptual framework for manufacturing system design and collaborative operations. The authors claim that current market conditions call for solid teamwork among suppliers, vendors, and customers. Teamwork requires communication and collaboration, and communication in turn demands appropriate technology to keep all the team members well informed. Although some aspects beyond the employee level are considered in this framework, it is well known that the characteristics that a company reflects come from the characteristics of its employees. For this reason, Sluga et al. (2005) considered teamwork, communication, and information technology as key elements.

Kleiner (2006) considers that the macroergonomic evaluation of a work system must include factors such as people, organization, technology, tasks, and environment. This author merges the factors of technology and tasks into an element that he calls the technical subsystem, which represents the way the tasks are performed. Also, Kleiner (2006) offers an overall description of the factors mentioned above, but he concurs with other authors in the five main factors for work system design and evaluation. On the other hand, Holden et al. (2008) provide a set of principles for managing changes at organizational level in manufacturing companies. The authors mention that human elements—such as knowledge, education, skills, and motivation—and organizational elements—such as organizational culture, teamwork, coordination, communication, employee social relationships, and supervision and management styles—are essential components of a work system.

Sittig and Singh (2015) proposed a sociotechnical model for the medical industry to study information technology in complex work systems. The model considers eight dimensions, among which we can find the Person factor, the Organization factor, and Technology factor. The Person factor comprises elements of education, skills, and knowledge, whereas the Organization factor is composed of communication and organizational culture, among others. Finally, the Technology factor focuses on information technology, namely computer technology (hardware and software) and its different devices. From a different perspective, Koyuncu et al. (2011), like Kleiner (2006), omit a detailed decomposition of the five main factors, yet they mention important elements to be considered in work system design and evaluation. Some of these elements include employee education, knowledge, skills, physical characteristics, psychological characteristics, and task variety. Similarly, the authors argue that to increase work system performance, we must emphasize on three factors: people, technology, and environment.

Authors Armutlulu and Noyan (2011) also considered macroergonomic elements in their studies. They proposed a multileveled structural equation model integrated by individual and organizational elements to explore the relationship between employee job satisfaction and organizational commitment. As findings, the authors concluded that job satisfaction is causally antecedent to organizational commitment at individual and branch levels. To develop this model, the authors took into account elements such as supervision styles, teamwork, communication, incentives (payments), and organizational commitment (organizational culture).

Chui et al. (2012) studied the pharmaceutical industry in terms of the barriers preventing pharmacists to offer cognitive pharmaceutical services (CPS). The goal of the research was to identify and describe work pharmacy characteristics that pharmacists changed to provide CPS. According to these authors, a system approach can help to better understand the barriers and facilitators to providing CPS. Chui et al. (2012) relied on the model of Carayon et al. (2006) to evaluate work system factors and elements and study how these factors and elements affect customer service processes. The macroergonomic factors and elements studied by Chui et al. (2012) were consistent with those presented by Carayon et al. (2006), since they used their model.

Our literature review also revealed that Carayon (2012) is consistent with Carayon et al. (2006) regarding most of the macroergonomic elements. However, the former mainly differs in elements such as employee motivation and needs, social relationships, supervision and management styles, and workstation layout.

Marras and Hancock (2014) analyzed human–system interaction. In their analysis, the authors argued that, historically, employee physical and cognitive aspects have usually been studied separately from each other, which is why they proposed to study them together. Similarly, in this analysis, Marras and Hancock (2014) broke down the physical and cognitive features of humans, as well as their interactions and integration. Also, for these authors, human motivation, physical characteristics, and social relationships are key aspects to the analysis of human–system interaction. As for the Tasks factor, Marras and Hancock (2014) believe that companies should consider task variety and must pay attention to how challenging or how demanding these tasks are. As for the Environment factor, the authors argue that lighting conditions, noise, and temperature are important to take into account.

Authors Karsh et al. (2014) introduced the term mesoergonomics and defined it as an open-system approach to ergonomic theory. The mesoergonomic approach studies the relationships between variables in at least two different levels. To define these variables, the authors used the model proposed by Karsh et al. (2006a, b), which takes into account macroergonomic elements of the Person factor, such as employee education, knowledge, skills, motivation, needs, and physical characteristics. As for the Organization factor, the model of Karsh et al. (2006a, b) includes organizational and safety culture, social relationships, performance evaluation, and rewards. Regarding the Tasks factor, the model assesses task content, task challenge, and workload. Finally, for the Environment factor, the model considers almost all of the elements proposed by Carayon et al. (2006), except for workstation layout.

Considering the previous research works and their contributions to work system design and evaluation, we can conclude that the macroergonomic factors most discussed in the literature are (Carayon et al. 2006; Holden et al. 2013; Realyvásquez et al. 2016c): (1) the Person factor, (2) the Organization factor, (3) the Technologies and Tools factor, (4) the Tasks factor, and (5) the physical Environment factor. Such factors can be decomposed into much simpler elements, known as macroergonomic elements.

Table 5.1 shows the results of the literature review and includes the macroergonomic elements and the authors that take them into account for the design and evaluation of work systems, including manufacturing work systems. Similarly, Fig. 5.1 hierarchically presents the five macroergonomic factors and their

Table 5.1 Macroergonomic factors and elements in manufacturing systems

Factor	Reference	Element	Reference	Total
Person	Kleiner (2006)	Education, knowledge, and skills	Carayon (2012), Carayon et al. (2006), Carayon and Smith (2000), Chui et al. (2012), Clegg (2000), Erensal and Albayrak (2004), Holden et al. (2008), Hyer et al. (1999), Karsh et al. (2006a, b, 2014), Karwowski (2006a), Koyuncu et al. (2011), Realyvásquez et al. (2016a, c), Sittig and Singh (2015)	15
		Physical characteristics	Carayon (2012), Carayon et al. (2006), Carayon and Smith (2000), Chui et al. (2012), Karsh et al. (2006a, b, 2014), Karwowski (2006a), Marras and Hancock (2014), Realyvásquez et al. (2016a, c)	10
		Psychological characteristics	Carayon (2012), Carayon et al. (2006), Carayon and Smith (2000), Chui et al. (2012), Clegg (2000), Erensal and Albayrak (2004), Karwowski (2006a), Koyuncu et al. (2011), Realyvásquez et al. (2016a, c)	10
		Motivation and needs	Armutlulu and Noyan (2011), Carayon et al. (2006), Carayon and Smith (2000), Chui et al. (2012), Clegg (2000), Erensal and Albayrak (2004), Holden et al. (2008), Karsh et al. (2006a, b, 2014), Marras and Hancock (2014), Realyvásquez et al. (2016a, c)	12

(continued)

Table 5.1 (continued)

Factor	Reference	Element	Reference	Total
Organization	Kleiner (2006)	Teamwork	Armutlulu and Noyan (2011), Carayon (2012), Carayon et al. (2006), Carayon and Smith (2000), Chui et al. (2012), Holden et al. (2008), Hyer et al. (1999), Realyvásquez et al. (2016a, c), Sluga et al. (2005)	10
		Coordination, collaboration, and communication	Armutlulu and Noyan (2011), Carayon (2012), Carayon et al. (2006), Carayon and Smith (2000), Chui et al. (2012), Clegg (2000), Erensal and Albayrak (2004), Holden et al. (2008), Hyer et al. (1999), Karwowski (2006a), Realyvásquez et al. (2016a, c), Sittig and Singh (2015), Sluga et al. (2005)	14
		Organizational culture and safety culture	Armutlulu and Noyan (2011), Carayon (2012), Carayon et al. (2006), Carayon and Smith (2000), Chui et al. (2012), Clegg (2000), Erensal and Albayrak (2004), Karsh et al. (2006a, b, 2014), Karwowski (2006a), Realyvásquez et al. (2016a, c), Sittig and Singh (2015)	13
		Work schedules	Carayon (2012), Carayon et al. (2006), Carayon and Smith (2000), Chui et al. (2012), Karwowski (2006a), Realyvásquez et al. (2016a, c)	7
		Social relationships	Carayon et al. (2006), Carayon and Smith (2000), Chui et al. (2012), Holden et al. (2008), Karsh et al. (2006a, b, 2014), Marras and Hancock (2014), Realyvásquez et al. (2016a, c)	9

(continued)

Table 5.1 (continued)

Factor	Reference	Element	Reference	Total
		Supervision and management styles	Armutlulu and Noyan (2011), Carayon et al. (2006), Carayon and Smith (2000), Chui et al. (2012), Clegg (2000), Holden et al. (2008), Hyer et al. (1999), Karwowski (2006a), Realyvásquez et al. (2016a, c)	10
		Performance evaluation, rewards, and incentives	Armutlulu and Noyan (2011), Carayon (2012), Carayon et al. (2006), Carayon and Smith (2000), Chui et al. (2012), Clegg (2000), Hyer et al. (1999), Karsh et al. (2006a, b, 2014), Karwowski (2006a), Realyvásquez et al. (2016a, c)	12
Technologies and Tools	Carayon and Smith (2000), Clegg (2000), Holden et al. (2008), Kleiner (2006)	Information technology	Carayon (2012), Carayon et al. (2006), Chui et al. (2012), Realyvásquez et al. (2016a, c), Sittig and Singh (2015), Sluga et al. (2005)	7
		Advanced manufacturing technology	Carayon et al. (2006), Realyvásquez et al. (2016a, c)	3
		Human resources characteristics in technology and tools	Carayon (2012), Carayon et al. (2006), Chui et al. (2012), Realyvásquez et al. (2016a, c)	5
Tasks	Clegg (2000), Kleiner (2006)	Task variety	Carayon (2012), Carayon et al. (2006), Carayon and Smith (2000), Chui et al. (2012), Hyer et al. (1999), Koyuncu et al. (2011), Marras and Hancock (2014), Realyvásquez et al. (2016a, c)	9

(continued)

Table 5.1 (continued)

Factor	Reference	Element	Reference	Total
		Job content, challenges, and use of skills	Carayon (2012), Carayon et al. (2006), Carayon and Smith (2000), Chui et al. (2012), Holden et al. (2008), Hyer et al. (1999), Karsh et al. (2006a, b, 2014), Marras and Hancock (2014), Realyvásquez et al. (2016a, c)	11
		Autonomy, job control, and participation	Carayon (2012), Carayon et al. (2006), Chui et al. (2012), Hyer et al. (1999), Realyvásquez et al. (2016a, c)	6
		Work demands (workload, attention required, etc.)	Carayon (2012), Carayon et al. (2006), Carayon and Smith (2000), Chui et al. (2012), Karsh et al. (2006a, b, 2014), Marras and Hancock (2014), Realyvásquez et al. (2016a, c)	9
Environment	Holden et al. (2008), Kleiner (2006), Koyuncu et al. (2011)	Distribution	Carayon (2012), Carayon et al. (2006), Carayon and Smith (2000), Chui et al. (2012), Hyer et al. (1999), Karsh et al. (2006a, b, 2014), Karwowski (2006a), Realyvásquez et al. (2016a, c)	10
		Noise	Carayon (2012), Carayon et al. (2006), Carayon and Smith (2000), Chui et al. (2012), Karsh et al. (2006a, b, 2014), Karwowski (2006a), Realyvásquez et al. (2016a, c)	9
		Lighting	Carayon (2012), Carayon et al. (2006), Carayon and Smith (2000), Chui et al.	9

(continued)

Table 5.1 (continued)

Factor	Reference	Element	Reference	Total
			(2012), Karsh et al. (2006a, b, 2014), Karwowski (2006a), Realyvásquez et al. (2016a, c)	
		Temperature, humidity, and air quality	Carayon (2012), Carayon et al. (2006), Carayon and Smith (2000), Chui et al. (2012), Karsh et al. (2006a, b, 2014), Karwowski (2006a), Realyvásquez et al. (2016a, c)	9
		Workstation layout	Carayon et al. (2006), Chui et al. (2012), Erensal and Albayrak (2004), Karwowski (2006a), Realyvásquez et al. (2016a, c)	9

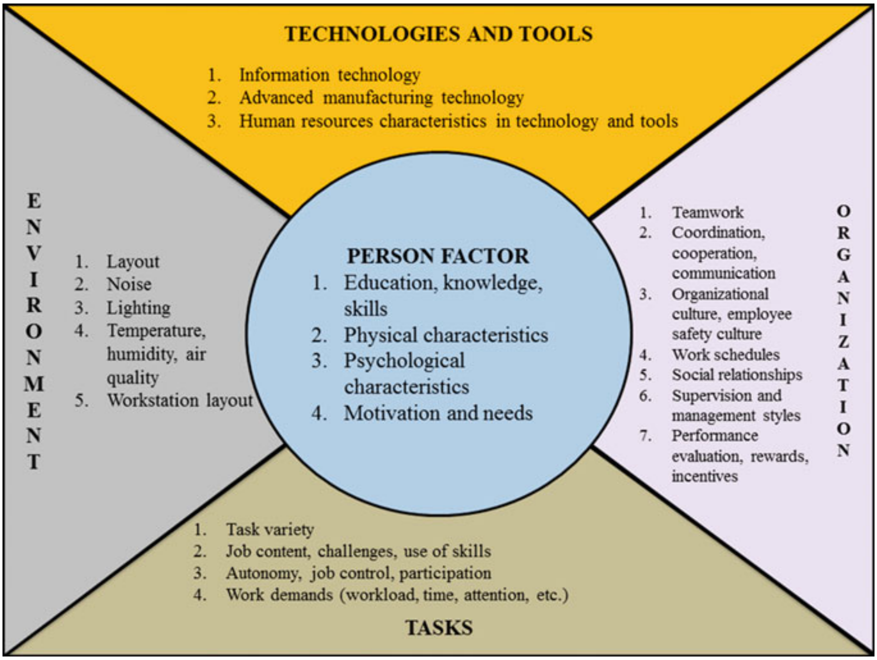

Fig. 5.1 Macroergonomic factors and elements

macroergonomic elements (Realyvásquez et al. 2016c). At first level, the figure shows the macroergonomic factors in bolded letters, whereas the macroergonomic elements are found at second level, written in cursive letters. In total, we address and will continue addressing throughout the book 23 macroergonomic elements, each of them linked to one of the five macroergonomic factors. Also notice that the Organization factor includes more elements than any other factor, whereas Technologies and Tools only include three.

From the data introduced in Table 5.1, we obtained the frequency percentage of every macroergonomic factor and element. Figure 5.2 shows that for the Person factor we collected 47 bibliographical resources that mention at least one macroergonomic element each. Of these 47 references, 31.91%, that is, 15 research works, address education, knowledge, and skills, which seem to be the most commonly explored element. On the other hand, physical characteristics and psychological characteristics were addressed by only 10 works each, or 21.28%.

As for the Organization factor, we collected 75 bibliographical resources, 14 of which discuss coordination, collaboration, and communication and represent 18.67% of the total references. Also, organizational culture and safety culture was covered by 13 (17.33%) research works and performance evaluation, rewards, and incentives by 12 (16%) works. Both teamwork and supervision and management styles are discussed in 10 works each (13.33%), social relationships by nine works (12%), and work schedules by only seven (9.33%) bibliographical resources (Fig. 5.3).

As shown in Fig. 5.4, we collected 15 bibliographical resources for the Technologies and Tools factor, seven of which address information technology (46.67%), five discuss human factor characteristics in tools and technologies (33.33%), and only three explore advanced manufacturing technology (20%). As

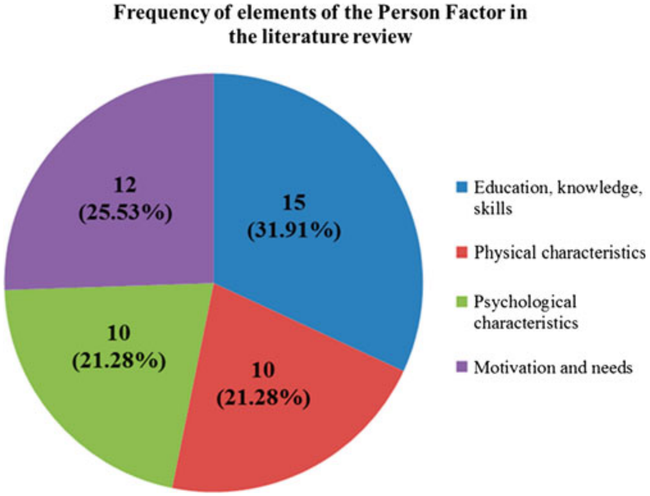

Fig. 5.2 Frequency of elements of the Person factor

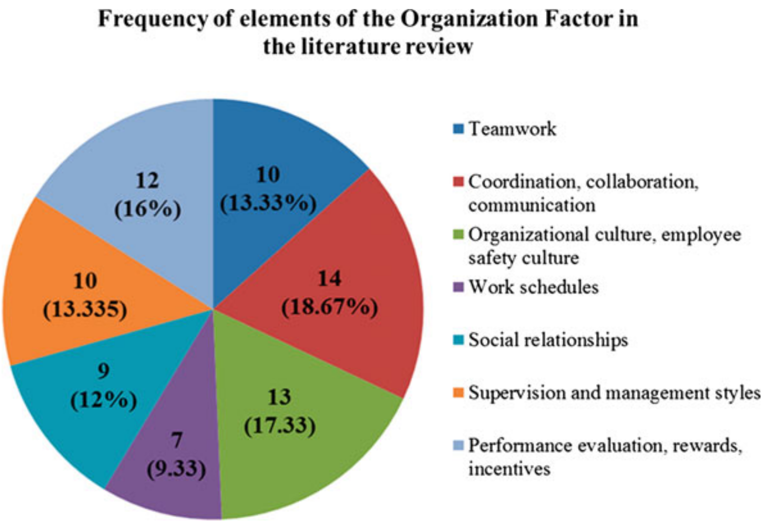

Fig. 5.3 Frequency of elements of the Organization factor

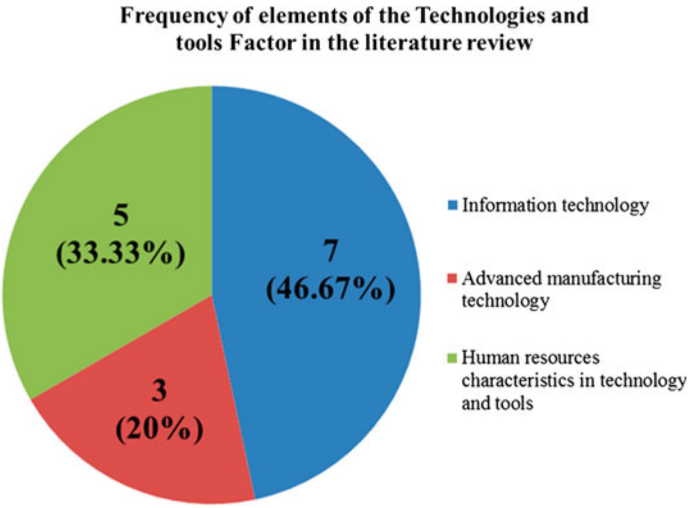

Fig. 5.4 Frequency of elements of Technologies and Tools factor

can be observed, it seems that information technology is the most common macroergonomic factor in the literature.

We collected 35 bibliographical resources for the Tasks factor, 11 of which explore work content, challenges, and use of skills. Respect task variety and work demands (workloads, attention required, etc.), both of them were mentioned in 9

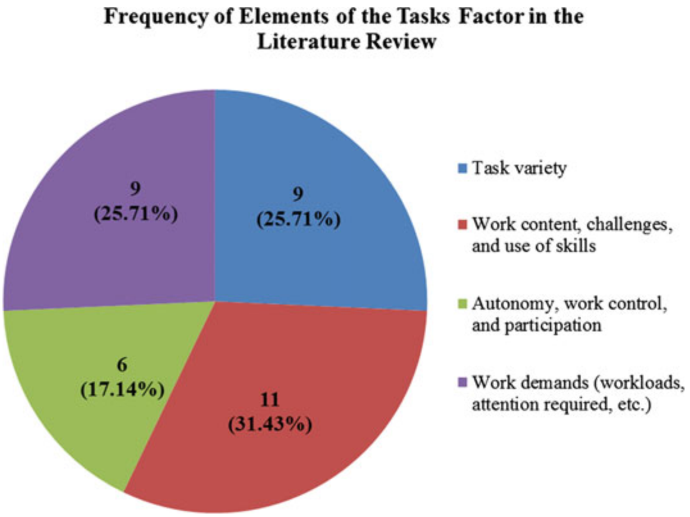

Fig. 5.5 Frequency of elements of Tasks factor

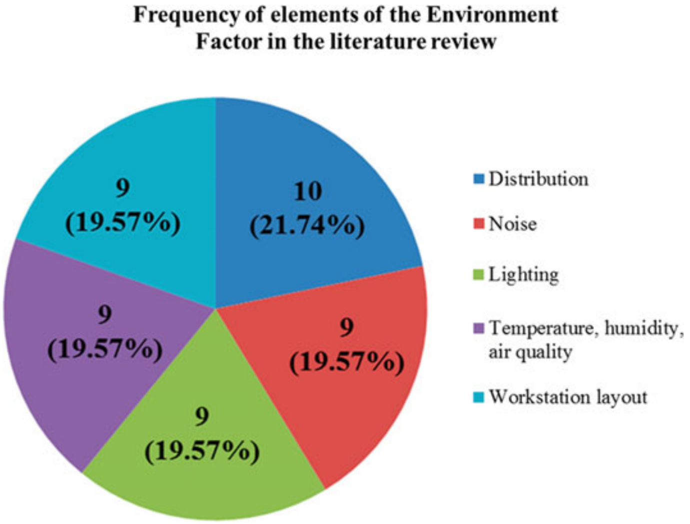

Fig. 5.6 Frequency of elements of the Environment factor

bibliographical resources, whereas only six address employee autonomy, work control, and participation. Figure 5.5 depicts the distribution of works exploring the Tasks factor through its macroergonomic elements.

Finally, for the Environment factor, we obtained 46 bibliographical resources that explore at least one macroergonomic element each. Distribution is explored by

10 research works (21.74%), whereas the remaining elements appear in nine works each (19.57%). Figure 5.6 shows the distribution of works exploring the Environment factor through its macroergonomic elements.

5.3 Conclusions

From this chapter, we can conclude that, although macroergonomics is an emerging discipline, more and more authors are conducting studies on macroergonomic elements and factors that can impact on work systems, including manufacturing systems.

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Chapter 6
Macroergonomic Effects on Manufacturing Systems

Abstract The macroergonomic factors and elements can have different effects on workers and manufacturing systems. As for workers, these effects may include aspects such as health and safety, job satisfaction, creativity, and individual performance. The effects on manufacturing systems, on the other hand, range from solving problems and reducing staff absenteeism to increasing customer satisfaction and loyalty, thereby improving productivity and competitiveness. In this chapter, we discuss the impact of macroergonomics on workers or employees and manufacturing work systems.

6.1 Effects of Macroergonomic Factors

Research has demonstrated that high macroergonomic compatibility has positive effects on manufacturing systems (Realyvásquez et al. 2015, 2016a, c; Robertson et al. 2015). For instance, Azadeh et al. (2005) argue that macroergonomic factors must be considered at the design phase of the system's developmental cycle to reduce system failures and organizational errors and significantly increase human performance. In another study, Habibi et al. (2012) investigated the relationship between macroergonomics and job satisfaction. The study was conducted among 84 employees across different automotive companies. The data were collected through two questionnaires: (1) the Minnesota Job Satisfaction Questionnaire and (2) the Macroergonomics Condition Questionnaire, which included questions about the person factor and the Organization factor, among others. The authors proposed a 0-to-100 macroergonomic score methodology using data aggregation techniques. In the end, the authors demonstrated that the higher the score, the better the work conditions and job satisfaction.

As regards macroergonomic implementations in product development, different authors mention that the principles of macroergonomics support the product development process and thus help respond better to new market exigencies (Putkonen et al. 2010; Barón-Maldonado and Rivera-Cadavid 2014). In this context, Palacios and Imada (1998) employed some macroergonomic concepts in office

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furniture design, for which they considered a set of organizational and technological trends affecting product quality and customer satisfaction (Barón-Maldonado and Rivera-Cadavid 2014).

As for the relationship between macroergonomics and lean manufacturing, authors Cornelli and de Macedo-Guimarães (2012) performed a macroergonomic intervention in a small manufacturing company in Brazil. For this intervention, the authors used the waste classification from lean manufacturing. Then, by implementing participatory ergonomics, the authors obtained a reduction of 31.5% in waste and an increase in employee commitment. From a different perspective, Azadeh et al. (2007) presented a holistic model to analyze and design efficiently integrated man–machine systems. The goals of the model were to improve working conditions, reduce employee absenteeism due to injuries, and use appropriate working methods. The model was implemented in a case study in a thermal power station and detected deficiencies at microergonomic and macroergonomic level. Also, the model improved system productivity and reliability.

6.2 The Effects of the Person Factor on Manufacturing System Performance

6.2.1 *Education, Skills, and Knowledge*

The literature reports a wide range of macroergonomic benefits for human resources. For instance, Becerra-Rodríguez and Álvarez-Giraldo (2011) conducted a study among 246 companies from the Caldas clothing cluster in Colombia and found a relationship between the person factor and business innovation. The main element of the Person factor that was considered was employee *Education, Knowledge, and Skills*. Similarly, Østergaard et al. (2011) found that the same macroergonomic element increases the likelihood of introducing innovation in a company. In fact, along with Quintana-García and Benavides-Velasco (2008), Østergaard et al. (2011) argue that employee *Education, Knowledge, and Skills* contribute to corporate competitiveness, as they promote the generation ideas and better problem solutions. Finally, Pellegrino and Hilton (2012) point out that current technological advances, globalization, and other changes call for new employee *Education, Knowledge, and Skills*, and when companies invest in such attributes, the economic gains are as important as, or even greater than, when investing in physical capital.

6.2.2 *Physical Characteristics*

In their research, Azadeh et al. (2006) implemented a macroergonomic approach in an advanced thermal power station. The implemented approach considered elements such as employee *Physical Characteristics* and demonstrated that this element increases system productivity and reliability. Likewise, Robertson et al. (2008) performed a macroergonomic intervention of flexible workspace design by considering employee *Physical Characteristics*, among other variables. The goal of the intervention was to explore the effects of macroergonomics on the psychosocial working environment, employee musculoskeletal health, and work efficiency in an office. A different number (n) of office workers was assigned to each of the following conditions:

1. flexible workspace ($n = 121$),
2. ergonomic training ($n = 92$),
3. flexible workspace + ergonomic training ($n = 31$), and
4. non-intervention control ($n = 45$).

The outcome measures were collected two months before the intervention and three and six months after the intervention. The results indicated that the macroergonomic compatibility of employee *Physical Characteristics* has positive and significant effects on the outcome variables (work-related musculoskeletal discomfort, job control, environmental satisfaction, sense of community, ergonomic climate, communication and collaboration, and business process efficiency). As a conclusion, the authors argued that macroergonomic interventions are effective among office workers.

6.2.3 Psychological Characteristics

Employee *Psychological Characteristics* is another element of the Person factor that affects worker and company performance. For instance, May et al. (2004) found a connection between employee *Psychological Characteristics* and *Motivation and Needs*. The authors found out that *Psychological Characteristics* increase employee motivation in terms of work engagement, thus resulting in better task adaptation and greater work enrichment. On the other hand, Etgar (2008) proposed a descriptive model and argued that customer *Psychological Characteristics* could improve manufacturing processes in terms of customer complaints, defects, inventory levels, and productivity (Ismail 2007; Chen et al. 2012), thus enhancing organizational performance. Also, Phillips and Bourne (2008) found a significant relationship between employee personal values (*Psychological Characteristics*) and customer outcomes in the treatment of substance abuse.

6.2.4 Motivation and Needs

Research conducted in the manufacturing industry seems to hardly explore the effects of employee *Motivation and Needs*. However, studies conducted in other areas have shown that this element has a positive impact on customers. As an example, Winefield and Barlow (1995) found a positive relationship between employee *Motivation and Needs* and customers at a child protection agency, whereas Azadeh et al. (2006) included this element within their macroergonomic approach implemented in the advanced thermal power station, demonstrating that employee *Motivation and Needs* and *Physical Characteristics* increased system productivity and reliability. Likewise, Hitka and Balážová (2015) point out that when employee *Motivation and Needs* are part of manufacturing process improvement strategies, organizational performance increases.

6.3 The Effects of the Organization Factor on Manufacturing System Performance

This section explores organizational elements throughout five categories: (1) teamwork; (2) organizational culture and safety culture; (3) coordination, collaboration, and communication; (4) work schedules; and (5) social relationships, supervision and management styles, performance evaluation, rewards, and incentives.

6.3.1 Teamwork

Teamwork is a key organizational element when it comes to improving work system performance. Azadeh et al. (2007) argue that a well-defined macroergonomic program for business productivity improvement involves *Teamwork* among operators, supervisors, and managers at all levels. Similarly, Combs et al. (2006) mention that *Teamwork* allows for effective information sharing and resource exchange, which in turn improves work efficiency and supports problem-solving. Also, Sadikoglu and Zehir (2010) point out at the importance of *Teamwork* in manufacturing systems and highlight its benefits at corporate level. More specifically, the authors claim that people in research, design, sales, and production areas must work interdependently as a team through traditional organizational functions, instead of working independently within their functions. To these authors, *Teamwork* can forecast production problems and improve service quality. Also, it is a fundamental requirement in production areas, as it prevents wasting of time.

Another advantage of *Teamwork* according to Sadikoglu and Zehir (2010) is that it contributes to successful organizational innovations, the generation of new ideas, and risk taking. Also, the authors mention that *Teamwork* makes employees feel valued, respected, and important, thereby increasing job satisfaction. Likewise, successful *Teamwork* practices increase employee professional knowledge and work consistency, thus enhancing organizational performance in terms of cost reduction and quality. Finally, Sadikoglu and Zehir (2010) also claim that *Teamwork* helps identify current and changing customer needs and expectations, compare competitors, and introduce new products or services to improve performance.

Although there is evidence that *Teamwork* has positive effects on manufacturing processes, customer satisfaction, and organizational performance in manufacturing systems (Realyvásquez et al. 2015), the literature also shows that *Teamwork* generates positive results in sectors other than manufacturing. For instance, Manzoor et al. (2011) analyzed the effects of Teamwork on employee performance among staff members of a higher education institution in Pakistan. This study used regression and correlation techniques to analyze the relationship between *Teamwork* and employee performance, finding that *Teamwork* positively impacts worker performance. In the end, the authors recommend implementing *Teamwork* activities to improve employee performance. Another case study in the service sector was conducted by Srivastava et al. (2006), who surveyed management teams in 102 hotel properties in the USA to analyze the relationship between leadership and *Teamwork* performance. The results indicated that empowerment is positively related to *Teamwork* efficacy, which in turn is positively related to employee performance. As observed, *Teamwork* is an essential element for improving organizational performance and competitiveness in any industrial sector.

6.3.2 Organizational Culture and Safety Culture

Organizational culture is a particular research topic that has not lost its impact on different variables. Aktaş et al. (2011) studied the relationship between organizational culture and organizational efficiency. The authors included leader values in terms of self-direction, stimulation, and power, and they found that organizational culture is related to organizational efficiency dimensions such as adaptability preparation, setting plans and goals, and human resources development, among others. Also, other studies have shown that organizational culture has a direct effect on corporate innovation in the services and manufacturing sectors. For example, Wang and Rafiq (2014) conducted a study in high-tech companies in the UK and China and analyzed the effects of organizational culture on product innovation outcomes. The results suggest a significant relationship between organizational culture and product innovation outcomes in both the UK and China. Similarly, Hogan and Coote (2014) conducted a study on service firms and used the Schein model to demonstrate that organizational culture has effects on innovation and business performance.

Authors Duygulu and Özeren (2009) conducted a study in construction, chemical industry, aviation, pharmaceutical, and steel and iron companies to determine the effects of organizational culture on company innovativeness. The result was that in all companies, organizational culture played an important role in innovation. In another similar study, Zehir et al. (2011) determined the relationship between organizational culture, leadership, and business performance. The study was conducted in companies in the manufacturing, finance, and telecommunications sectors in Turkey. To collect data, the authors surveyed 295 employees, and the statistical analyses demonstrated the effects of culture and leadership over business performance. Finally, Realyvásquez et al. (2015) demonstrated through a structural equation model that the macroergonomic compatibility of *Organizational Culture and Safety Culture* has positive direct effects on customer satisfaction and loyalty, manufacturing processes, and organizational performance.

As for safety culture, the other component of the *Organizational Culture and Safety Culture*, the literature basically mentions that it minimizes the frequency and severity of occupational accidents, injuries, and illnesses (O'Toole 2002a). As an example, Zohar (2014) mentions that safety culture significantly decreases the number of injuries. Also, companies increase the likelihood of compliance with safety rules and procedures (Neal et al. 2000). In another study using safety concepts, Azadeh et al. (2005) evaluated the effects of total system design (TSD) factors on human performance in an electric power plant. For this study, the authors administered a questionnaire to collect data and examined the relationship between TSD factors and human performance through a nonparametric correlation analysis (Kramer's Phi) and the Krustal–Wallis test of means. The results indicated that TSD factors, including safety processes, influence human performance. In conclusion, all these works prove that *Organizational Culture and Safety Culture* have significant and positive effects on work systems, including manufacturing work systems, and should therefore be considered at the design phase of such systems.

6.3.3 Coordination, Collaboration, and Communication Effects

Employee *Coordination, Collaboration, and Communication* are essential for a timely and efficient execution of each of the activities of a project. To prove this, Fussell et al. (2000) investigated collaborative performance on a manual task performed by workers and helpers, who were located either side by side or connected through video or audio links. The results showed that the workers completed the task more quickly and accurately when the helpers were located in the same place than when they were connected through an audio link. This implies that proximity between workers and helpers facilitates coordination, collaboration, and communication between them, thus improving performance. Similarly, Padilla-Soria (2013) mentions that when workers who already have a desirable profile help other workers, such inexperienced employees can successfully achieve the desired profile. Also, Borca and Baesu (2014) provided an overview of organizational communication by analyzing its many definitions and concluded that effective organizational communication has a positive effect on company performance, competitiveness, and image.

Organizational communication has been the focus of attention because of its important impact on other aspects. Author le Roux (2014) found that effective communication skills improve organizational performance, whereas Mitrofan and Bulborea (2013) conducted a study in a banking organization to highlight the influence that communication exerts on structuring interpersonal relationships. The authors concluded that efficient workplace communication was important for corporate success and that close interpersonal communication and relationships between subordinates and managers could improve long-term organizational performance.

It has also been argued that organizational communication fosters horizontal, upward, or downward communication among employees (Nordin et al. 2014). For example, in companies with defensive climates, employees have the tendency to abstain from communicating their needs and may suffer from low motivation levels. Similarly, Jaradat and Sy (2012) stated that companies or agencies have to interact and operate with other people through communication, and such communication affects all the aspects of the business. As can be seen, communication plays a critical role in decision-making and companies need it for success. In fact, companies with excellent communication motivate their employees to work cooperatively and more efficiently (Luthans 2005).

Recently, authors Realyvásquez et al. (2015) proved that the macroergonomic compatibility of organizational communication has positive effects on customer satisfaction, manufacturing process reliability, and organizational performance. Regarding organizational communication, the authors evaluated the level of employee *Coordination, Collaboration, and Communication* at all hierarchical levels. On the other hand, Jacobs et al. (2016) argue that employee *Coordination, Collaboration, and Communication* are fundamental in corporate success and a key factor to employee satisfaction. However, today, companies are forced to maintain appropriate *Coordination, Collaboration, and Communication* not only internally, but also externally with suppliers and customers. In this context, Mohr et al. (1996) mention that *Coordination, Collaboration, and Communication* create an atmosphere of mutual support among workers, thereby creating volitional compliance among partners. These authors developed a model to examine the effects of *Coordination, Collaboration, and Communication* between a supplier and a manufacturing company. As a result, they found that *Coordination, Collaboration, and* collaborative *Communication* help improve supplier satisfaction. As can be observed, good *Coordination, Collaboration, and Communication* bring benefits not only to workers, but also to manufacturers and suppliers alike.

In their study, Hernández-Castorena et al. (2015) analyzed whether *Coordination, Collaboration, and Communication* between small- and medium-sized enterprises (SMEs) in manufacturing and suppliers had a significant effect on such manufacturers. To conduct this research, the authors developed an evaluation tool administered to the SMEs managers and owners. The study indicated that it is important to establish a close relationship with suppliers, because the nature of supplies requires integrated strategies to ensure timely deliveries. Therefore, it is important to maintain close *Coordination, Collaboration, and Communication* to improve the performance of manufacturing companies.

Nowadays, manufacturing companies face uncertain environments that demand great efforts toward achieving full *Coordination, Collaboration, and Communication* in the supply chain to take advantage of the resources and knowledge of suppliers and customers. Cao and Zhang (2011) conducted a study to discover the nature of *Coordination, Collaboration, and Communication* in the supply chain and to explore its impact on company performance. To carry out this research, the authors developed some reliable and valid instruments, and the data were collected through a Web survey in US manufacturing firms, while the statistical methods used included confirmatory factor analysis and structural equation modeling. Then, Cao and Zhang (2011) found that supply chain *Coordination, Collaboration, and Communication* are a collaborative advantage, improve process efficiency, and offer flexibility, quality, and innovation. Based on such findings, we conclude that *Coordination, Collaboration, and Communication* are necessary elements to maintain a good performance at individual, team, and organizational level.

6.3.4 Work Schedules

The literature demonstrates that *Work Schedules* influence a company in many aspects, such as worker lifestyle, job satisfaction, absenteeism, and the productivity–performance relationship, among others. This suggests that coping with the challenges of work schedules can help improve these corporate aspects (Bushnell et al. 2010). In their work, Baltes et al. (1999) performed a meta-analysis to estimate the effects of flexible schedules and compressed schedules on several work-related criteria, such as productivity/performance, job satisfaction, absenteeism, and employee satisfaction regarding work schedules. The researchers mention that the effects of both types of schedules were overall positive, but the effects were different across the outcome criteria. For example, compressed schedules did not significantly affect absenteeism.

In another study, Bushnell et al. (2010) analyzed the effects of *Work Schedules* in a large manufacturing company. To collect data, the authors administered the Health Risk Assessment (HRA) questionnaire to 26,442 workers and studied factors of smoking, lack of exercise, moderate-to-high alcohol consumption, obesity (BMI $\geq$ 30), and short sleep duration across three types of work schedules (day, night, or rotating shift) and daily work hours (8, 10, or 12). The results indicated that long shifts and rotating night shifts were generally associated with less sleep and more smoking. In addition, night shifts were generally associated with higher BMI, while long shifts and rotating shifts were associated with a lower level of physical exercise. In other words, the long *Work Schedules* and rotating schedules had the most consistent pattern of unhealthy lifestyles.

Authors Vegso et al. (2007) explored whether the risk of suffering from occupational injuries in manufacturing companies was related to the number of hours that employees worked the previous week. The authors utilized a case-crossover design to contrast the hours worked prior to an injury shift with those worked prior to a non-injury shift for hourly workers. The results indicated that hours prior to injury significantly exceeded hours during the control week. That is, workers who worked more than 64 h in the week before the shift had an 88% excess risk if compared to those who worked 40 h or fewer. From a similar perspective, Dembe et al. (2005) analyzed the effects of overtime on the risk of occupational injuries and illnesses among working adults from the USA. The study included responses from 10,793 American workers who participated in the National Longitudinal Survey of Youth (NLSY). The responses were used to evaluate workers' job histories, work schedules, and the occurrence of occupational injuries and illnesses between 1987 and 2000. A total of 110,236 job records were analyzed, comprising a total of 89,729 person-years of accumulated working time. As a result, the authors found that working in jobs with overtime *Work Schedules* was associated with an occupational injury risk rate of up to 61% over non-overtime jobs. It was also found that working at least 12 h per day was associated with a 37% increased hazard rate, whereas working at least 60 h per week was associated with a 23% increased hazard rate. Such findings confirm that the macroergonomic compatibility of *Work schedules* is a key to employee health and safety, and thus organizational performance.

6.3.5 Social Relationships, Supervision and Management Styles, and Performance Evaluation, Rewards, and Incentives Effects

The organizational literature points out that social capital is a valuable asset derived from access to resources available through *Social relationships* (Krause et al. 2007). The impact of social capital over performance has been widely studied. As an example, Moran (2005) examined the impact of managerial *Social relationships* on managerial performance and found that social relationships had an effect on innovation-oriented tasks. On the other hand, Krause et al. (2007) argued that co-specialization may be the result of investments in skills and routines adapted to the exchange and development of *Social relationships.* Likewise, other authors mention that *Social relationships* increase expectations of collaboration and stimulate learning cycles over time (Krause et al. 2007). In addition, there is evidence that the quality of *Social relationships* has different effects on workers, such as health, creativity, and well-being. In this sense, Kiecolt-Glaser et al. (2010) found that conflictive *Social relationships* (i.e., those lacking macroergonomic compatibility) can have effects on the proinflammatory secretion of cytokines, which in turn can cause depression, stress, and other behaviors detrimental to health.

Authors Liao et al. (2010) proposed a cross-level contingent process model to explain how and when the quality of *Social relationships* between workers and supervisors or co-workers affected individual creativity in work teams. Using longitudinal, multisource data from 828 employees on 116 teams, the authors found that social relationships with supervisors and co-workers had unique indirect effects on worker creativity via self-efficacy. Similarly, Chen et al. (2016) conducted an empirical study in manufacturing and service companies and investigated the effects of the quality of employee *Social relationships* on employee welfare. The study was conducted among 571 workers, and the authors performed Pearson's correlation analysis and multiple linear regressions. The results indicated that the quality of employee *Social relationships* has positive effects on employee welfare.

Supervision and management styles are another key element to employee motivation, creativity, and performance. Several studies have demonstrated that some current *Supervision and management* practices include abusive behaviors on the part of senior managers. In this sense, Liu et al. (2012) examined how and when abusive supervision could influence worker creativity and showed that team leader abusive supervision mediates the negative relationship between department leader abusive supervision and workers, thus undermining employee creativity. Also, according to Courtright et al. (2016), one of the reasons why supervisors exhibit abusive behavior toward subordinates is personal family–work conflicts.

Other studies suggest that macroergonomically compatible *Supervision and management styles* have positive effects on workers. As an example, Zhang and Bartol (2010) built and tested a theoretical model linking leadership to creativity through several intervening variables. The study was conducted among professional employees and their supervisors in a Chinese company, and the results indicated that empowering leadership positively affected psychological empowerment, which in turn influenced both intrinsic motivation and creative process engagement. On the other hand, Ertürk (2012) conducted a study wherein he studied the relationship between supervisor trust and employee innovation capabilities. The study was carried out in manufacturing systems in Turkey with data from 518 operators. The data analysis showed that supervisor trust was strongly and positively related to employee innovative capabilities.

From a different perspective, Zehir et al. (2011) analyzed the relationship between leadership styles (*Supervision and management styles*), culture, and organizational performance. The authors surveyed 295 workers in companies across three different sectors—manufacturing, finance, and telecommunications—in Turkey and found that *Supervision and management styles* have positive effects on organizational performance. Also, Wang et al. (2010) examined the relationship between *Supervision and management styles* and organizational performance, among other variables. To conduct this study, the researchers reviewed 246 valid questionnaires sent to the corporate owners, executors, and operators of Kaohsiung's Nanzi Export Processing Zone in south Taiwan. The study revealed that charismatic, transformational, and visionary *Supervision and management styles* were positively related to organizational performance. Once again, the literature demonstrates that when a macroergonomic element is implemented to achieve high compatibility, the results can be beneficial to both employees and corporations.

The last organizational element is *Performance evaluation, rewards and incentives*. Several studies have been conducted to explore the effects of this macroergonomic element within manufacturing systems. For instance, Garbers and Konradt (2014) analyzed 146 studies comprising 31,861 workers in total to examine the effects of individual- and team-based financial incentives on worker performance. As main findings, the authors found that individual incentives had had a positive impact on worker performance in 116 studies, whereas 30 studies had found a positive effect of team-based rewards on performance, with equitably distributed rewards resulting in higher performance than equally distributed rewards. Also, Danish and Usman (2010) analyzed the relationship between rewards, motivation, and recognition among employees of diverse type of organizations to gain wide representation of sectorial composition. The analysis included data obtained from 220 questionnaires, and the results indicated that reward and recognition have a great impact on employee motivation. In conclusion, *Social relationships, Supervision and management styles,* as well as *Performance evaluation, rewards, and incentives,* have positive effects on workers and businesses, provided they are approached from an ergonomic perspective.

6.4 The Effects of the Technologies and Tools Factor on Manufacturing System Performance

This factor is discussed in the following sections throughout two elements: *Information Technology* and *Advanced Manufacturing Technology.*

6.4.1 Information Technology Effects

The development of *Information technology* today, especially in the World Wide Web (WWW) and its applications, such as social and media networks, has allowed people to live in a society with enough information to support the generation of new ideas (Ni et al. 2014). Likewise, *Information technology* has influenced other areas, such as education, health care, manufacturing, transportation, trade, pure services, and even warfare (Gunasekaran et al. 2006). A clear example of this is the use of an iPad for auditing and improving occupational safety in the construction industry (Lin et al. 2014)

In manufacturing work systems, *Information technology* impacts economic growth and technological and social changes, which is why managing the direct impacts of some variables on other variables is more complex than producing goods (Williams 2011). Several authors have studied the impact of *Information technology* on production and administrative processes across industrial sectors. For example, Stiroh (2002) found that *Information technology* could be associated with the accelerated growth of average labor productivity, while Chou et al. (2014) concluded that countries with high *Information technology* capital and/or complementarity innovation had high total factor productivity. Similarly, Yao et al. (2010) and Aliu and Halili (2013) concluded that *Information technology* improves production processes in manufacturing systems. Consequently, such improvements bring better organizational performance Oyedele and Tham (2007) and greater customer satisfaction, as customer needs are better met (Etgar 2008).

In her dissertation, Calderón (2013) points out that many manufacturing companies have reached success after implementing appropriate *Information technology* to search and consolidate new markets and attain competitive advantages. Other authors who have also verified the competitiveness that *Information technology* offers are Márquez-Cañizares et al. (2012). These authors analyzed the impact of *Information technology* on the competitiveness of manufacturing companies when used in industrial design. To achieve this, Márquez-Cañizares et al. (2012) conducted a qualitative investigation in six companies in different countries. The results indicated that nowadays *Information technology* is a key element to manufacturing system competitiveness.

Some other experts have found that *Information technology* has an impact on customers. For example, *Information Technology* has been used to enhance care interventions for health improvements (Bauer et al. 2014), thus increasing patient satisfaction. Likewise, it was found that *Information technology* can be used to manage strategic relationships between the buyer (client) and the supplier to improve the consistency and performance of such relationships (Morita and Nakahara 2004; Makkonen 2014). In addition, according to Levina and Ross (2003), the use of *Information technology* in customer–supplier relationships helps define priorities, anticipate resource needs, and communicate problems and changes in projects. As a result, companies are able to deliver better services and meet customer needs more easily.

Authors such as dos Reis et al. (2014) mention that *Information technology* in production processes allows companies to increase competitiveness and operational and economic performance. Similarly, while Dale (2001) and Stiroh (2002) point out that *Information technology* is a key to economic growth, other studies confirm that this technology acts as a facilitator in the organizational learning process. In addition, *Information technology* influences the development of distinctive technology competencies that in turn increase company performance (Robey et al. 2000; Real et al. 2006; Ruiz-Mercader et al. 2006). Meanwhile, Shao and Lin (2001, 2002) claim that *Information technology* has a positive impact on technical efficiency and therefore contributes to organizational performance.

Finally, there are also authors who refer to *Information technology* as the main facilitator of process innovation (Davenport 2013), while others mention that nowadays, with the increasing use of *Information technology*, its design and placement are critical for comfort, health, safety, and productivity, as well as for providing greater accuracy in task execution (Hedge et al. 2011). In addition, it has been shown that when *Information technology* contains an ergonomic design, the risk of musculoskeletal disorders can be reduced (Hedge et al. 2011).

6.4.2 Advanced Manufacturing Technology

Advanced manufacturing technology includes computer-based technologies such as CNC machinery, automated guided vehicle systems, and computer-aided design. Dean and Snell (1991) point out that the most important feature of *Advanced manufacturing technology* is its potential to integrate the different stages of a manufacturing process, which consequently allows companies to produce large volumes of standardized products and small lots with high quality (Gyan-Baffour 1994). Also, *Advanced manufacturing technology* comprises a set of computer-based or numerical control technologies that have a significant impact on product, process, and system informational aspects (Small and Chen 1995; Ordoobadi and Mulvaney 2001; Percival and Cozzarin 2010) and thus contribute to a strong competitive advantage (Matta and Semeraro 2005; Percival and Cozzarin 2010).

According to Saraph and Sebastian (1992) and Bayo-Moriones and Merino-Díaz de Cerio (2004), this technology has brought significant changes in manufacturing in terms of competitive strategies. Competitiveness in technology is a combination of flexibility, efficiency, and quality that significantly minimizes costs and optimizes quality. Also, industries that seek to remain competitive in a global market use and invest in *Advanced manufacturing technology*. However, considering ergonomic and safety factors is essential when implementing technology adequate to human beings. Likewise, the literature has shown that when *Advanced manufacturing technology* contains a design that considers ergonomic attributes, different benefits can arise, not only for workers but also for companies. For instance, Siemieniuch and Sinclair (1995) argue that the usability of advanced manufacturing technology allows the user to control the pace and sequence of human–machine interaction. Also, the authors state that improving usability leads to an effective, efficient, safe, comfortable, and flexible use of equipment, which in turn helps prevent errors, control tasks, decrease employee training, improve productivity, and reduce information loads. Also, authors O'Neill and Evans (2000) and Maldonado et al. (2013) claim that the adjustability of *Advanced manufacturing technology* has important effects on workers and the production process, as it improves task control, increases motivation and performance, and minimizes stress.

As for the benefits of *Advanced manufacturing technology*, Kotha and Swamidass (2000) explored the relationship between strategies, *Advanced manufacturing technology,* and performance. The study was conducted among 160 manufacturing companies in the USA and showed that *Advanced manufacturing technology* was associated with better performance. On the other hand, Helander and Burri (1995) demonstrated that ergonomic attributes in *Advanced manufacturing technology* bring such benefits as increased productivity, lower production costs, higher product quality, greater employee involvement, customer satisfaction, and fewer risks of suffering from injuries. On the other hand, according to Vivarelli (2014), studies conducted in the 1990s found that *Advanced manufacturing technology* was associated with higher employment growth in US manufacturing firms from 1987 to 1991. In other words, when *Advanced manufacturing technology* considers artifact–human compatibility, companies obtain positive results.

There is also empirical evidence proving that ergonomically incompatible technology can be detrimental to organizational performance. In this sense, Muzammil and Hasan (2004) and Aluclu et al. (2008) found that the noise caused by technologies, whether continuous or intermittent, can negatively affect human performance and thus cause low production levels. Meanwhile, Karwowski (2006) points out that postural discomfort and the application of effort cause pain and fatigue, affect productivity, cause poor quality, and increase errors, the incidence of musculoskeletal disorders, and costs. Moreover, according to this author, ergonomic equipment increases its own quality, efficiency, and profitability, as it allows employees to adopt comfortable postures and avoid applying physical force repeatedly. Similarly, Pilcher et al. (2002) and Maldonado et al. (2013) argue that when workers are exposed to extreme temperatures while using *Advanced manufacturing technology*, their performance may be adversely affected.

6.5 The Effects of the Tasks Factor on Manufacturing System Performance

This factor is divided into two categories: task variety and work demands.

6.5.1 Task Variety

Task Variety refers to the number and frequency of tasks an employee completes (Barrick et al. 2013) during a given period. Authors Coelho and Augusto (2010) found a positive relationship between *Task Variety* and worker creativity, whereas Chae et al. (2015) argued that when job tasks are too varied, employees often encounter difficulty predicting problems or activities. Therefore, in their research, the authors found that *Task Variety* significantly affected worker creativity, team member exchange, and knowledge sharing.[1] Similarly, Barrick et al. (2013) point out that *Task Variety* can help workers gain autonomy, since workers who have a high openness to jobs actively seek opportunities to gain autonomy and personal growth through creative, imaginative, and curious behavior. Likewise, Hackman and Oldham (1976) and Carayon et al. (1999) claim that *Task Variety* affects employee performance, motivation, and satisfaction.

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[1] Team member exchange refers to the reciprocity between a member and their team regarding the contribution of ideas, feedback, and assistance from this member to other members and, at the same time, the reception by this member of information, assistance, and recognition from other members (Chae et al. 2015).

In their research, Zaniboni et al. (2013) compared the effects of *Task Variety* on burnout and turnover intentions of older and younger workers, finding that increased *Task Variety* led to less work-related burnout and turnover intentions in younger workers. Also, Shantz et al. (2013) analyzed the effects of employee commitment as a mediator of the job design–performance relationship. The authors analyzed data from 283 employees in a consultancy and construction firm based in the UK and focused on supervisors' independent performance evaluations. As a result, Shantz et al. (2013) found that employees who held jobs with greater *Task Variety* were more engaged and supervisors scored them better. Finally, Hui et al. (2010) mention that employee organization-based self-esteem (OBSE) can be increased by giving them tasks that fit their disposition. The authors examined combinations, instead of individual dispositions separately, on OBSE. To increase OBSE, they proposed giving multitasking employees (people who are polychronic) greater *Task Variety*. The data analysis from 260 middle managers and their immediate supervisors in three Chinese organizations revealed that as *Task Variety* increased in polychronic employees, OBSE levels also increased.

6.5.2 Work Demands

Work Demands can be a cause of corporate success or failure. *Work Demands* are defined as psychological stressors that are present in the work environment or workload (Peeters and Rutte 2005). Several studies have found a negative indirect relationship between *Work Demands* and production processes. For instance, some authors claim that high *Work Demands* cause employee burnout, which in turn predicts depression and little work engagement (Hakanen et al. 2008). In addition, *Work demands* can cause emotional exhaustion and work stress (Peeters and Rutte 2005), or they minimize supervisor availability (Kim and Stoner 2008). However, there are also studies that demonstrate that adequate *Work Demands* lead to employee well-being and learning (Peeters and Rutte 2005). In other words, the effects of *Work Demands* have an impact on employee performance, which in turn has an impact on production processes.

There are also studies that demonstrate that *Work Demands* play a critical role in customer satisfaction in manufacturing systems, since employee–customer interactions may be influenced by *Work Demands*. For example, Bakker et al. (2008) related *Work Demands* to family–work conflicts (husband vs. wife, which can be seen as mutual clients). In addition, Hakanen et al. (2008) point out that high *Work Demands* can cause burnout, which can be manifested through reduced personal achievement, marked by a tendency of employees to evaluate themselves, particularly with regard to work with clients. Another study also suggests that workers with high emotional *Work Demands* may have a depersonalized attitude toward clients (Xanthopoulou et al. 2013). All these *Work demands* effects can cause customer dissatisfaction.

The main objective of most companies is to improve their competitiveness in the global market. To achieve this, companies have to improve their organizational performance, which is a construct, difficult to measure, that refers to whether a company works well in the administrative and operational functions according to its mission and whether it actually accomplishes its mission or institutional mandate (Kim 2004). It has also been shown that *Work demands* can affect individual and organizational performance. For example, García-Herrero et al. (2013) state that *Work demands* cause stress, which in turn affects organizational performance. Another study found that *Work demands* are positively related to emotional exhaustion and negatively to vigor and dedication (Montgomery et al. 2015), which negatively affects organizational performance. Finally, Gilboa et al. (2008) point out that the stress caused by *Work demands* may affect job performance due to a poor employee's commitment, motivation to invest effort, and motivation to maintain personal discipline within the company.

6.6 The Effects of the Environment Factor on Manufacturing System Performance

Another important effect to study from a macroergonomic view is the environment in which the activities are developed, which is discussed in more detail below.

6.6.1 Noise

Noise is defined as "unwanted sound" and is perceived as a stressor and environmental annoyance (Stansfeld and Matheson 2003). According to this research, *Noise* has negative effects on human health and task performance. These effects are classified into auditory and non-auditory effects (Chao et al. 2013). Konings et al. (2009) and Chao et al. (2013) found that, while an auditory effect is hearing loss, non-auditory effects include accelerated heart rate, high blood pressure (Lusk et al. 2002), muscle contraction leading to fatigue, and decreased sensitivity to light. Also, Stansfeld and Matheson (2003) found that *Noise* can cause hypertension, cardiovascular diseases, psychological symptoms such as aggression and mental disorders, and memory loss. The parameters that determine the severity of these effects are as follows: (1) *Noise* level; (2) time exposure; (3) *Noise* frequency characteristics; and (4) individual characteristics (Chao et al. 2013; Realyvásquez et al. 2016c).

Not all *Noise* effects are directly related to health problems. In fact, *Noise* can also affect worker performance. For example, Stansfeld and Matheson (2003) found that *Noise* can interfere with a task performance. In addition, Sloof and van Praag (2010) conducted an experiment with two groups of workers to determine the effects of high *Noise* levels. The first group worked in an environment with a stable *Noise* level, while the second group worked in an environment with variable *Noise* levels. The results showed that subjects working in the volatile environment had to make more efforts to complete their tasks than those who worked in stable Noise levels.

Saeki et al. (2004) and Dockrell and Shield (2006) also performed different experiments to test *Noise*-level effects on human performance. In all their studies, the authors concluded that participants performed better when *Noise* was at its lowest level. Other studies suggest that *Noise* influences employee attitudes, behaviors, satisfaction, and work performance (Crouch and Nimran 1989; Larsen et al. 1998; Lee and Brand 2005) and can also be an environmental stressor related to job satisfaction (Sundstrom et al. 1994; Lee and Brand 2005). In addition, Realyvásquez et al. (2016c) found that the macroergonomic compatibility of *Noise* levels has direct and positive effects on worker psychological characteristics and indirect and positive effects on their performance, whereas Vischer (2008) mentions that *Noise* is a primary source of discomfort that reduces productivity. Finally, Azadeh et al. (2006) implemented a macroergonomic approach in an advanced thermal power plant. The authors considered elements of different factors, including the Environment (i.e., *Lighting, Noise, Temperature, Humidity, Distribution, and Workstation layout*), and the macroergonomic approach actually increased plant productivity and reliability.

6.6.2 Lighting

Since the late 1990s, *Lighting* quality has balanced the human needs as well as the environmental and economic aspects of life (Bellia et al. 2011). In the work area, *Lighting* is an Environment element that can affect employee health and performance in their work area (Juslén and Tenner 2005). In fact, according to several authors, Work Area *Lighting* is a key element in determining errors, accidents, absenteeism, worker well-being, and productivity (van Bommel et al. 2002a; Juslén and Tenner 2005; Hoffmann et al. 2008). For example, adequate *Lighting* for screen-based work helps ensure functional employee comfort (Vischer 2008).

Moreover, Vischer (2008) and Bellia et al. (2011) point out that in addition to *Noise*, an inadequate or insufficient *Lighting* exposure can cause stress and affect each worker's work performance, which often results in negative effects on productivity. Similarly, other studies have shown that *Lighting* can have serious psychological consequences on workers, such as mental fatigue, slow task response, negative changes in attitudes and behaviors, and lower satisfaction (Lee and Brand 2005; Hawes et al. 2012). Therefore, adequate *Lighting* can help employees feel less sleepy, more energetic and happier (Smolders and de Kort

2014). For instance, van Bommel et al. (2002b) calculated the total productivity momentum by improving *Lighting* and found that improving *Lighting* in work areas increases productivity up to 80%.

6.6.3 Temperature, Humidity, and Air Quality

Temperature is defined as a physical quantity that expresses the degree or level of heat or cold of bodies or the environment (PCE Instruments 2016). On the other hand, humidity is classified into two categories: absolute humidity (AH) and relative humidity (RH). AH refers to the absolute amount of water in the air, while RH is defined as the relative proportion of water in the air compared to the maximum amount of water vapor (Realyvásquez et al. 2016c). In this chapter, humidity is considered as a single element that comprises the two categories, while air quality refers to the level of air pollutants that are controlled and regulated by standards set by regulations (Realyvásquez et al. 2016c).

All these variables have been analyzed in the previous research works to study their effects on different aspects of the work space, including workers. In addition, several studies have analyzed the relationship between air temperature and human performance. However, most of these investigations have been conducted in areas different from those of manufacturing systems. For example, Niemelä et al. (2002) found that call-center worker performance tends to decrease when temperature exceeds 25 °C. Similarly, Pepler and Warner (1978) found an inverse U-shaped relationship between the time required to perform a task and the temperature in the work area. Likewise, Wyon (1996) found that the loss of productivity due to inadequate temperature levels was strongly related to the nature of the task the workers were carrying out.

Several investigations support the hypothesis that there is a temperature range in which task performance is not affected (Witterseh 2001; Federspiel et al. 2002). Lorsch (1994) mention that there is a critical temperature zone (between 32.2 and 35 °C) over which performance in precision mental tasks decreases. Also, Seppanen et al. (2006) and Cui et al. (2013) found that the highest productivity at office work occurred at 22 °C and that at higher or lower temperatures, productivity declined. In addition, there are also studies that show that temperature has an effect on learning and motivation processes, which in turn affects performance (Lan et al. 2009, 2010; Cui et al. 2013).

Temperature influences not only the performance of workers, but also their health. According to Vischer (2008), certain psychological aspects are related to work area elements and therefore to organizational productivity. Other studies have also revealed that temperature has effects on employee attitudes, behaviors, performance (Crouch and Nimran 1989; Larsen et al. 1998; Lee and Brand 2005), and regrettably. Most of the psychological effects of temperature are related to aggressive behavior (Geen and Donnerstein 1998). For example, Baron and Bell (1976) conducted several experiments with undergraduate students to determine the effects of temperature upon student behavior. The results indicated that high ambient temperatures produce aggressive behavior. On the other hand, Vrij et al. (1994) analyzed the impact of temperature on police officers' behavior and also found that at high temperatures, the officers presented aggressive behavior.

As far as humidity is concerned, experts have demonstrated that high levels of it affect performance in individual tasks (Vischer 2008). Authors Tsutsumi et al. (2007) conducted subjective experiments to evaluate the effects of humidity on human performance under transient conditions from hot and humid environment to thermally neutral conditions. The results indicated that subjective performance was at the same level under all conditions. However, subjects reported to be more tired at 70% RH. Also, Shi et al. (2013) point out that humidity has effects on physiological aspects, such as heart rate, body temperature, blood pressure, and sweating, which impact on performance.

Few studies have analyzed the relationship between air quality and human performance in manufacturing systems. However, some authors who analyzed this relationship in office work found that air quality had a significant impact on productivity (Tsuzuki et al. 1999; Huizenga et al. 2006). For instance, Huizenga et al. (2006) applied a survey to construction workers where they were asked whether the air quality in their work area improved or interfered with their ability to perform their tasks. The results showed that air quality had a significant influence on task performance. Wargocki et al. (2000) also agreed that good air quality has a positive impact on office worker performance. Finally, other studies have shown that air quality has an impact on employee satisfaction (Schakib-Ekbatan et al. 2010; Bluyssen et al. 2011; Cao et al. 2012; Frontczak et al. 2012), which, in turn, is positively correlated with productivity (Frontczak et al. 2012).

Polluted air is also the cause of different diseases and problems, such as cancer, anemia, impaired coordination, gait abnormalities, inability to drive, lack of attention and concentration, and poor cognitive performance. On the other hand, high exposure to contaminated air can cause psychological disorders that last for weeks or even months (World Health Organization. Regional Office for Europe 2000; Realyvásquez et al. 2016c). The likelihood of a person suffering from the presence of a pollutant depends on several aspects, such as the individual's sensitivity to that pollutant, their psychological and physical health, the level of concentration of the pollutant in the air, and the duration and frequency of the exposure (Realyvásquez et al. 2016c).

In conclusion, it is clear that the environmental conditions of the work area play a very important role in employee health and safety, which is why it is necessary to monitor and control such conditions. This will be reflected not only on employee health and safety, but also in their individual, team, and organizational performance. To conclude this review, Table 6.1 summarizes the benefits of macroergonomic factors and elements.

Table 6.1 Impact of macroergonomic factors and elements

Impact	References	Citations
Increased employee performance	Hackman and Oldham (1976), Pepler and Warner (1978), Crouch and Nimran (1989), Lorsch (1994), Larsen et al. (1998), Baltes et al. (1999), Tsuzuki et al. (1999), Carayon et al. (1999), Carayon and Smith (2000), Wargocki et al. (2000), Niemelä et al. (2002), Pilcher et al. (2002), Saeki et al. (2004), Azadeh et al. (2005), Juslén and Tenner (2005), Lee and Brand (2005), Peeters and Rutte (2005), Huizenga et al. (2006), Dockrell and Shield (2006), Tsutsumi et al. (2007), Gilboa et al. 2008, Vischer (2008), Lan et al. (2009, 2010), Bellia et al. (2011), Manzoor et al. (2011), Jaradat and Sy (2012), Cui et al. (2013), Maldonado et al. (2013), Shi et al. (2013), Shantz et al. (2013), Garbers and Konradt (2014), Realyvásquez et al. (2016c)	33
Increased organizational performance	Baltes et al. (1999), Kotha and Swamidass (2000), Robey et al. (2000), Beevis and Slade (2003), Azadeh et al. (2005), Luthans (2005), Real et al. (2006), Ruiz-Mercader et al. (2006), Ismail (2007), Oyedele and Tham (2007), Vischer (2008), Etgar (2008), Dul and Neumann (2009), Wang et al. (2010), Cao and Zhang (2011), Zehir et al. (2011), Jaradat and Sy (2012), Chen et al. (2012), Mitrofan and Bulborea (2013), García-Herrero et al. (2013), dos Reis et al. 2014), le Roux (2014), Hitka and Balážová (2015), Realyvásquez et al. (2015), Montgomery et al. (2015), Jacobs et al. (2016), Realyvásquez et al. (2016a)	27
System productivity	Helander and Burri (1995), Siemieniuch and Sinclair (1995), Wyon (1996), Tsuzuki et al. (1999), O'Neill and Evans (2000), Stiroh (2002), van Bommel et al. (2002a, b), Beevis and Slade (2003), Muzammil and Hasan (2004), Juslén and Tenner (2005), Azadeh et al. (2006), Huizenga et al. (2006), Seppanen et al. (2006), Azadeh et al. (2007), Aluclu et al. (2008), Hoffmann et al. (2008), Vischer (2008), Dul and Neumann (2009), Hedge et al. (2011), Cui et al. (2013), Maldonado et al. (2013), Chou et al. (2014), Realyvásquez et al. (2015, 2016a, b)	25
Safety and health	Siemieniuch and Sinclair (1995), World Health Organization. Regional Office for Europe (2000), Lusk et al. (2002), Beevis and Slade (2003), Juslén and Tenner (2005), Robertson et al. (2008), Vischer (2008), Konings et al. (2009), Dul and Neumann (2009), Kiecolt-Glaser et al. (2010), Hedge et al. (2011), Chao et al. (2013), Shi et al. (2013), Realyvásquez et al. (2015, 2016a, b, c), Chen et al. (2016)	18
Employee satisfaction	Hackman and Oldham (1976), Crouch and Nimran (1989), Sundstrom et al. (1994), Larsen et al. (1998), Baltes et al. (1999), Carayon et al. (1999), Carayon and Smith (2000), Lee and Brand (2005), Luthans (2005), Danish and Usman (2010), Schakib-Ekbatan et al. (2010), Bluyssen et al. (2011), Cao et al. (2012), Habibi et al. (2012), Jaradat and Sy (2012), Frontczak et al. (2012), Jacobs et al. (2016)	17

(continued)

Table 6.1 (continued)

Impact	References	Citations
Product quality	Saraph and Sebastian (1992), Helander and Burri (1995), Small and Chen (1995), Palacios and Imada (1998), Ordoobadi and Mulvaney (2001), Beevis and Slade (2003), Bayo-Moriones and Merino-Díaz de Cerio (2004), Karwowski (2006), Dul and Neumann (2009), Percival and Cozzarin (2010), Putkonen et al. (2010), Cao and Zhang (2011), Barón-Maldonado and Rivera-Cadavid (2014), Realyvásquez et al. (2015, 2016a, b)	16
Occupational risks minimization	Helander and Burri (1995), O'Toole (2002a, b), Juslén and Tenner (2005), Dembe et al. (2005), Karwowski 2006, Vegso et al. (2007), Hoffmann et al. (2008), Bushnell et al. (2010), Zohar (2014)	9
Innovation	Moran (2005), Duygulu and Özeren (2009), Becerra-Rodríguez and Álvarez-Giraldo (2011), Cao and Zhang (2011), Ertürk (2012), Davenport (2013), Hogan and Coote (2014), Ni et al. (2014)	8
Employee creativity	Zhang and Bartol (2010), Kiecolt-Glaser et al. (2010), Liao et al. (2010), Coelho and Augusto (2010), Liu et al. (2012), Barrick et al. (2013), Ni et al. (2014), Chae et al. (2015)	8
Corporate competitiveness	Baltes et al. (1999), Matta and Semeraro (2005), Quintana-García and Benavides-Velasco (2008), Percival and Cozzarin (2010), Márquez-Cañizares et al. (2012), Calderón (2013), dos Reis et al. (2014)	7
Customer satisfaction and loyalty	Oyedele and Tham (2007), Etgar (2008), Xanthopoulou et al. (2013), Bauer et al. (2014), Realyvásquez et al. (2015)	5
System reliability	Azadeh et al. (2006), Karwowski (2006), Azadeh et al. (2007), Imada (2008)	4
Work control	Siemieniuch and Sinclair (1995), O'Neill and Evans (2000), Robertson et al. (2008), Maldonado et al. (2013)	4
Business process efficiency	Robertson et al. (2008), Yao et al. (2010), Cao and Zhang (2011), Realyvásquez et al. (2015)	4
New skills acquisition	Carayon and Smith (2000), Krause et al. (2007), Padilla-Soria (2013)	3
Communication and collaboration	Krause et al. (2007), Robertson et al. (2008)	2
Work life quality	Carayon et al. (1999), Kiecolt-Glaser et al. (2010)	2
Problem-solving	Combs et al. (2006), Quintana-García and Benavides-Velasco (2008)	2
Work conditions improvement	Habibi et al. (2012)	1
Environmental satisfaction	Robertson et al. (2008)	1
Sense of community	Robertson et al. (2008)	1

(continued)

Table 6.1 (continued)

Impact	References	Citations
Waste reduction	Cornelli and de Macedo-Guimarães (2012)	1
Regulatory compliance	Neal et al. (2000)	1
Absenteeism reduction	Baltes et al. (1999)	1

6.7 Conclusions

As observed in Table 6.1, and according to the literature review, most ergonomic studies focus mainly on performance improvements, at both worker and company levels. This may be due to the fact that ergonomic researchers always try to ensure that ergonomic practices be accompanied by better work performance to convince company managers of the benefits of ergonomics, since, in many cases, managers think that ergonomics only reflects positive results at person (worker) level, and this is not interesting to them. However, in the long run, improving employee performance will be reflected on better organizational performance.

As discussed in this review, ergonomics impacts on both employee performance and corporate performance. Benefits such as safety and health, occupational risks reduction, satisfaction, employee creativity, new skills acquisition, and customer satisfaction and loyalty are all seeds for good performance at worker and organizational levels. Also, at first sight some ergonomic benefits or effects may have nothing to do with corporations; however, these effects include environmental satisfaction, a sense of community among employees, and regulatory compliance, among others. Many of them may motivate companies to remain in the market.

Now, ergonomics, especially macroergonomics, does not offer overnight benefits. To see the effects of macroergonomic compatibility, it is necessary to have a work plan and form a committee engaged with employee well-being and corporate performance. It is important to take into account the participation of all the workers of the different hierarchical levels, as well as the interactions of all the macroergonomic factors and elements and their effects. Finally, although some studies emphasize on a specific ergonomic benefit or effect, it does not mean that other effects have not taken place. They might have occurred after the study was conducted or were simply not detected. This is why experts recommended that, when implementing ergonomic practices at either microergonomic or macroergonomic levels, all the effects be documented, regardless of the research goals.

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Chapter 7
The Impact of the Person Factor on Manufacturing System Performance: A Causal Model

Abstract The macroergonomic compatibility of the Person factor can have positive effects on manufacturing systems. In this chapter, we analyze the direct, indirect, and total effects of the macroergonomic compatibility of human-related elements on manufacturing system performance. Namely, we evaluate the effects of the compatibility of three Person-related variables—*Physical Characteristics*, *Psychological Characteristics*, and *Motivation and Needs*—on three manufacturing system performance variables—*Customers*, *Production Processes*, and *Organizational Performance*. To conduct this evaluation, we propose ten hypotheses and validate the effects between the variables using a structural equation model. To collect data regarding these variables, we developed a Macroergonomic Compatibility Questionnaire (MCQ) and administered it among senior and middle managers of Mexican manufacturing work systems. Our results revealed that macroergonomic elements of the Person factor have significant effects on manufacturing system performance.

7.1 The Macroergonomic Compatibility Questionnaire (MCQ)

7.1.1 Developing the Macroergonomic Compatibility Questionnaire (MCQ)

To measure the effects of the Person factor on manufacturing system performance, we developed and administered a MCQ. We developed three versions of this MCQ: the worker version (MCQ-WV), the health department version (MCQ-HDV), and the experts version (MCQ-EV). Each one of them is thoroughly discussed below.

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7.1.1.1 The Worker Version (MCQ-WV)

The MCQ-WV can be administered to employees from all organizational levels and includes three sections. The first section collects demographic information, such as worker name, gender, job position, seniority, type of manufacturing company, and ergonomic methods implemented. The section includes six questions that were used in this research to conduct a descriptive analysis of the sample.

The second version collects data regarding the implementation degree of macroergonomic practices (MPs). Namely, it asks participants to rate the extent to which manufacturing companies implement MPs and how often macroergonomic elements are taken into account. Initially, this part of the MCQ contained 150 potential questions to be assessed according to the literature review (Realyvásquez et al. 2016a); then, following the assistance of subject matter experts, the 92 most appropriate questions were kept to be answered using a five-point fuzzy Likert scale. This type of rating scale has been widely used in recent and similar studies (Likert 1932; Glover et al. 2011; Li 2013; García-Alcaraz et al. 2014).

The survey rating scale and its descriptors can be read as follows: (1) totally disagree, (2) disagree, (3) neutral, (4) agree, (5) totally agree. Similarly, Fig. 7.1 depicts the scale of the MCQ-WV, whereas Table 7.1 illustrates the second section of this questionnaire, corresponding to the assessment of the Person factor through three macroergonomic elements: *Physical Characteristics*, *Psychological Characteristics*, and *Motivation and Needs*. The table shows the questionnaire items in the left column and the rating scale in the right column.

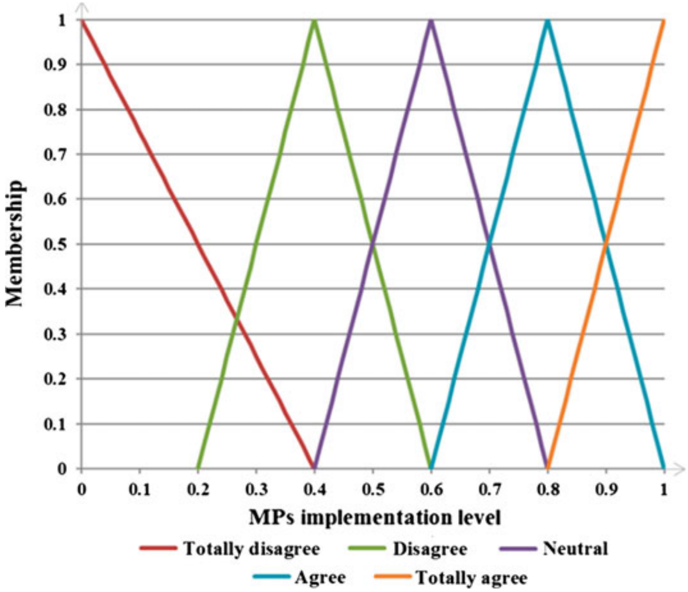

Fig. 7.1 Fuzzy Likert scale for the MCQ-VW and MCQ-HDV

Table 7.1 Section II of the MCQ-WV

In your company	1	2	3	4	5
Physical Characteristics					
Employee physical characteristics (weight, height, strength) are considered for task allocation					
Employees receive attention when they present physical discomfort					
The causes of employee physical discomfort are analyzed					
Psychological Characteristics					
Employee psychological characteristics (distress, stress, depression, satisfaction) are considered for task allocation					
Employees receive attention when they present psychological discomfort, such as mental stress, depression					
The causes of employee psychological discomfort are analyzed					
Tasks are designed in a way they prevent psychological discomfort					
Motivation and Needs					
Motivation and needs are taken into account for tasks allocation					
Employees are motivated to work through problem-solving approaches					
Labor help is given to employees when they need it					
Promotions and professional growth opportunities are possible					

The third section of the MCQ-WV collects data on the company benefits obtained from MPs implementation. This part of the questionnaire asks participants in general to rate how often, in their opinion, companies obtain the listed benefits in terms of production processes, customers, and organizational performance. The section uses the same Likert scale as section II. Table 7.2 illustrates this third section of the MCQ-WV.

Table 7.2 Section III of the MCQ-WV

In your company	1	2	3	4	5
Production Processes					
Customer complaints are few					
Product defects are few					
Inventory levels are low					
Productivity has increased over time					
Customers					
Customer needs and expectations are important					
Customers are satisfied with the products they receive					
Customers remain loyal to the company					
The number of customers has increased over time					
Organizational Performance					
Productivity has improved					
The number of employees has increased					
Product variety has increased					
The business has improved					

The data collected from section II and section III were used to construct the structural equation model discussed later and define the effects of the Person factor on manufacturing system performance.

7.1.1.2 The Health Department Version (MCQ-HDV)

This version of the MCQ was administered in every health department of the surveyed manufacturing companies. The survey includes two sections: Health and Safety Indicators and Current Conditions Indicators. Section I allowed us to collect data regarding the number of injuries, accidents, and illnesses occurred in companies in the last year. Table 7.3 shows this section.

The second section of the MCQ-HDV aimed at gathering data regarding the risks of employees suffering from injuries, accidents, or illnesses in any degree, in the company's current conditions. For this section, the participants were asked to rate the items using the same scale as in Fig. 7.1. Table 7.4 shows an example of this section.

Information collected thanks to the MCQ-HDV allowed us to validate the manufacturing system macroergonomic compatibility index (MCI), which will be discussed in further chapters.

7.1.1.3 The Experts Version (MCQ-EV)

This version was administered to ergonomics experts of the surveyed manufacturing companies. The MCQ-EV is composed of only one section in which participants rate or assess (as *w*) the importance of a set of macroergonomic practices. Table 7.5 shows this version of the MCQ.

The scale used in Table 7.5 includes the following values: (1) Not important, (2) Slightly important, (3) Moderately important, (4) Important, (5) Very important. This scale, presented in Fig. 7.2, allowed us to evaluate the importance of implementing a set of MPs in each macroergonomic element (Celik et al. 2009; Maldonado-Macías et al. 2013). Also, information collected using this questionnaire helped us decide whether a given macroergonomic element should remain in the MCQ and allowed us to develop our macroergonomic compatibility index. Both procedures will be discussed in detail in further chapters.

Table 7.3 Section I of the MCQ-HDV

Company name	
Question	Number
According to your records, how many injuries have occurred in the company in the last year?	
According to your records, how many accidents have occurred in the company in the last year?	
According to your records, how many illnesses have occurred in the company in the last year?	

Table 7.4 Section II of the MCQ-HDV

In your company	1	2	3	4	5
Workers are safe from injuries					
Workers are safe from accidents					
Workers are safe from illnesses					
Work-related injuries have gradually decreased since the company started operating					
Few work-related injuries occur					
Few work-related illnesses occur					
The degree of severity of work-related injuries is low					
The degree of severity of work-related accidents is low					

Table 7.5 MCW-EV for the Person factor

Instructions: In your opinion, how important is to implement the following macroergonomic practices in manufacturing systems? Please answer all the questions					
	Importance				
Macroergonomic practices	1	2	3	4	5
Ergonomic assessment of employee education, skills, and knowledge					
Ergonomic assessment of employee physical characteristics					
Ergonomic assessment of employee psychological characteristics					
Ergonomic assessment of employee motivation and needs					

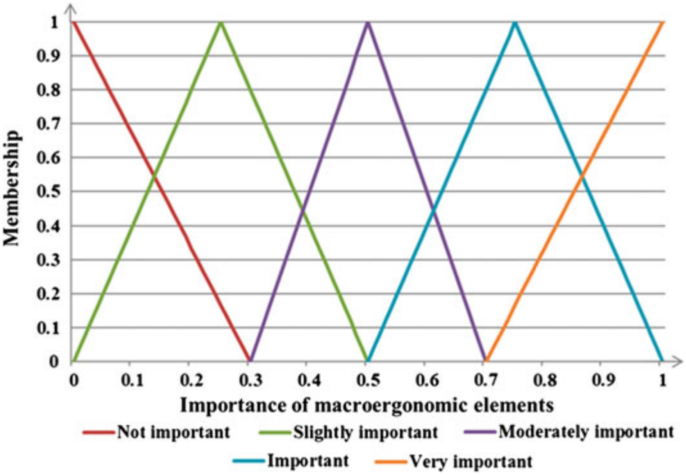

Fig. 7.2 Fuzzy Likert scale for the MCQ-EV

7.1.2 Administering the MCQ

To conduct this research, we collected information from five manufacturing work systems and six ergonomics experts. The MCQ-WV was administered to middle and senior managers—although it is appropriate for any worker at any organizational level—since employees know best the companies in terms of functioning, deficiencies, and opportunities for improvement. Surveyed workers from the middle and senior management departments included executive managers, supervisors, chiefs of staff, and administrators. On the other hand, the MCQ-HDV was administered to physicians working in the surveyed manufacturing companies. Finally, the MCQ-EV was responded by certified ergonomics experts, members of the International Ergonomics Association, and/or the Ergonomists Society of Mexico (SEMAC, by its Spanish acronym).

Regarding the administration process, we administered the MCQ-WV and the MCQ-HDV as follows:

(1) Invitation: The Maquiladoras Association (AMAC, INDEX JUÁREZ, by its Spanish acronym) and the National Institute of Statistics, Geography, and Informatics (INEGI, by its Spanish acronym) helped us reach companies to invite them to a meeting. Both AMAC and INEGI provided us the contact information of ergonomics experts working in manufacturing companies located in Chihuahua, Mexico.
(2) Schedule meeting: To gather as many potential participants as possible, we organized a meeting with both company health departments and SEMAC manufacturers. The meeting aimed at briefly presenting our research.
(3) Reach potential participating companies: After the meeting, we contacted 63 potential participating manufacturing systems by phone or e-mail. Companies that did not respond were personally visited.
(4) Explain research goal: Companies that were successfully reached were explained in detail the research goal, the importance of their collaboration, and the potential benefits of participating.
(5) Schedule survey administration session: Interested company executive managers contacted the senior and middle managers, informed them of the project, and scheduled a survey administration session.

Although 20 manufacturing systems were initially interested in participating, only five of them took part in the project. As a result, we collected data from 188 workers from middle and senior management departments. Table 7.6 shows the frequency of each surveyed position and its corresponding percentage.

Table 7.6 Frequency and percentage of surveyed positions

Position	Frequency	Percentage
Manager	30	16
Supervisor	57	30.3
Chief of staff	62	33
Administrator	39	20.7
Total	188	100

Table 7.7 Characteristics of ergonomics experts

Characteristic	E1	E2	E3	E4	E5	E6
Ergonomics certification	X	X	X	X	X	X
Expertise in the manufacturing industry	X	X	X	X	X	X
Occupational health	X	X	X		X	X
Member of international ergonomics organizations	X	X			X	
Member of national ergonomics organizations	X	X	X	X	X	X
Publications in journals	X	X	X	X	X	X
Field experience (in years)	22	18	30	23	16	15
Postgraduate degree	X	X	X	X	X	

E Expert

As for the MCQ-EV, we contacted company ergonomics experts by e-mail. These experts were selected after carefully reviewing their résumé, professional background, expertise, and ergonomics certifications. Once selected, we invited them to be part of the research as a group of experts. The six participating experts answered the surveyed via e-mail. The expert evaluation allowed us to keep in the MCQ those factors and elements that showed low reliability levels as expressed in their ordinal alpha values. In fact, the assessment of experts meant that such factors and elements were actually important for measuring the macroergonomic compatibility of a work system. Table 7.7 shows the experts selection criteria.

The data collected from the MCQ-EV helped us decide whether the macroergonomic elements showing ordinal alpha values below 0.7 should remain in the questionnaire. These results are discussed in later chapters when developing the macroergonomic compatibility index.

7.1.3 *Reliability Analysis of the MCQ*

Usually, the reliability of ordinal data is estimated using the Cronbach's alpha index (Ocaña et al. 2013; García-Alcaraz et al. 2014), even if such data are discontinuous or non-normal (Freiberg et al. 2013). Usually, the Cronbach's alpha index is considered appropriate for ordinal data as long as the violations of normality and continuity assumptions do not produce statistically significant effects on the results (Freiberg et al. 2013). However, other authors claim that using the Cronbach's alpha necessarily involves continuous and normal data (Oliden and Zumbo 2008; Basto and Pereira 2012; Gaderman et al. 2012), and thus, the reliability of ordinal scales should be estimated using the ordinal alpha index to provide more precise reliability estimates.

The reliability of our MCQ was estimated using the ordinal alpha index, only accepting values equal to or above 0.7. The questionnaire was analyzed by dimensions corresponding to the assessed macroergonomic elements (see Chap. 5). The data were captured on statistical software SPSS v. 24®, and for the screening process, we identified missing values and outliers. Both were replaced the median value of the given dimension. This procedure is appropriate for ordinal values contained in a Likert scale (Hair et al. 2006, 2010; García-Alcaraz et al. 2014). Afterward, we obtained a polychoric correlation matrix to estimate the factor loadings λ for every survey item corresponding to a macroergonomic element. Finally, using these factor loadings, we calculated the alpha ordinal index for each macroergonomic element using Eq. (7.1) (Oliden and Zumbo 2008; Domínguez 2012).

$$\alpha_{\text{ordinal}} = \frac{n}{n-1}\left[\frac{n\left(\bar{\lambda}\right)^2 - \bar{\lambda}^2}{n\left(\bar{\lambda}\right)^2 + u^2}\right] \tag{7.1}$$

where

n	number of items of a macroergonomic element
$\bar{\lambda}$	average factor loadings of n items
λ^2	average factor loadings of the square of the n factor loadings
$u^2 = 1 - \lambda^2$	average unicity of n items.

The variables that satisfied the reliability analysis were kept in the MCQ, whereas those showing α values below 0.7 were preliminary removed. However, the MCQ-EV data later helped us to determine whether these elements could be kept in the MCQ despite their low α values. Table 7.8 introduces the α values of every macroergonomic element of the Person factor as well as the experts' assessments.

7.1.4 Factor Analysis of the MCQ

The MCQ was also validated by a factor analysis. This technique has been considered as the most appropriate way to both identify variables explaining the variation and covariation in a set of items and remove those that have no impact whatsoever. Also, factor analysis deals with observed measurements (Brown 2015) and is useful in variable reduction when data are presented in an ordinal scale (Castañeda et al. 2010). In this chapter, the viability of every macroergonomic element of the Person factor was analyzed trough a factor analysis using Bartlett's sphericity test and the Kaiser–Meyer–Olkin (KMO) test (Schulze et al. 2015).

Table 7.8 Ordinal alpha values and average crisp weights of macroergonomic elements of the factor person

Macroergonomic element	Ordinal alpha	Experts w^*
Psychological Characteristics	0.911	0.580
Motivation and Needs	0.848	0.650
Physical Characteristics	0.834	0.760
Education, Knowledge, Skills	0.783	0.650

Experts recommend performing a factor analysis when the KMO is higher than or equal to 0.8 (Ferrando and Anguiano-Carrasco 2010). On the other hand, if the KMO value in a given macroergonomic element is lower than 0.5, factor analysis may not be effective to assess data dimensionality (Shumway-Cook et al. 2015). As for the rotation, we used varimax rotation, since it provides a greater extracted variance associated to a single factor (Wang et al. 2005). For variable reduction, we removed variable items showing communality values lower than 0.5 (Kamboj et al. 2014). Also, the KMO test showed high adequacy for conducting factor analysis. As for communality, eight of the 92 elements showed communality values lower than 0.5, meaning that the MCQ was statistically validated by 91.30% of its items.

7.2 Structural Equations Models

Structural equation modeling (SEM) is a statistical tool that takes a confirmatory approach (i.e., hypothesis testing) to the analysis of structural theories. Typically, SEM represents causal processes producing observations on multiple variables. The term structural equation model elucidates two important aspects of the technique: (1) studied causal processes are represented by a set of structural equations (i.e., regressions) and (2) these structural relationships can be graphically modeled to better conceptualize the studied theory (Byrne 2013). SEMs are considered the most appropriate technique when analyzing causal relationships that involve multiple dependent or independent variables (García-Alcaraz et al. 2014). The resulting hypothetical model can be statistically tested by a simultaneous and comprehensive analysis of the system to determine its consistency with the obtained data. If the goodness of fit of a model is appropriate, the relationships between variables are more likely to be feasible. On the other hand, if the goodness of fit is not suitable, the feasibility for the declared relationships is rejected (Byrne 2013).

Behind structural equation models, there is a confirmatory logic of research. The researcher designs a model, which is nothing more than a hypothesis, and then compares this model with the collected data. SEMs are different from statistical methods for segmentation that responds to an exploratory logic by empirically searching for the explanatory variables that cause greater effects on a given response variable. Moreover, SEMs look for causes not defined as latent variables, which emerge from the elaboration of a theoretical construct (Castro and Lizasoain 2012).

SEM is a global method for quantifying and testing substantive theories. Methodologically, it is a collection of statistical techniques that help establish a set of relationships between one or more predictor or explanatory variables and one or more response variables. Both predictor and response variables can be observed variables and/or latent variables or factors. Therefore, SEMs incorporate latent variables and observed variables. Latent variables are hypothetical, theoretical constructs of special relevance that cannot be directly observed (but rather inferred) by any operative means (Castro and Lizasoain 2012). However, their manifestations can be observed by cautiously measuring other variables (i.e., observed variables).

SEMs can be used to quantify the plausibility of a complex theoretical hypothesis expressed through the potential relationships between constructs or to test such relationships under measurements. Hence, SEMs take into account measurement errors of the variables, which is a substantial difference from multivariate statistical methods (Castro and Lizasoain 2012; Raykov and Marcoulides 2012). Finally, SEMs are usually represented through diagrams demonstrating the hypothesized relationships and an equation system that formalizes such relationships and expresses their methodological function within the model (Castro and Lizasoain 2012).

In this chapter, we used the SEM technique to test the effects of Person-related variables (macroergonomic elements) on manufacturing system performance. Every relationship in the model was considered statistically significant only if its associated P value was lower than 0.5. Thus, all relationships showing $P > 0.5$ were removed from the model, as they were not considered statistically significant at a 95% confidence level. Also, we considered the explained variance of a dependent variable as significant only if its corresponding R-squared (R^2) value was higher than 0.02, as this implied enough predictive validity (Realyvásquez et al. 2016c). As for discriminant and convergent validity, we estimated the Average Variance Extracted (AVE) and the cross-loading factors for each variable. For convergent validity, experts suggest 0.5 as the minimum value of AVE and a significant P value ($P < 0.05$ in this research) for every item (Fornell and Larcker 1981; Nunnally and Bernstein 2005; Kock 2012; García-Alcaraz et al. 2014).

As regards collinearity between latent variables, we estimated the variance inflation factors (VIFs), setting 3.3 as the maximum value. That is, the VIF value of a latent variable had to be lower than 3.3 to discard collinearity problems (Petter et al. 2007; Cenfetelli and Bassellier 2009; García-Alcaraz et al. 2014). Finally, as our data were collected using ordinal scales, we calculated the Q-squared (Q^2) coefficient as a measure of nonparametric predictive validity, accepting values above zero (Kock 2012; García-Alcaraz et al. 2014).

7.2.1 *Effects of the Person Factor on Manufacturing System Performance—Hypothesis*

As mentioned earlier, the model presented in this chapter evaluates the effects of the Person factor through its macroergonomic elements on the overall performance of manufacturing systems. To measure theses effects, we formulated ten hypotheses and statistically tested them using the SEM technique. On the one hand, we considered the Person factor variables or macroergonomic elements—*Physical Characteristics*, *Psychological Characteristics*, *Motivation and Needs*—as independent latent variables. The MCQ items corresponding to these latent variables can be consulted in Table 7.1. On the other hand, we studied manufacturing system performance variables—*Production Processes*, *Customers*, *Organizational Performance*—as dependent latent variables. The MCQ items corresponding to these latent variables can be consulted in Table 7.2.

To formulate the hypotheses, we conducted a comprehensive review of the literature, mainly in specialized journals of ergonomics and manufacturing. Surprisingly, we found out that few studies have explored the relationship between the macroergonomic compatibility of human factors and the performance of manufacturing work systems. However, similar studies to this research have been conducted in other work systems or knowledge fields, and such works significantly contributed to the development of the hypothesized relationships here presented.

Some studies have revealed that human *Physical Characteristics* (weight, height, strength) can have an impact on human *Psychological Characteristics* (anxiety, stress, depression) (O'Grady 1989; Baumeister and Leary 1995). According to the (American Psychiatric Association 2014), human *Psychological Characteristics* refer to the individual traits that give employees a perception of the work environment. Among the experts having found a relationship between human *Physical Characteristics* and *Psychological Characteristics*, we can cite (Tsaousis and Nikolaou 2005), who conducted a research work among adults and found a positive relationship between emotional intelligence (EI) and better physical and psychological health. Namely, the authors found out that IE was negatively associated with smoking and alcohol consumption and positively related to life quality. Also, in their study, (Salem et al. 2008) measured the work compatibility of a set of variables among 147 construction workers. One of these variables was employee physical activity, which was intrinsically related to *Physical Characteristics*. As the main findings, the authors concluded that physical activity could be associated with less occupational stress.

Unfortunately, research in the manufacturing industry has not yet explored the relationship between employee *Physical Characteristics* and *Psychological Characteristics* from a macroergonomic approach. For this reason, we propose the first research hypothesis ($H_{7.1}$) of this chapter as follows:

$H_{7.1}$: In manufacturing work systems, employee *Physical Characteristics* have a positive direct effect on employee *Psychological Characteristics*.

Regarding *Motivation and Needs*, motivation can be described as the doing of an activity lead by its inherent satisfactions and results (Ryan and Deci 2000). Needs, on the other hand, can be conceived as a sense of lacking something (Abarca-Morán 2013). *Motivation and Needs* is thus a macroergonomic element including an additional economic reward, occupational safety, communication, and spare time (Hitka and Balážová 2015). Various experts point out at a relationship between human *Physical Characteristics* and *Motivation and Needs*. For instance, (Seghers et al. 2014) found out that children's physical characteristics had an impact of their physical goals (e.g., sports, leisure). Likewise, (Baena-Extremera et al. 2014) demonstrated that human *Motivation and Needs* have a stronger impact on men than women in terms of physical activity. Finally, (Owen et al. 2014) also identified a positive relationship between *Motivation and Needs* and children and teens

Physical Characteristics. Unluckily, the relationship between the physical traits of employees and their motivation and needs has not been sufficiently explored in the manufacturing industry. We thus propose the second research hypothesis ($H_{7.2}$) for this chapter as follows:

$H_{7.2}$: In manufacturing work systems, employee *Physical Characteristics* have a positive direct effect on employee *Motivation and Needs*.

In their work, (May et al. 2004) demonstrated that human *Psychological Characteristics* and human *Motivation and Needs* were interrelated. More specifically, the authors found out that employee psychological characteristics increased the motivation and thus the commitment of workers to perform their jobs as good as possible. Considering these findings, the third research hypothesis ($H_{7.3}$) of this chapter reads as follows:

$H_{7.3}$: In manufacturing work systems, employee *Psychological Characteristics* have a positive direct effect on employee *Motivation and Needs*.

Psychological Characteristics are a key element not only to personal success, but also to organizational success. In a descriptive model, (Etgar 2008) demonstrated that *Customer Psychological Characteristics* can improve *Production Processes* performance as expressed by customer complaints, product defects, inventory levels and productivity, goods, and services (Ismail 2007; Chen et al. 2012). Eventually, all these improvements result in improved *Organizational Performance*. Considering these arguments and the model of (Etgar 2008), the fourth working hypothesis ($H_{7.4}$) of this chapter states as follows:

$H_{7.4}$: In manufacturing work systems, employee *Psychological Characteristics* have a positive direct impact on *Production Processes*.

According to (Luneburg and Susman 2005; Realyvásquez et al. 2016b), a customer is a person or an entity that employs or retains another person for financial or other compensations to conduct lobbying activities on behalf of that person or entity. In this chapter, latent variable *Customers* comprises aspects such as number and loyalty. Based on previous research, we state the fifth ($H_{7.5}$) research hypothesis of this chapter as follows:

$H_{7.5}$: In manufacturing work systems, employee *Psychological Characteristics* have a positive direct effect on *Customers*.

Research has shown that employee *Motivation and Needs* can have an impact on customers. Although the literature addressing this phenomenon in the manufacturing industry scarce, (Winefield and Barlow 1995) conducted a study among child protection workers and found a positive relationship between worker *Motivation and Needs* and *Customers*. Meanwhile, (Phillips and Bourne 2008) showed a positive relationship between employee personal values and *Customers* within a drug treatment service. Considering these findings, the sixth ($H_{7.6}$) hypothesis of this chapter can be proposed below:

$H_{7.6}$: In manufacturing work systems, employee *Motivation and Needs* have a positive direct effect on *Customers*.

Organizational Performance is a complex variable (Realyvásquez et al. 2016b). To authors (Kim 2004; Realyvásquez et al. 2016b), *Organizational Performance* elucidates whether a company has a good functioning of its administrative and operational activities according to the corporate goal and whether its activities and products or services are consistent with the corporate goal. In this book, *Organizational Performance* takes into account the number of employees (Melián-González and Bulchand-Gidumal 2016), product variety (Ismail 2007), and business volume (Armstrong and Baron 2002). According to experts, employee *Motivation and Needs* affect either positively or negatively the *Production Processes* of manufacturing systems, and thus have the potential to enhance *Organizational Performance* (Hitka and Balážová 2015). Considering these findings as well as the relationship between *Motivation and Needs* and *Customers*, we believe that the former has effects on the *Organizational Performance* of manufacturing companies. Therefore, from a macroergonomic perspective, hypotheses seven and eight ($H_{7.7}$ and $H_{7.8}$) of this chapter can be read as follows:

$H_{7.7}$: In manufacturing work systems, employee *Motivation and Needs* have a positive direct effect on *Production Processes*.
$H_{7.8}$: In manufacturing work systems, employee *Motivation and Needs* have a positive direct effect on *Customers*.

Research has demonstrated that *Customers* have a strong impact on work systems. For instance, (Alden et al. 2004) found out a positive relationship between *Customer* satisfaction and preference loyalty in the healthcare sector that contributed to the increased competitiveness of the clinics. Also, (Junquera et al. 2012) proved that *Customer* involvement in environmental and *Organizational Performance* problems had a positive impact on the competitiveness of manufacturing work systems. Considering these findings, we propose the ninth research hypothesis ($H_{7.9}$) of this chapter from a macroergonomic perspective:

$H_{7.9}$: In manufacturing work systems, *Customers* have a positive direct effect on *Organizational Performance*.

Authors (Lagacé and Bourgault 2003) claim that *Production Processes* are a key element to long-term sustainability, whereas (Realyvásquez et al. 2015, 2016b) found out that reliable *Production Processes* have an effect on the *Organizational Performance* of manufacturing work systems. In this sense, (Abdulmalek and Rajgopal 2007) provided examples of a reliable *Production Process* from a manufacturing company. These studies and their findings allow us to study the relationship between *Production Processes* and *Organizational Performance* from a macroergonomic perspective in the context of manufacturing systems by proposing the tenth and last working hypothesis of this chapter:

$H_{7.10}$: In manufacturing work systems, *Production Processes* have a positive direct effect on *Organizational Performance*.

Figure 7.3 illustrates the hypothetical causal model, which depicts the hypothesized relationships between latent variables. The model was analyzed using software WarpPLS5®, which uses partial least squares (PLS) for the data analysis. PLS algorithms are useful when evaluating nonlinear models (Ockert 2014; Kock 2015). However, notice that in this book, we do not provide fit indices such as the chi-squared (X^2), the root mean square error of approximation (RMSEA), or the goodness of fit index (GFI), since they were not relevant to our research (Ockert 2014). Finally, software WarpPLS® is widely recommended for small samples (García-Alcaraz et al. 2014; Kock 2015).

To evaluate the model, we computed three model fit and quality indices: Average Path Coefficient (APC), Average *R*-Squared (ARS), and Average Variance Inflation Factor (AVIF). APC and ARS include P values. To accept or reject any relationship, the *P* values of both APC and ARS had to be lower than 0.05; that is, significant at the 95% confidence level. Once the insignificant relationships were discarded, we analyzed the factor loading values. We removed items showing higher loadings in any other variable but wherein they belonged (García-Alcaraz et al. 2014; Kock 2015). Finally, we calculated three types of effects. Direct effects aimed at validating the research hypotheses and implied direct relationships between variables. We also estimated indirect effects and total effects (i.e., sum of direct and indirect effects).

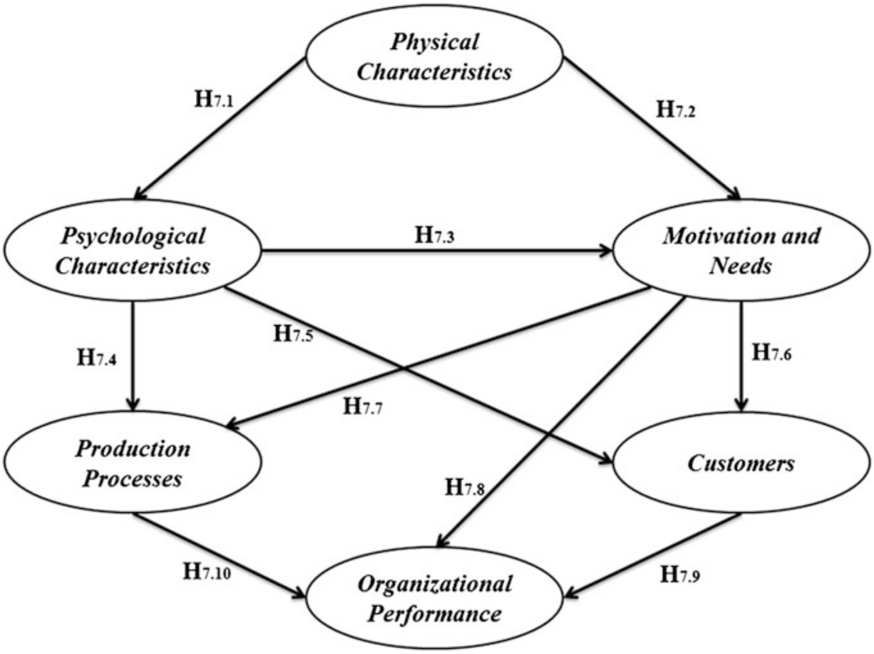

Fig. 7.3 Hypothetical model

7.3 Findings

This section discusses the results from the model assessment.

7.3.1 *Model Fit and Quality Indices*

In this model, APC and ARS showed values of 0.313 and 0.312, respectively, and their corresponding P values were lower than 0.001. Therefore, we concluded that all the model relationships were statistically significant. Similarly, the value of the Tenenhaus GoF (GoF = 0.048) index demonstrated that the model had large explanatory power and predictive capability (Kock 2015). As for the validity of the MCQ, all the Cronbach's alpha values were higher than 0.7, and AVE reported values above 0.5 in all the latent variables. From the Cronbach's alpha and AVE values, we confirmed the high reliability and convergent and discriminant validity of the questionnaire. Additionally, the R^2 coefficient had acceptable values (i.e., higher than 0.02) in all the dependent latent variables. Finally, all the Q^2 values were above zero, thereby implying that every dependent latent variable had high nonparametric predictive validity. Table 7.9 shows the MCQ validation results for the macroergonomic factor Person.

7.3.2 *Direct Effects*

Figure 7.4 introduces the direct effects between the analyzed variables. Direct effects measure the sensitivity to changes from a dependent latent variable caused by one independent latent variable, while all the remaining variables in the analysis remain unchanging (Pearl 2001). Each direct effect is usually associated with a beta (β) value and a P value. β values are standardized dependence measurement values. For instance, the relationship between employee *Physical Characteristics* and

Table 7.9 Structural validation of the MCQ-Person factor

Index	Physical Characteristics	Psychological Characteristics	Motivation and Needs	Customers	Production Process	Organizational Performance
R-Squared (R^2)		0.238	0.400	0.298	0.355	0.411
Cronbach's alpha	0.713	0.840	0.764	0.822	0.770	0.782
Average variance extracted (AVE)	0.642	0.677	0.588	0.654	0.600	0.697
Q-Squared (Q^2)		0.244	0.406	0.305	0.357	0.415

Psychological Characteristics shows $\beta = 0.49$, meaning that when the former variable increases by one standard deviation, the latter increases by 0.49 standard deviations.

P values are hypothesis test values and determine whether a relationship is statistically significant at a 95% confidence level; that is, $P < 0.05$. As can be observed, all the hypothesized relationships were statistically significant since they all showed *P* values lower than 0.05. Regarding the effects magnitude, we found the largest direct effect in the relationship *Physical Characteristics–Psychological Characteristics*. The second largest effect was caused by *Psychological Characteristics* on *Motivation and Needs*, and it was followed by the relationship *Customers–Organizational Performance*. All these effects showed β values higher than 0.4. Considering these values, the structural equations for the dependent latent variables of this chapter can be stated as follows:

$$\text{Psychological Characteristics} = 0.49 \times \text{Physical Characteristics} + \text{Error} \tag{7.2}$$

$$\begin{aligned}\text{Motivation and Needs} = {} & 0.33 \times \text{Physical Characteristics} + 0.41 \\ & \times \text{Psychological Characteristics} + \text{Error}\end{aligned} \tag{7.3}$$

$$\begin{aligned}\text{Production Processes} = {} & 0.29 \times \text{Psychological Characteristics} + 0.24 \\ & \times \text{Motivation and Needs} + \text{Error}\end{aligned} \tag{7.4}$$

$$\begin{aligned}\text{Customers} = {} & 0.31 \times \text{Psychological Characteristics} + 0.30 \\ & \times \text{Motivation and Needs} + \text{Error}\end{aligned} \tag{7.5}$$

$$\begin{aligned}\text{Organizational Performance} = {} & 0.29 \times \text{Psychological Characteristics} + 0.24 \\ & \times \text{Motivation and Needs} + \text{Error}\end{aligned} \tag{7.6}$$

Table 7.10 summarizes the results for the tested hypotheses (i.e., acceptance or rejection) depicted in Fig. 7.4.

Table 7.10 Testing of hypotheses

Hypothesis	Independent variable	Dependent variable	Decision
$H_{7.1}$	Physical Characteristics	Psychological Characteristics	Accepted
$H_{7.2}$	Physical Characteristics	Motivation and Needs	Accepted
$H_{7.3}$	Psychological Characteristics	Motivation and Needs	Accepted
$H_{7.4}$	Psychological Characteristics	Production Processes	Accepted
$H_{7.5}$	Psychological Characteristics	Customers	Accepted
$H_{7.6}$	Motivation and Needs	Customers	Accepted
$H_{7.7}$	Motivation and Needs	Production Processes	Accepted
$H_{7.8}$	Motivation and Needs	Organizational Performance	Accepted
$H_{7.9}$	Customers	Organizational Performance	Accepted
$H_{7.10}$	Production Processes	Organizational Performance	Accepted

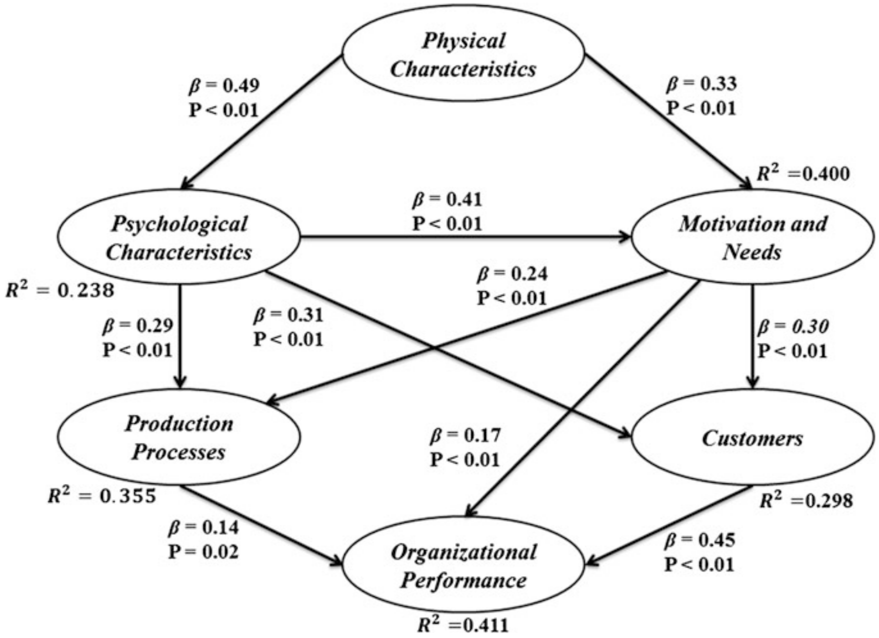

Fig. 7.4 Direct effects between latent variables

7.3.3 *Indirect Effects*

The indirect effects between two latent variables occur through other dimensions acting as intermediaries. Visually, indirect relationships can be tracked by following two or more model paths (García-Alcaraz et al. 2014; Realyvásquez et al. 2016c). Table 7.11 presents the indirect effects found in this model. According to the P values, all the indirect relationships were statistically significant, since they reported $P < 0.05$. Also, notice that the largest indirect effects were caused by *Physical Characteristics* on *Customers*, following the effects of *Psychological Characteristics* on *Organizational Performance*.

Table 7.11 Sum of indirect effects

To	From		
	Physical Characteristics	Psychological Characteristics	Motivation and Needs
Motivation and Needs	0.198*		
Customers	0.314*	0.123**	
Production Processes	0.266*	0.093**	
Organizational Performance	0.268*	0.319*	0.170**

*Significant at 99.9%
**Significant at 98%

Table 7.12 Total effects

To	From				
	Physical Characteristics	Psychological Characteristics	Motivation and Needs	Clients	Production Processes
Psychological Characteristics	0.49*				
Motivation and needs	0.528*	0.41*			
Customers	0.314*	0.433*	0.30*		
Production Processes	0.266*	0.383*	0.24*		
Organizational Performance	0.268*	0.319*	0.34*	0.45*	0.14**

*Significant at 99.9%
**Significant at 98%

Indirect effects can be interpreted in the same way as direct effects. For instance, the indirect relationship *Physical Characteristics—Customers* showed $\beta = 0.314$, meaning that when the first latent variable increased by one standard deviation, the second latent variable also increased by 0.314 standard deviations.

7.3.4 Total Effects

The total effects of a relationship correspond to the sum of its direct and indirect effects (García-Alcaraz et al. 2014; Realyvásquez et al. 2016c). Table 7.12 introduces the total effects found in this model.

In this model, we found that the largest total effects were caused by employee *Physical Characteristics* on employee *Motivation and Needs* and by employee *Physical Characteristics* on *Psychological Characteristics*. Also, our results revealed that although all the macroergonomic characteristics of employees had visible total effects on *Customers*, *Production Processes*, and *Organizational Performance*, *Customers* have the largest total effects on *Organizational Performance*. Such results demonstrate that *Customers* are a key to competitiveness.

7.4 Conclusions

Findings reported in Fig. 7.4, and Table 7.11 demonstrate that employee *Physical Characteristics and Psychological Characteristics* are a key to the competitiveness of manufacturing systems located in Chihuahua, Mexico. Employee *Physical Characteristics* have direct, indirect, and total effects on almost all the remaining latent variables. Similarly, the *Psychological Characteristics* of workers cause the largest effect on their own *Motivation and Needs*, but also on *Customers*, and *Production Processes*. In addition, *Psychological Characteristics* have the largest indirect effects on *Organizational Performance* and the largest total effects on *Customers and Production Processes*. Likewise, we found that *Customers* of Mexican manufacturing systems have the strongest direct and total impact on both *Organizational Performance* and *Production Processes*. Such results imply that manufacturing systems must pay close attention to customer-related variables, such as satisfaction, loyalty, and complaints if they wish to increase their competitiveness.

Considering the results of Fig. 7.4, we propose the following conclusions:

- In manufacturing work systems, the macroergonomic compatibility of employee *Physical Characteristics* is necessary for the macroergonomic compatibility of employee *Psychological Characteristics* ($H_{7.1}$).
- In manufacturing work systems, the macroergonomic compatibility of employee *Physical Characteristics* and employee *Psychological Characteristics* is necessary for the macroergonomic compatibility of employee *Motivation and Needs* ($H_{7.2}$, $H_{7.3}$).
- In manufacturing work systems, the macroergonomic compatibility of employee *Physical Characteristics* and *Motivation and Needs* is necessary for *Customer* satisfaction ($H_{7.5}$, $H_{7.6}$).
- In manufacturing work systems, the macroergonomic compatibility of employee *Psychological Characteristics* and employee *Motivation and Needs* is necessary to effective *Production Processes* ($H_{7.4}$, $H_{7.7}$).
- In manufacturing work systems, the macroergonomic compatibility of employee *Motivation and Needs*, *Customer* satisfaction, and effective *Production Processes* is necessary for good *Organizational Performance* ($H_{7.8}$, $H_{7.9}$, $H_{7.10}$).

Finally, this research lacked enough statistical evidence to reject any of the aforementioned hypothesized relationships. However, our results are only valid to employees and manufacturing systems having participated in the study. To reach a higher, global impact and increase the validity of our model (see Fig. 7.3), we recommend reproducing this study in other countries and cultures. Our methodology here presented is an original, brand-new approach that relates the effects of the macroergonomic compatibility of employee *Physical* and *Psychological* characteristics on manufacturing system performance—studied through *Customers*, *Production Processes*, and *Organizational Performance*. As for the MCQ, it proved to be a new, reliable, and effective instrument when it comes to collecting data on macroergonomic practices in manufacturing work systems. The questionnaire is a valuable tool to measure macroergonomic compatibility in manufacturing companies with the help of statistical or mathematical models.

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Chapter 8
The Impact of the Organization Factor on Manufacturing System Performance: A Causal Model

Abstract This chapter proposes a hypothetical causal model that relates organizational elements with the performance of manufacturing work systems. More specifically, the model here presented studies the effects of three macroergonomic organizational elements—*Organizational Culture and Safety Culture, Coordination, Collaboration, and Communication*, and *Teamwork*—on *Customers, Production Processes,* and *Organizational Performance*. As for the data collection instrument, we administered the Macroergonomic Compatibility Questionnaire (MCQ) to middle and senior managers of Mexican manufacturing companies located in the state of Chihuahua. Our findings revealed that the macroergonomic elements of the Organization factor increase competitiveness, since they have significant effects on the performance of manufacturing systems. Similarly, we found that *Customers* and *Production Processes* can positively impact *Organizational Performance*.

8.1 Macroergonomic Compatibility Questionnaire

8.1.1 Developing the Macroergonomic Compatibility Questionnaire

The questionnaire used to collect data on the Organization factor corresponds to the one previously presented and used in Chap. 7. The same macroergonomic compatibility questionnaire (MCQ) was used throughout Chaps. 7, 8, 9, and 10. However, each chapter takes into account and discusses only the survey items of its corresponding macroergonomic factor. In this chapter, thus, we discuss how we collected data on the macroergonomic compatibility of the Organization factor through the MCQ parts that address this factor. Table 8.1 shows the items of Section II of the MCQ-WV that correspond to the Organization factor. As in the previous chapter, the factor is studied through its macroergonomic elements, including *Organizational Culture and Safety Culture, Coordination, Collaboration, and Communication*, and *Teamwork*. The right column shows the Likert scale used to answer the questionnaire.

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Table 8.1 Section II of the MCQ-WV

In your company	1	2	3	4	5
Organizational culture and safety culture					
Corporate goals and values are clearly transmitted from the beginning					
Employees know the corporate goals					
Employees strive to achieve the corporate goals and work under corporate values					
Change is promoted					
Division of work helps achieve corporate goals					
A safety culture is promoted among employees					
Safety inspections are performed regularly					
Coordination, collaboration, and communication					
Employees work in coordination, collaboration, and communication					
Employees can communicate with one another regardless of their hierarchical position					
Employees receive feedback to maintain effective organizational communication					
The company has different forms of communication (visual, oral, auditory, written)					
Teamwork					
Employees complete some tasks in teams					
Employees receive help from coworkers if they have questions or encounter difficulties when performing a task					
Employee ideas, opinions, and suggestions are respected					
Employees receive feedback on their performance from coworkers and managers					

To collect the data regarding the benefits of implementing macroergonomic practices in manufacturing companies, employees responded to Section III of the MCQ-WV, which was first introduced in Chap. 7 (see Table 7.2). The data collected from Tables 8.1 and 7.2 allowed us to build a structural equation model to identify the effects of the Organization factor on manufacturing system performance from a macroergonomic perspective.

Table 8.2 shows the questions or items assessing the Organization factor in the experts' version of the questionnaire (MCQ-EV). The right column includes the five-point Likert scale used to answer the questionnaire (see Table 7.2). As a reminder, the MCQ-EV gathered information regarding the importance of a set of practices to the macroergonomic compatibility of the Organization factor.

The experts' assessments through the MCQ-EV helped us decide whether a given macroergonomic element could remain in the questionnaire despite having shown an ordinal alpha value below 0.7.

Table 8.2 MCQ-EV: Organization factor

Instructions: In your opinion, how important is to implement the following macroergonomic practices in manufacturing systems? Please answer all the questions					
	Importance				
Macroergonomic practices	1	2	3	4	5
Ergonomic assessment of tasks performed in team					
Ergonomic assessment of employee coordination, collaboration, and communication					
Ergonomic assessment of the organizational culture and the safety culture					
Ergonomic assessment of the work schedules set by the company					
Ergonomic assessment of the social relationships among workers					
Ergonomic assessment of supervisory and management styles					
Ergonomic assessment of performance evaluations, rewards, and incentives					

8.1.2 Administering the Macroergonomic Compatibility Questionnaire (MCQ)

To collect data on organizational elements from a macroergonomic perspective, we followed the steps as in Chap. 7 (see Sect. 7.1.2).

8.1.3 Reliability of the Macroergonomic Compatibility Questionnaire (MCQ)

As in the previous chapter, we tested the reliability of the three organizational elements by computing the ordinal alpha index for every one of them (see Eq. 7.1). Table 8.3 shows the analysis results and also the experts' assessments (w) regarding the importance of each organizational element.

As can be observed, only the macroergonomic element *Work Schedules* reported an ordinal alpha index below 0.7. According to the methodology previously discussed, we preliminarily removed this element. However, according to the expert's

Table 8.3 Ordinal alpha values and average crisp weights of macroergonomic elements of the Organization factor

Macroergonomic element	Ordinal alpha	Experts w^*
Teamwork	0.857	0.680
Organizational culture and safety culture	0.855	0.730
Performance evaluation, rewards, and incentives	0.837	0.610
Supervision and management styles	0.826	0.760
Coordination, collaboration, and communication	0.819	0.650
Social relationships	0.781	0.540
Work schedules	0.593	0.760

weights, both *Supervision and Management Styles* and *Work Schedules* were the most important elements for the macroergonomic compatibility of the Organization factor. Therefore, in the end, *Work Schedules* was reintroduced in the MCQ and considered for additional analyses.

8.2 Structural Equation Model

8.2.1 Effects of the Organization Factor on Manufacturing System Performance—Hypotheses

The model presented in this chapter studies the effects of the Organization factor on the performance of manufacturing systems. To succeed in this study, we proposed ten hypotheses and later tested them using the structural equation modeling (SEM) technique. As independent latent variables, we considered the macroergonomic elements of *Organizational Culture and Safety Culture, Coordination, Collaboration,* and *Communication*, and *Teamwork*. The items corresponding to these latent variables are listed in Table 8.1. As for the dependent latent variables, they corresponded to work system performance variables: *Customers*, *Production Processes*, and *Organizational Performance*. The items corresponding to these latent variables are presented in Table 7.2 of Chap. 7.

To propose the ten hypotheses, we conducted a comprehensive review of the literature, mainly in journals of ergonomics and manufacturing. According to this review, few studies have explored the effects of macroergonomic organizational elements on the performance of manufacturing systems. Fortunately, similar research works have been carried out in other work systems, and such works helped us hypothesize about the relationships between the proposed variables.

Research has demonstrated that *Organizational Culture and Safety Culture* have an impact on various corporate aspects. For instance, Aktaş et al. (2011) found out that *Organizational Culture and Safety Culture* had effects on organizational efficiency, whereas Nes et al. (2007) discovered that cultural difference between export and import companies affected the exporter–foreign middleman relationship in terms of communication. Similarly, Webber (2011) proved that managers having a strong identification to their company had more loyal customers if compared to managers that did not have identification to their company. Also, MacIntosh and Doherty (2007) analyzed the external perception of *Organizational Culture* on a fitness company in Canada and found that *Customer* perceptions regarding the *Organizational Culture* had an impact on preference loyalty. Considering these findings, the first two research hypotheses ($H_{8.1}$, $H_{8.2}$) of this chapter read as follows:

$H_{8.1}$: In manufacturing work systems, the macroergonomic compatibility of *Organizational Culture and Safety Culture* has positive direct effects on the macroergonomic compatibility of *Coordination, Collaboration*, and *Communication.*

$H_{8.2}$: In manufacturing work systems, the macroergonomic compatibility of *Organizational Culture and Safety Culture* has positive direct effects on *Customer* loyalty.

Authors Borca and Baesu (2014) claimed that *Coordination, Collaboration*, *and Communication* have visible effects on *Organizational Performance* and competitiveness and improve the corporate image. Similarly, le Roux (2014) discovered that effective communication strategies improve *Organizational Performance*, whereas Mitrofan and Bulborea (2013) emphasized on the influence of communication in structuring interpersonal relationships in a banking organization. The authors concluded that efficient communication is a key to the success or failure of companies, and close relationships between managers and their subordinates improve long-term work performance.

In their work, Nordin et al. (2014) demonstrated that *Coordination, Collaboration, and Communication* encourage or hinder horizontal, upward, or downward communication among employees. For instance, in companies with defensive climates, employees avoid communicating their needs and show low motivation levels. In addition, Jaradat and Sy (2012) argue that companies, business, or agencies that offer a product or service have to interact and operate with other people through communication, and such communication influences every aspect of the organization. Finally, Luthans (2005) stated that communication plays an important role in decision-making and is thus necessary for success. Moreover, organizations that ensure a good communication environment better motivate the employees to work cooperatively and efficiently.

Considering our discussion regarding the role of *Coordination, Collaboration, and Communication* in work system performance, we propose the next three research hypotheses ($H_{8.3}$, $H_{8.4}$, $H_{8.5}$) of this chapter as follows:

$H_{8.3}$: In manufacturing work systems, the macroergonomic compatibility of *Coordination, Collaboration, and Communication* has positive direct effects on the macroergonomic compatibility of *Teamwork.*

$H_{8.4}$: In manufacturing work systems, the macroergonomic compatibility of *Coordination, Collaboration, and Communication* has positive direct effects on *Customer* loyalty.

$H_{8.5}$: In manufacturing work systems, the macroergonomic compatibility of *Coordination, Collaboration, and Communication* has positive direct effects on *Organizational Performance*.

Multiple studies suggest a positive relationship between *Teamwork* and *Organizational Performance*. In their work, Baker et al. (2006) found that *Teamwork* increased company reliability, while Hoegl and Gemuenden (2001) discovered that the same variable was crucial to develop innovative problems. Meanwhile, Tohidi and Tarokh (2006) studied the relationship between *Teamwork* performance and team size. The authors concluded that optimal team size is reached when the cost per team member is positive and marginally non-decreasing. Finally, Davidson and Tay (2003) argue that *Teamwork* influences competitiveness, whereas Tabassi et al. (2012) and Yang et al. (2011) found that organizations that promote *Teamwork* also improve *Organizational Performance* and encounter less difficulty when developing projects. Considering these findings, we propose hypotheses $H_{8.6}$ and $H_{8.7}$ of this chapter below:

$H_{8.6}$: In manufacturing work systems, the macroergonomic compatibility of *Teamwork* has positive directs effect on *Production Processes*.
$H_{8.7}$: In manufacturing work systems, the macroergonomic compatibility of *Teamwork* has positive direct effects on *Organizational Performance*.

Studies have revealed that *Production Processes* have an impact of internal and external corporate aspects. Colledani et al. (2014) state that manufacturing work systems operate to meet high product quality and increase *Customer* loyalty by using the least amount of necessary resources. Similarly, according to Lagacé and Bourgault (2003), reliable *Production Processes* are a key condition to long-term sustainability. In addition, it has been demonstrated that *Production Processes* have a positive direct effect on the *Organizational Performance* of manufacturing work systems (Realyvásquez et al. 2015, 2016a). Finally, Abdulmalek and Rajgopal (2007) provided examples of a reliable *Production Process* from a manufacturing company. Based on these findings, hypotheses $H_{8.8}$ and $H_{8.9}$ of this chapter read as follows:

$H_{8.8}$: In manufacturing work systems, *Production Processes* have positive direct effects on *Customers*.
$H_{8.9}$: In manufacturing work systems, *Production Processes* have positive direct effects on *Organizational Performance*.

Customers play an important role in competitiveness. In their research, Alden et al. (2004) discovered a positive relationship between *Customer* satisfaction and preference loyalty, which encouraged the clinics to remain competitive. Similarly, Junquera et al. (2012) found that *Customer* involvement in environmental and organizational performance issues had a positive effect on the competitiveness of manufacturing companies. Following these findings, we propose the last research hypothesis of this chapter as follows:

$H_{8.10}$: In manufacturing work systems, *Customers* have positive direct effects on *Organizational Performance.*

Figure 8.1 depicts the causal model proposed to relate the macroergonomic compatibility of the Organization factor with the overall performance of manufacturing companies. The model was analyzed using statistical software WarpPLS v. 5, which is useful when having relatively small samples (García-Alcaraz et al. 2014; Kock 2015). Also, WarpPLS v. 5 is based on partial least squares (PLS) algorithms instead of conventional lineal regression algorithms. PLS algorithms allow non-lineal models to be effectively evaluated (Ockert 2014; Kock

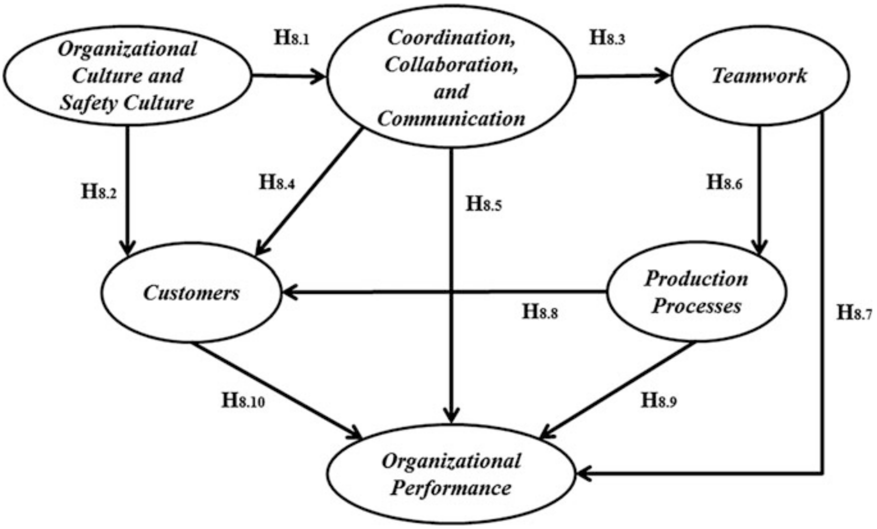

Fig. 8.1 Proposed model

2015). Also, we do not provide fit indices such as chi-squared (X^2), the root-mean-square error of approximation (RMSEA), or the goodness of fit index (GFI), since they were irrelevant to the study (Ockert 2014).

To test the model, we computed three model fit indices: Average Path Coefficient (APC), Average R-Squared (ARS), and Average Variance Inflation Factor (AVIF). APC and ARS have P values. To accept any relationship, the two P values had to be lower than 0.05, that is, significant at a 95% confidence level. The relationships that were not statistically significant were removed from the model. Then, we analyzed the factor loadings. If the value of given item showed a higher value in a latent variable to which it did not belong, this item was removed. As for AVIF, we set 5 as the maximum accepted value (García-Alcaraz et al. 2014; Kock 2015). Finally, we tested three types of effects. Direct effects were used to validate our hypotheses and implied a direct relationship between two latent variables. We also estimated indirect effects and total effects, being the latter the sum of the direct effects and the indirect effects for a relationship.

8.3 Results

This section is divided into several subsections and presents the results obtained after testing the model.

8.3.1 Model Fit and Quality Indices

APC and ARS showed values of 0.412 and 0.380, respectively, with *P* values lower than 0.001. As for the Tenenhaus goodness of fit (GoF) index, its value—GoF = 0.479—demonstrated that our model had enough explanatory power and predictive capability (Kock 2015). Also, according to the Cronbach's alpha index, the MCQ is a highly reliable instrument, since all dimensions reported values above 0.7. Similarly, all the dimensions showed AVE values above 0.5, which validated the MCQ discriminant and convergent validity. Finally, the R^2 coefficient was higher than 0.2 in every dependent latent variable, whereas all the Q^2 values were higher than 0. Such results denote high parametric predictive validity. Table 8.4 lists the structural validation of the MCQ for the Organization factor.

8.3.2 Direct Effects

Figure 8.2 shows the direct effects between the latent variables. Direct effects generally measure the sensitivity of a dependent variable to changes caused by an independent latent variable, while the other latent variables remain fixed (Pearl 2001). All the direct effects were associated with a β value and a *P* value, being β values standardized dependence measurements. For instance, in the relationship between *Teamwork* and *Production Processes*, $\beta = 0.51$ implies that when the first latent variable increases by one standard deviation, the second latent variable increases by 0.51 standard deviations. On the other hand, P values represent hypothesis testing values and indicated whether the relationships were statistically significant at a 95% confidence level; that is, $P < 0.05$. Therefore, hypotheses $H_{8.5}$ and $H_{8.7}$, depicted in doted lines, were removed from the model, since they reported P values higher than 0.05 ($P = 0.06$ and $P = 0.18$, respectively).

In this model, the largest direct effects were caused by *Organizational Culture and Safety Culture* on *Coordination, Collaboration, and Communication,* since in

Table 8.4 MCQ structural validation for the factor organization

Index	Organizational culture and safety culture	Coordination, collaboration, and communication	Teamwork	Customers	Production processes	Organizational performance
R-Squared (R^2)		0.418	0.403	0.428	0.265	0.389
Cronbach's alpha	0.810	0.713	0.779	0.822	0.770	0.782
Average variance extracted (AVE)	0.514	0.545	0.601	0.654	0.600	0.697
Q-Squared (Q^2)		0.422	0.406	0.433	0.270	0.392

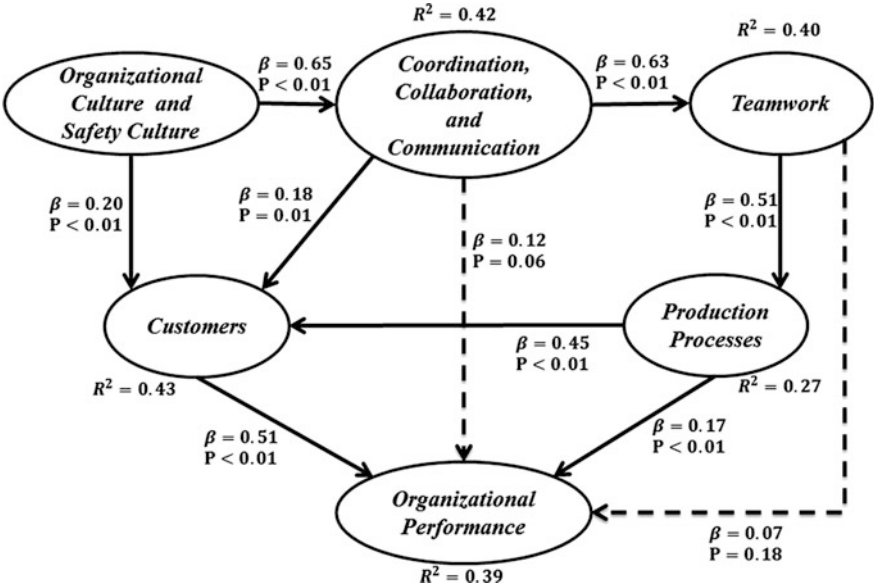

Fig. 8.2 Direct effects between latent variables

this relationship $\beta = 0.65$. Also, *Coordination, Collaboration, and Communication* had one of the largest directs effects on *Teamwork*, showing $\beta = 0.\ 63$. As for the R^2 values, they indicated the percentage of explained variance of dependent latent variables; that is, these values reflect to what extent an independent or exogenous latent variable was responsible for the variability of a dependent or endogenous latent variable. For instance, dependent latent variable *Coordination, Collaboration, and Communication* showed $R^2 = 0.42$, and this implies that its variability was 42% explained by *Organizational Culture and Safety Culture*. Similarly, the variability of *Teamwork* was 40% explained by *Coordination, Collaboration, and Communication*, whereas *Production Processes* was 27% explained by *Teamwork*.

Sometimes, latent variables depend upon more than one independent latent variable. In this research, for instance, we found that *Customers* were 43% explained by three latent variables: 8.4% by *Coordination, Collaboration, and Communication*, 8.9% by *Organizational Culture and Safety Culture*, and 25.7% by *Production Processes*. Also, *Organizational Performance* was 39% explained by *Customers* (31%) and *Production Processes* (8%).

Figure 8.3 illustrates only the significant effects of the model, that is, without the dotted lines.

Considering the aforementioned results, the structural equations for the dependent latent variables are proposed as follows:

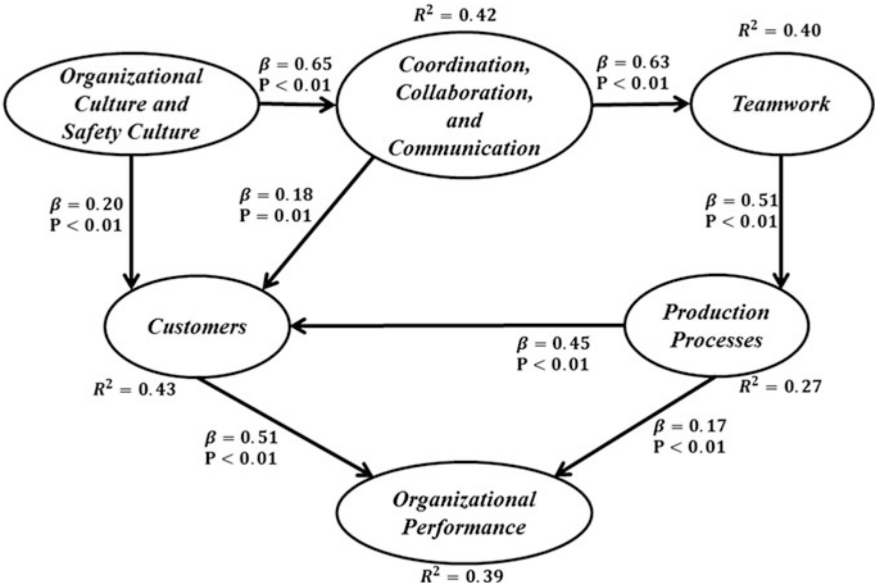

Fig. 8.3 Significant direct effects between latent variables

$$\begin{aligned}\text{Coordination, Collaboration, and Communication} &= 0.51\\ &\times \text{Organizational Culture and Safety Culture} + \text{Error}\end{aligned} \quad (8.1)$$

$$\text{Teamwork} = 0.63 \times \text{Coordination, Collaboration, and Communication} + \text{Error} \quad (8.2)$$

$$\text{Production Processes} = 0.51 \times \text{Teamwork} + \text{Error} \quad (8.3)$$

$$\begin{aligned}\text{Customers} = {} & 0.20 \times \text{Organizational Culture and Safety Culture} + 0.18\\ & \times \text{Coordination, Collaboration, and Communication} + 0.45\\ & \times \text{Production Processes} + \text{Error}\end{aligned} \quad (8.4)$$

$$\begin{aligned}\text{Organizational Performance} = {} & 0.17 \times \text{Production Processes} + 0.51\\ & \times \text{Customers} + \text{Error}.\end{aligned} \quad (8.5)$$

Table 8.5 summarizes the hypotheses validation results. Hypotheses $H_{8.5}$ and $H_{8.7}$ were rejected and removed from the model.

Table 8.5 Hypotheses validation results

Hypothesis	Independent variable	Dependent variable	Decision
$H_{8.1}$	Organizational culture and safety culture	Coordination, collaboration, and communication	Accepted
$H_{8.2}$	Organizational culture and safety culture	Customers	Accepted
$H_{8.3}$	Coordination, collaboration, and Communication	Teamwork	Accepted
$H_{8.4}$	Coordination, collaboration, and communication	Customers	Accepted
$H_{8.5}$	Coordination, collaboration, and communication	Organizational performance	Rejected
$H_{8.6}$	Teamwork	Production processes	Accepted
$H_{8.7}$	Teamwork	Organizational performance	Rejected
$H_{8.8}$	Production processes	Customers	Accepted
$H_{8.9}$	Production processes	Organizational performance	Accepted
$H_{8.10}$	Customers	Organizational performance	Accepted

8.4 Indirect Effects

Indirect effects occur between two dimensions or latent variables through other dimensions known as mediators. Visually, indirect effects can be tracked by following two or more segment paths (García-Alcaraz et al. 2014; Realyvásquez et al. 2016b). Table 8.6 illustrates these indirect relationships, and all of them were statistically significant at a 99% confidence level, since all the P values were lower than 0.001. Additionally, we found that *Organizational Culture and Safety Culture* had the highest indirect effects on *Teamwork*. That said, indirect effects can be interpreted similar to direct effects. For instance, in the indirect relationship between *Teamwork* and *Customers*, $\beta = 0.231$ means that when the first latent variable increased by one standard deviation, the second latent variable increased by 0.231 standard deviations.

Table 8.6 Sum of indirect effects

To	From			
	Organizational culture and safety culture	Coordination, collaboration, and communication	Teamwork	Production processes
Teamwork	0.410*			
Production processes	0.211*	0.327*		
Customers	0.210*	0.114*	0.231*	
Organizational performance	0.242*	0.221*	0.206*	0.229*

*Significant at 99.9%

Table 8.7 Total effects

To	From				
	Organizational culture and safety culture	Coordination, collaboration, and communication	Teamwork	Production processes	Customers
Coordination, collaboration, and communication	0.646*				
Teamwork	0.410*	0.643*			
Production processes	0.211*	0.327*	0.515*		
Customers	0.405*	0.324*	0.231*	0.448*	
Organizational performance	0.242*	0.221*	0.206*	0.229*	0.510*

*Significant at 99.9%

8.5 Total Effects

The total effects of a relationship are the sum of its direct and indirect effects (García-Alcaraz et al. 2014; Realyvásquez et al. 2016b). Table 8.7 summarizes the total effects found in the model. All of them were statistically significant at a 99.9% confidence level, as all the P values were lower than 99.9%. Such results imply that the analyzed macroergonomic elements had either direct or indirect effects on *Organizational Performance*.

According to Table 8.7, the largest total effects were in the relationship between *Organizational Culture and Safety Culture* and *Coordination, Collaboration, and Communication*, showing $\beta = 0.646$. Likewise, the effects of *Coordination, Collaboration, and Communication* on *Customers* showed a significantly large effect, as $\beta = 0.643$, thereby demonstrating that *Customers* play an important role in business competitiveness.

8.6 Conclusions

The results presented in Fig. 8.3, Table 8.6, and Table 8.7 demonstrate that *Organizational Culture and Safety Culture*, as well as *Coordination, Collaboration, and Communication* can significantly contribute to the competitiveness of Mexican manufacturing companies located in Chihuahua. Likewise, we found that all the analyzed latent variables had significant total effects on one another, yet the relationship between *Customers* and *Organizational Performance* showed the largest effect value. In turn, *Customers* were significantly affected by *Production Processes*, whose variability largely depended on *Teamwork*. Similarly, the variability of *Teamwork* was largely affected by *Coordination, Collaboration, and*

Communication, whose variability mostly depended on *Organizational Culture and Safety Culture.* Such results reveal that organizational macroergonomic elements are at the core of reliable *Production Processes*, good *Organizational Performance*, and satisfied *Customers*.

As for the indirect effects, this study found that *Organizational Performance* had the strongest impact on *Teamwork* ($\beta = 0.242$), whereas *Teamwork* showed the largest effect on *Customers*, as $\beta = 0.231$. Finally, latent variable *Coordination, Collaboration, and Communication* had the largest indirect effects on *Production Processes*, being $\beta = 0.327$. Following these results, we conclude that organizational macroergonomic elements have a positive impact on the competitiveness of Mexican manufacturing companies based in Chihuahua.

As for the data summarized in Fig. 8.2, we establish the following conclusions regarding the model proposed in Fig. 8.1:

- In manufacturing work systems, the macroergonomic compatibility of *Organizational Culture and Safety Culture* is necessary for the macroergonomic compatibility of *Coordination, Collaboration, and Communication* ($H_{8.1}$).
- In manufacturing work systems, the macroergonomic compatibility of *Organizational Culture and Safety Culture* and the macroergonomic compatibility of *Coordination, Collaboration, and Communication* are necessary for *Customer* satisfaction ($H_{8.2}$, $H_{8.4}$, $H_{8.8}$).
- In manufacturing work systems, the macroergonomic compatibility of *Coordination, Collaboration, and Communication* is necessary for the macroergonomic compatibility of *Teamwork* ($H_{8.3}$).
- In manufacturing work systems, the macroergonomic compatibility of *Teamwork* is necessary for efficient *Production Processes* ($H_{8.6}$).
- In manufacturing work systems, efficiency in *Production Processes* and *Customer* satisfaction are necessary for good *Organizational Performance* ($H_{8.9}$, $H_{8.10}$).

This study found enough statistical evidence to reject two hypothesized relationships—$H_{8.5}$ and $H_{8.7}$. However, these results are only valid to the manufacturing companies having participating in the research. To make generalizations, similar research has to be extended to other countries, cultures, and industrial sectors, as this would increase the external validity of our model. That said, our methodology is an original, brand-new approach to macroergonomic compatibility measurement, since it associates organizational macroergonomic compatibility—throughout a set of macroergonomic elements—with overall manufacturing system performance (assessed through *Customers*, *Production Processes*, and *Organizational Performance*). Finally, as far as the MCQ is concerned, we believe that it is a new and effective tool for gathering information regarding macroergonomic practices in the manufacturing industry. The MCQ effectively contributes to measuring work system macroergonomic compatibility with the aid of statistical methods and mathematical models.

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Chapter 9
The Impact of the Technologies and Tools Factor on Manufacturing System Performance: A Causal Model

Abstract In this chapter, we present a hypothetical causal model to understand the impact of tools and technologies as a macroergonomic factor on manufacturing system performance. More specifically, the model assesses the effects of three macroergonomic elements of technologies and tools on *Production Processes*, *Customers*, and *Organizational Performance*. Data were obtained after administering the Macroergonomic Compatibility Questionnaire (MCQ) to middle and senior managers on Mexican manufacturing companies located in the state of Chihuahua. Results reveal that information technology has significant effects on manufacturing system performance, which is why they must be considered as a source of competitiveness. Also, we found that *Customers* and *Production Processes* have a positive impact on *Organizational Performance*.

9.1 The Macroergonomic Compatibility Questionnaire (MCQ)

9.1.1 Developing the Macroergonomic Compatibility Questionnaire (MCQ)

Table 9.1 lists the MCQ items corresponding to macroergonomic factor Technologies and Tools and its corresponding elements: *Information Technology*, *Advanced Manufacturing Technology*, and *Human Factors Characteristics of Technologies and Tools*. The right column corresponds to the fuzzy Likert scale used to rate the items (see Chap. 7).

This chapter focuses only on the effects of Technologies and Tools elements on manufacturing system performance. For this reason, other macroergonomic factors and elements were not considered in the structural equation model here developed. Likewise, to collect data regarding the benefits of macroergonomic practices (MPs), we used the third section of the MCQ worker version (MCQ-WV), thoroughly discussed in Chap. 7 (see Table 7.2). The data obtained from section II and section III of the MCQ-WV were used to construct the model and determine the effects of

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Table 9.1 Section II of MCQ-WV

In your company	1	2	3	4	5
Information Technology					
Human and ergonomic factors are considered when investing in information technologies					
The tasks require the use of different information technologies					
The tasks that require the use of information technology are performed in risks-free environments					
Employees are informed of the technologies they use					
Employees have positive attitudes toward the technologies that they use					
Information technology has a positive impact on employee well-being and performance					
Using and adapting to information technology is not time-consuming					
Advanced Manufacturing Technology					
The company relies on diverse manufacturing technologies					
Human and ergonomic factors are considered when investing in manufacturing technology					
Tasks requiring the use of manufacturing technology are performed in risks-free environments					
Using and adapting to manufacturing technology is not time-consuming					
Human Factors Characteristics of Technologies and Tools					
Macroergonomic human and ergonomic characteristics are considered when purchasing manufacturing technology and tools					
Tasks performed with hand tools are risk-safe					

technologies and tools, as a macroergonomic factor, on manufacturing system performance.

Sometimes in statistical analyses, variables (in this case, elements) do not reach the desired ordinal alpha value when testing their reliability, yet such variables may still be relevant to the study. Therefore, to definitely exclude or keep any macroergonomic element having shown an ordinal alpha value below 0.7, we used the experts' version of the MCQ (MCQ-EV). In this survey, ergonomics experts had to rate the importance of a set of macroergonomic practices that reflected the importance of the analyzed macroergonomic elements. Table 9.2 lists the MCQ-EV items for the macroergonomic factor Technologies and Tools. Unlike in previous chapters, the number of survey items is not consistent with the number of studied macroergonomic elements, as both *Information Technology* and *Advanced*

Table 9.2 MCQ-EV for macroergonomic factor technologies and tools

Instructions: In your opinion, how important is to implement the following macroergonomic practices in manufacturing systems? Please answer all the questions					
	Importance				
Macroergonomic practices	1	2	3	4	5
Technologies and tools used by the employees					
Human factors characteristics of technologies and tool					

Manufacturing Technology were analyzed through a same item. Finally, notice that the right column of the table shows the fuzzy Likert scale used to rate these items (see Fig. 7.2).

9.1.2 Administering the Macroergonomic Compatibility Questionnaire (MCQ)

To collect the data, we followed the same survey administration steps as in Chap. 7 (see Sect. 7.1.2).

9.1.3 Reliability Analysis of the Questionnaire

As in previous chapters, the reliability of the macroergonomic Technologies and Tools elements was tested by estimating the ordinal alpha index (see Eq. 7.1). Table 9.3 shows the ordinal alpha values obtained in the three macroergonomic elements, and the weights from experts obtained from the MCQ-EV.

As in the previous two chapters, the three macroergonomic elements of Technologies and Tools showed ordinal alpha indices equal to or higher than 0.7. Thus, they were all kept in the MCQ and were used to develop the structural equation model (SEM).

9.2 Structural Equation Model

9.2.1 The Effects of the Technologies and Tools Factor on Manufacturing System Performance: Hypotheses Formulation

The SEM presented in this chapter studies the impact of Technologies and Tools, as a macroergonomic factor, on manufacturing system performance. Precisely, the model measures the effects among *Information Technology*, as the independent latent variable, *Customers*, *Production Processes*, and *Organizational Performance*, as dependent latent variables. The items used to analyze the three last variables can be consulted in Table 7.2 from Chap. 7. Then, to formulate the hypotheses, we

Table 9.3 Ordinal alpha values and average crisp weights of technologies and tools elements

Macroergonomic element	Ordinal alpha	Experts w^*
Information technology	0.832	0.780
Human factor characteristics of technologies and tools	0.811	0.700
Advanced manufacturing technology	0.787	0.780

performed a review of the literature in specialized journals of ergonomics and manufacturing. After carefully conducting this review, we found that studies carried out in the manufacturing industry do not analyze the effects of the macroergonomic compatibility of technologies and tools on manufacturing system performance. This gap was the motivation leading this study. To propose the hypotheses, we thus took into account research works similar to this study but conducted in other fields and work systems.

9.2.1.1 The Effects of *Information Technology* on *Production Processes*

According to Romaní (2009), *Information Technology* (IT) is technological devices (hardware and software) that facilitate the edition, generation, storage, and transmission of data between different information systems. IT integrates computer media, telecommunications, and networks and ensures interpersonal and multidirectional communication. Moreover, this type of technology plays a crucial role in knowledge access, generation, exchange, diffusion, and management. Some examples of IT include electronic data exchange (EDI), radio-frequency identification (RFID), the Internet, and the World Wide Web (WWW) (Gunasekaran et al. 2006).

According to Scheer and Nüttgens (2000), the term "business process" alludes to a process that is relevant when adding value to a company. Any business process primarily consists of *Customer* requirements that lead to the acceptation of a product order by the sales department. Then, the sales department communicates with the procurement department which supplies the required components. Finally, the production department plans and executes the production order. The first element in a business process is thus *Customer* needs, whereas the last element is product manufacturing.

Customers are also a key element of *Production Processes.* More specifically, *Customer* complaints along with other variables such as product defects, inventory levels, and productivity have proved to impact the *Production Processes* of work systems. From this perspective, numerous studies have analyzed the effects of *Information Technology* on different processes across companies and industrial sectors. For instance, Stiroh (2002) found that *Information Technology* could be associated with accelerated productivity. Similarly, Chou et al. (2014) concluded that countries with high *Information Technology* capital and/or good innovation complementarity increased their total factor productivity.[1] Research has equally demonstrated that *Information Technology* improves the *Production Processes* of manufacturing work systems (Yao et al. 2010; Aliu and Halili 2013). As for its impact on other areas, Melián-González and Bulchand-Gidumal (2016) showed that

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[1] Total factor productivity (TFP) is the portion of output not explained by the amount of inputs in production. As such, its level is determined by how efficiently and intensely the inputs are used in production (Comin 2008).

the use of *Information Technology* in the tourism industry exerts positive impacts on hotel check-in and check-out processes, whereas Surej (2015) demonstrated that *Information Technology* supports teachers in the teaching-learning process.

Improvements reached thanks to the implementation of *Information Technology* consequently lead to higher *Customer* satisfaction, since needs are better met (Etgar 2008). In turn, *Customer* satisfaction enhances *Organizational Performance* (Oyedele and Tham 2007). Following these findings and our discussion, we propose the first research hypothesis of this chapter as follows:

$H_{9.1}$: In manufacturing work systems, the macroergonomic compatibility of *Information Technology* has a positive direct effect on *Production Processes*.

9.2.1.2 The Effects of *Information Technology* on *Customers*

The Lobbying Disclosure Act (LDA) defines a customer as “a person or entity that retains or employs another person to engage in lobbying activities on behalf of that person or entity” (Luneburg and Susman 2005). This book considers *Customers* as an intermediate variable composed of four items: customer needs (Etgar 2008; Wilson and Carayon 2014), customer satisfaction, (Etgar 2008; Webber 2011), customer loyalty (Piegorsch et al. 2006; Webber 2011), and number of customers (Do et al. 2004; Piegorsch et al. 2006).

Experts have found that *Information Technology* has an impact on *Customers* across a wide range of sectors. As a result, *Information Technology* has been used to improve healthcare interventions (Bauer et al. 2014), thereby increasing customer (patient) satisfaction. Similarly, Morita and Nakahara (2004), Makkonen and Vuori (2014) demonstrated that Japanese manufacturer–supplier relationships could be better managed thanks to the use of *Information Technology*. Finally, in their work, Levina and Ross (2003) showed that in buyer–supplier relationships, *Information Technology* enabled to better define priorities, anticipate needs, and inform of changes. In other words, technological support allows companies to offer customers a better service and meet their needs more effectively. Following this discussion, we propose the next two research hypotheses ($H_{9.2}$ and $H_{9.3}$) as follows:

$H_{9.2}$: In manufacturing work systems, the macroergonomic compatibility of *Information Technology* has a positive direct effect on *Customers.*
$H_{9.3}$: In manufacturing work systems, the macroergonomic compatibility of *Production Processes* has a positive direct effect on *Customers.*

9.2.1.3 The Effects of *Information Technology* on *Organizational Performance*

Nowadays, the development of *Information Technology*—mainly in the WWW and its applications, such as social networks and means of communication—has contributed to the spread of information, and thus the generation of new ideas, in and among different social circles (Ni et al. 2014). Moreover, *Information Technology* has greatly benefitted areas such as education, health, manufacturing, transport, trade, services, and even war (Gunasekaran et al. 2006). A clear example of this phenomenon is the use of the iPad to audit and improve occupational safety in the construction industry (Lin et al. 2014).

Authors such as dos Reis and Freitas (2014) claim that *Information Technology* in *Production Processes* allows companies to increase competitiveness, operational performance, and economic performance. On the other hand, Dale (2001) and Stiroh (2002) point out that *Information Technology* has been acknowledged as a key element to economic growth, while other studies confirm that this kind of technology is a facilitator in the organizational learning process. *Information Technology* also influences the development of diverse technological competencies, which in turn increase industrial system performance (Robey et al. 2000; Real et al. 2006; Ruiz-Mercader et al. 2006). Finally, authors Shao and Lin (2001) have stated that *Information Technology* has a positive impact on technical efficiency, thereby contributing to a good *Organizational Performance.*

In this book, the *Organizational Performance* of manufacturing systems is considered as the final variable. According to some experts, *Organizational Performance* is a complex and multidimensional variable (Avci et al. 2011; Melián-González and Bulchand-Gidumal 2016). To several organizations, *Organizational performance* is based on economic results (Chandler et al. 2011; Melián-González and Bulchand-Gidumal 2016), yet in this research it is grounded on lean manufacturing principles and benefits and is measured throughout three items: number of employees (Axtell 2001; Melián-González and Bulchand-Gidumal 2016), product variety (Ismail 2007), and business volume (Armstrong and Baron 2002). Based on this discussion, the fourth research hypothesis of this chapter reads as follows:

$H_{9.4}$: In manufacturing work systems, the macroergonomic compatibility of *Information Technology* has a positive direct effect on *Organizational Performance.*

9.2.1.4 The Effects of *Production Processes* on *Organizational Performance*

In manufacturing work systems, *Production Process* reliability is one of the most significant aspects to be improved in terms of *Organizational Performance*. Studies have demonstrated that different organizational processes have positive impacts on *Organizational Performance*. Damanpour et al. (2009) argue that innovation in services, technology, and administration processes contribute to an effective *Organizational Performance*, whereas to Gunday et al. (2011), innovation is an essential component of business strategies, since it helps to improve *Production Process* reliability while enhancing *Organizational Performance*. Likewise, other studies have showed that reliable *Production Processes* have a positive impact on the *Organizational Performance* of manufacturing work systems (Realyvásquez et al. 2015). In this sense, authors Abdulmalek and Rajgopal (2007) illustrated a reliable *Production Process* of a manufacturing company. Following this discussion, the fifth research hypothesis ($H_{9.5}$) of this chapter can read as follows:

$H_{9.5}$: In manufacturing work systems, the macroergonomic compatibility of *Production Processes* has a positive direct effect on *Organizational Performance.*

9.2.1.5 The Effects of *Customers* on *Organizational Performance*

Research has demonstrated that *Customers* influence *Organizational* Performance. Satisfied *Customers* are the main source of employment (Kaderlan 1999; Oyedele and Tham 2007) and the most significant source of business competitiveness. In fact, as (Oyedele and Tham 2007; Maister 2012) claim, when companies are able to better understand and meet *Customer* needs, they can significantly increase their competitiveness. Also, *Customers* have the potential to improve other business aspects, such as employee skills and commitment, both having an impact on *Organizational Performance* (Oyedele and Tham 2007). Similarly, when *Customers* lack knowledge and experience, companies may fail or produce low-quality products. All this allows the sixth research hypothesis ($H_{9.6}$) of this chapter to be proposed below:

$H_{9.6}$: In manufacturing work systems, the macroergonomic compatibility of *Customers* has a positive direct effect on *Organizational Performance.*

Figure 9.1 illustrates the hypothetical causal model proposed in this chapter to study the relationship between *Information Technology* and the three variables of manufacturing system performance. The hypothesized relationships were analyzed using statistical software WarpPLS5®, which relies on partial least squares (PLS) for data analysis. PLS are not conventional lineal regression algorithms, but

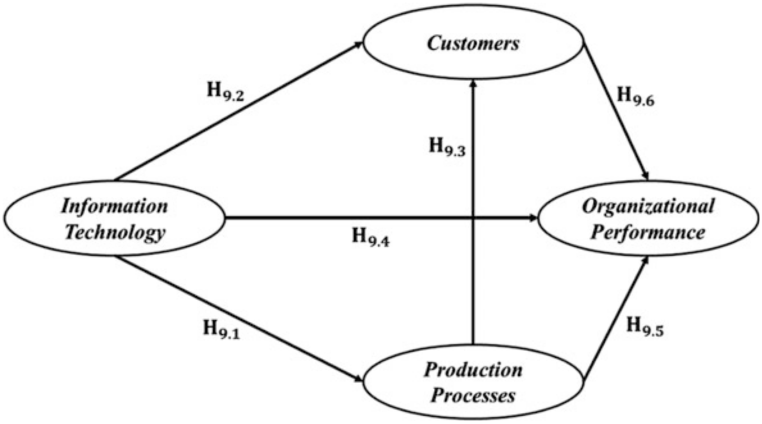

Fig. 9.1 Hypothetical model

are effective for managing non-linear models (Ockert 2014; Kock 2015). Also, notice that the model analysis does not provide model fit indices such as chi-squared (X^2), the root mean square error of approximation (RMSEA), and the goodness of fit (GIF), since they are not relevant to our study (Ockert 2014). Finally, WarpPLS® is a software tool widely used for analyzing relatively small samples (García-Alcaraz et al. 2014; Kock 2015).

To test the model, three model fit and quality indices were estimated: Average Path Coefficient (APC), Average R-Squared (ARS), and Average Variance Inflation Factor. APC and ARS have *P* values, used as a general criterion to accept or reject the hypothesized relationships. That said, such *P* values had to be lower than 0.05 ($P < 0.05$); that is, statistically significant at a 95% confidence level. Therefore, statistically not significant relationships were removed from the model. Then, we analyzed the factor loadings of the items and removed all those showing higher factor loading values in any variable in which they did not belong. As for AVIF, we set the maximum value at five (García-Alcaraz et al. 2014; Kock 2015). Finally, we analyzed direct, indirect, and total effects between variables. The direct effects were used to validate the hypothesized relationships discussed earlier and depicted in Fig. 9.1, whereas the indirect effects reflected indirect relationships between two latent variables. Finally, the total effects of a relationship were the sum of its direct and indirect effects.

9.3 Results

9.3.1 Model Fit and Quality Indices

APC and ARS showed values of 0.396 and 0.373, respectively, and *P* values lower than 0.001. The Tenenhaus GoF index equaled 0.479 units and thus confirmed the model's explanatory and predictive capabilities (Kock 2015). As for the MCQ analysis, the Cronbach's alpha value tested and demonstrated the questionnaire's high reliability, as all the analyzed dimensions or latent variables had values higher than 0.7. Similarly, the AVE values confirmed the survey's discriminant and convergent validity, since they were all above 0.5. The R^2 and Q^2 values from dependent latent variables were acceptable (higher than 0.02 and 0, respectively), thus confirming the survey's high predictive validity from both a parametric

Table 9.4 MCQ validation for macroergonomic factor technologies and tools

Index	Information technology	Customers	Production processes	Organizational performance
R-Squared (R^2)		0.424	0.308	0.389
Cronbach's alpha	0.757	0.822	0.770	0.782
Average variance extracted (AVE)	0.511	0.654	0.600	0.697
Q-Squared (Q^2)		0.426	0.311	0.392

perspective and a non-parametric perspective. Table 9.4 shows the MCQ validation results for macroergonomic factor Technologies and Tools.

9.3.2 Direct Effects

Figure 9.2 illustrates the direct effects between the analyzed latent variables. Direct effects measure the sensitivity of a dependent latent variable to changes caused by an independent latent variable, while the other latent variables remain fixed (Pearl 2001). As can be observed in the figure, each direct effect is expressed by a β value and a P value; the former being a standardized measure of dependence, and the latter testing the effect significance at a 95% confidence level (i.e. $P < 0.05$). Considering such values, we can state that in any significant relationship when latent variable A increases by one standard deviation, latent variable B increases by β standard deviations. For instance, in the relationship between *Information Technology* and *Production Processes*, $\beta = 0.55$ implies that as *Information Technology* increases by one standard deviation, *Production Processes* increases by 0.55 standard deviations.

As previously mentioned, statistically not significant relationships were removed from the model. Notice that in Fig. 9.2 the relationship between *Information Technology* and *Organizational Performance* ($H_{9.4}$) is not statistically significant since its P value is higher than 0.05 ($P = 0.30$). On the other hand, the relationship between *Information Technology* and *Organizational Performance* showed the largest effect in the analysis ($\beta = 0.55$), and it was then followed by the relationship between *Customers* and *Organizational Performance* ($\beta = 0.51$). As for the R^2 values, we found that *Production Processes* were 31% explained by *Information*

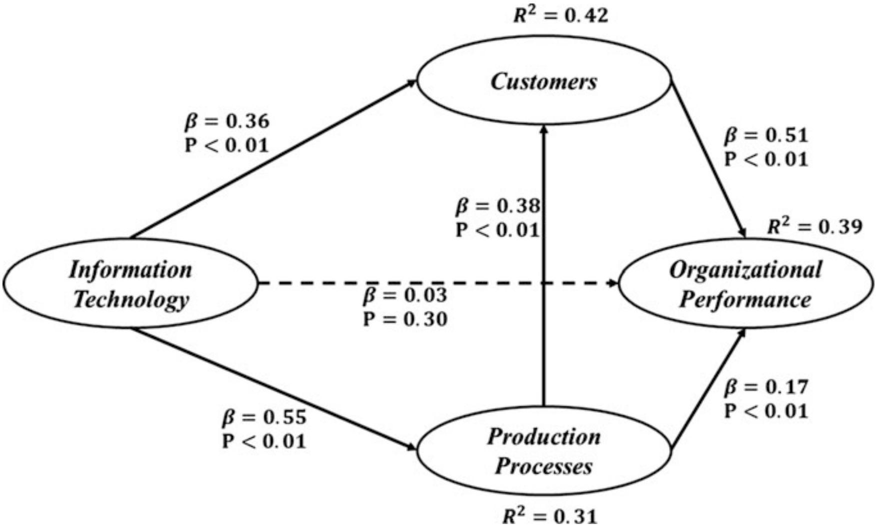

Fig. 9.2 Direct effects between latent variables

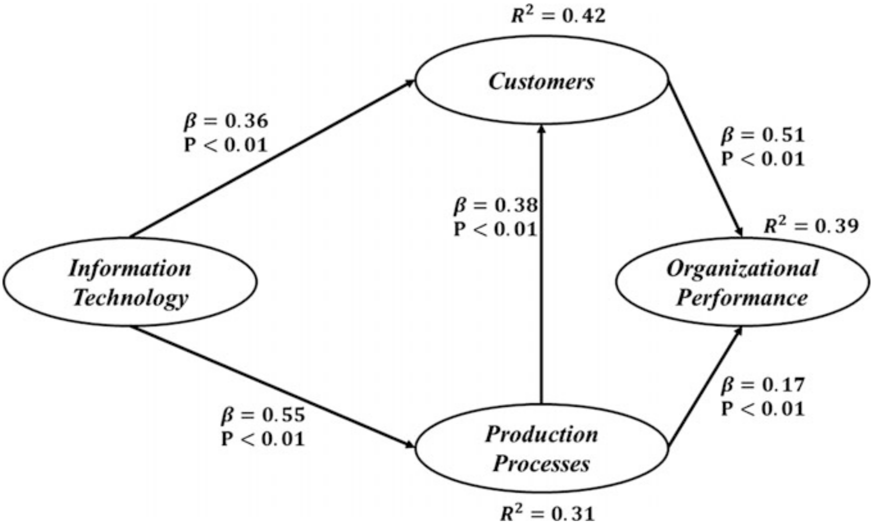

Fig. 9.3 Significant effects between latent variables

Technology, since $R^2 = 0.31$. However, sometimes dependent latent variables are explained by several independent latent variables. In this case, we found that *Customers* were 42% explained by *Information Technology* (20.43%) and *Production Processes* (21.57%). Also, the total variability of *Organizational Performance* was 39% explained by *Customers* (31%) and *Production Processes* (8%).

Figure 9.3 illustrates only the significant effects found between the latent variables.

Considering the results obtained for the direct effects, the structural equations of the analyzed dependent latent variables can be formulated as follows:

$$\text{Customers} = 0.36 * \text{Information Technology} + 0.38\ \text{Production Processes} + \text{Error} \tag{9.1}$$

$$\text{Production Processes} = 0.55 * \text{ICTs} + \text{Error} \tag{9.2}$$

$$\begin{aligned}\text{Organizational Performance} = 0.51 * \text{Customers} + 0.17 \\ * \text{Production Processes} + \text{Error}\end{aligned} \tag{9.3}$$

Table 9.5 summarizes the results obtained for the hypothesized relationships. As previously mentioned, only hypothesis $H_{9.4}$ was rejected.

9.3.3 Indirect Effects

Indirect effects occur between two latent variables through other dimensions acting as intermediaries. Visually, they can be tracked using two or more model paths

Table 9.5 Tested hypotheses

Hypothesis	Independent variable	Dependent variable	Conclusion
$H_{9.1}$	Information Technology	Production Processes	Accepted
$H_{9.2}$	Information Technology	Customers	Accepted
$H_{9.3}$	Production Processes	Customers	Accepted
$H_{9.4}$	Information Technology	Organizational Performance	Rejected
$H_{9.5}$	Production Processes	Organizational Performance	Accepted
$H_{9.6}$	Customers	Organizational Performance	Accepted

Table 9.6 Sum of indirect effects

To	From	
	Information Technology	Production Processes
Production processes		
Customers	0.211*	
Organizational performance	0.387*	0.194*

*Significant at a 99.9% level

(García-Alcaraz et al. 2014; Realyvásquez et al. 2016). Table 9.6 presents the analysis of indirect effects. All the estimated *P* values were below 0.001, thus demonstrating that every effect was statistically significant at a 99.9% confidence level. Notice also that the largest indirect effect has a value of 0.387 and was caused by *Information Technology* on *Organizational Performance*. Indirect effects can be interpreted in the same way as direct effects. For instance, in the indirect relationship between *Information Technology* and *Customers*, we found that when the former increased by one standard deviation, the latter increased by 0.211 standard deviations.

9.3.4 Total Effects

The total effects of a relationship are the sum of its direct and indirect effects (García-Alcaraz et al. 2014; Realyvásquez et al. 2016). For this chapter, Table 9.7 introduces the total effects estimated for the hypothesized relationships. All the estimated total effects were significant at a 99.9% confidence level, since each

Table 9.7 Total effects

To	From		
	Information Technology	Customers	Production Processes
Customers	0.573*		0.381*
Production Processes	0.555*		
Organizational Performance	0.387*	0.510*	0.365*

*Significant at 99.9%

P value was lower than 0.001. Such results imply that *Information Technology* has significant effects—either direct or indirect—on *Organizational Performance.*

According to Table 9.7, the most significant total effects were found in two relationships: between *Information Technology* and *Customers* and between *Information Technology* and *Production Processes*, showing values of 0.573 and 0.555, respectively. Also, it was found that three variables—*Information Technology*, *Customers*, and *Production Processes*—had significant effects on *Organizational Performance.* These findings demonstrate that *Customers* are a key element of business competitiveness.

9.4 Conclusions

Following the results presented in Fig. 9.3, Tables 9.5 and 9.7, we conclude that *Information Technology* is essential to the competitiveness of manufacturing work systems located in Chihuahua, Mexico. Moreover, it has been demonstrated that *Information Technology* has significant effects on all the analyzed dependent latent variables, which implies that the macroergonomic compatibility of *Information Technology* brings positive results to manufacturing companies. Also, the fact that *Customers* had direct and total effects on *Organizational Performance* demonstrates that companies have to strive to understand the needs and requirements of clients if they want to improve business competitiveness.

The results presented in Fig. 9.2 also allow us to propose the following conclusions regarding the hypothetical model depicted in Fig. 9.1:

- In manufacturing work systems, the macroergonomic compatibility of *Information Technology* is necessary to gain *Production Process* efficiency ($H_{9.1}$).
- In manufacturing work systems, the macroergonomic compatibility of *Information Technology* and *Production Process* efficiency is necessary to reach *Customer* satisfaction ($H_{9.2}$, $H_{9.3}$).
- In manufacturing work systems, *Production Process* efficiency and *Customer* satisfaction are necessary for good *Organizational Performance* ($H_{9.5}$, $H_{9.6}$).

Finally, in this chapter we found enough statistical evidence to reject one of the hypothesized relationships, namely $H_{9.4}$. However, note that results here discussed are only valid to manufacturing companies and employees having participated in the study. For our model to reach a higher impact across the globe, it may be necessary to test the external reliability of the approach—including the MCQ—in other cultures and regions across the different industrial sectors. That said, the methodology here proposed is a novel approach to studying how the macroergonomic compatibility of Technologies and Tools in the manufacturing sector can be associated with work system performance (i.e., *Customers*, *Production Processes*, and *Organizational Performance*). As for the MCQ, we consider it as a new, efficient instrument to collect data regarding macroergonomic practices in the manufacturing sector. With the help of statistical methods or mathematical models, the MCQ can be a useful tool to measure macroergonomic compatibility in work systems.

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Chapter 10

The Impact of Macroergonomic Factor "Tasks" on Manufacturing System Performance

Abstract This chapter presents a hypothetical model that studies the relationship between tasks, as a macroergonomic factor, and the performance of manufacturing work systems. More specifically, the model studies how *Work Demands*, a macroergonomic element of the Task factor, can be associated with performance variables such as *Customers*, *Production Processes*, and *Organizational Performance*. As in previous chapters, the data used to develop and test the model were collected among Mexican manufacturing companies located in Chihuahua. Results revealed that *Work Demands* are an essential element to increase competitiveness since they have significant effects on performance variables. Similarly, we found that *Customers* and *Production Processes* play a role in *Organizational Performance.*

10.1 The Macroergonomic Compatibility Questionnaire (MCQ)

10.1.1 Developing the Macroergonomic Compatibility Questionnaire (MCQ)

Table 10.1 shows the items listed in the worker version of the Macroergonomic Compatibility Questionnaire (MCQ-WV) and used to assess the macroergonomic compatibility of the Task factor through four macroergonomic elements: *Task Variety*; *Job Content, Challenges, and Use of Skills; Autonomy, Job Control, and Participation;* and *Work Demands*. The left column of the table lists the survey items, and the right column includes the fuzzy Likert scale used to rate them. For more detailed information regarding the scale and its development, please refer to Chap. 7.

It is important to mention that this chapter only addresses the effects of *Work Demands* on manufacturing system performance, and therefore discards the remaining three macroergonomic elements of the Tasks factor. This means that the hypothetical model presented later takes into account only four latent variables,

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Table 10.1 Section II of the MCQ-WV for the task factor

In your company	1	2	3	4	5
Task variety					
Employees complete a variety of tasks with good performance					
Employees are encouraged to learn how to perform a variety of tasks					
Employees rotate their assigned jobs in a daily basis					
Job content, challenges, use of skills					
Superiors take appropriate advantage of employee skills					
Employees are encouraged to develop new work skills by performing challenging tasks					
Employees are empowered to make their own decisions regarding their work					
Autonomy, job control, and participation					
Employees can decide on which methods they will use to complete a specific task					
Employees can decide the sequence of the tasks they perform					
Employees are allowed to use their initiative					
Employees can take part in improvement proposals					
Work demands (workload, pressure, cognitive effort, attention paid)					
Tasks are designed in a way they are performed one at a time					
Tasks performed are straightforward and do not present major complications					
Employees monitor/process little amount of information while performing a certain task					
Tasks involve solving problems whose solutions are obvious					
Employees need to make use of their creativity to perform tasks					
Tasks are periodically evaluated with respect to work demands					

the three work system performance variables (*Customers, Production Processes, Organizational Performance*), and *Work Demands*, as a variable of the macroergonomic factor Tasks. As regards the benefits obtained from the macroergonomic practices (MPs), we used the third section of the MCQ-WV in which the participants had to rate the extent to which their companies benefitted from a series of aspects. For more information regarding the list of MPs benefits, please refer to Table 7.2 in Chap. 7.

On the other hand, Table 10.2 shows the experts' version of the MCQ (MCQ-EV) for the factor Tasks, which was administered to ergonomics experts. As in Chaps. 7 and 8, the number of survey items is consistent with the number of macroergonomic elements of the Tasks factor. The left column of Table 10.2 lists the MCQ-EV items, whereas the right column includes the fuzzy Likert scale used to answer them. As in previous chapters, in the MCQ-EV the ergonomics experts had to rate the importance of a set of macroergonomic practices of the Task factor.

As mentioned in previous chapters, the data collected throughout the MCQ-EV revealed whether a given element could remain in the analysis despite having shown a low ordinal alpha value. In other words, the experts' assessments regarding

Table 10.2 MCQ-EV for the task factor

Instructions: In your opinion, how important is to implement the following macroergonomic practices in manufacturing systems? Please answer all the questions					
	Importance				
Macroergonomic practices	1	2	3	4	5
Task variety					
Job content, challenges, and use of skills when performing work tasks					
Employee autonomy, job control, and participation					
The demands of tasks performed (workload, mental effort, attention required, time, etc.)					

the four listed MPs confirmed whether an apparently not significant macroergonomic element was actually significant to assess the relationship between Tasks and manufacturing system performance from a macroergonomic perspective.

10.1.2 Administering the Macroergonomic Compatibility Questionnaire (MCQ)

The MCQ in all its versions for the Tasks factor was administered among manufacturing systems located in Chihuahua as discussed in Chap. 7, namely Sect. 7.1.2.

10.1.3 Reliability Analysis of the Macroergonomic Compatibility Questionnaire (MCQ)

To test the reliability of the MCQ for the Tasks factor, we estimated the ordinal alpha index of every macroergonomic element (see Eq. 7.1). Table 10.3 shows the index values obtained and the assessments or weights (*w*) provided by experts. As can be observed, all the elements showed an ordinal alpha value above 0.7, the minimum accepted value, which implies that they could be kept in the MCQ and could be used for further analyses.

Table 10.3 Ordinal alpha values and average crisp weights of macroergonomic elements for the tasks factor

Macroergonomic element	Ordinal alpha index	Experts w^*
Task variety	0.751	0.830
JON content, challenges, and use of skills	0.858	0.760
Autonomy, job control, and participation	0.828	0.680
Work demands	0.802	0.800

10.2 Structural Equation Model

10.2.1 The Effects of the Tasks Factor on Manufacturing System Performance

This chapter presents a structural equation model (SEM) that measures the effects of the Tasks factor on work system performance variables. More specifically, the model measures the effects of *Work Demands*, as the independent latent variable, on *Customers*, *Production Processes*, and *Organizational Performance*, as the dependent latent variables. The items used to study *Work Demands* can be consulted in Table 10.1, whereas the items corresponding to the three performance variables are listed in Table 7.2 (see Chap. 7). To measure the effects, we propose five research hypotheses, formulated after carefully reviewing the literature in ergonomics and manufacturing journals. Surprisingly, we found that no previous research has explored the effects of *Work Demands* macroergonomic compatibility on manufacturing system performance. However, studies similar to this one have been performed in other work systems and contributed to the development of our research hypotheses.

10.2.1.1 Effects of *Work Demands* on *Production Processes*

Depending on their level of complexity and requirements, *Work Demands* can be the source of either success or failure in manufacturing work systems. *Work demands* are defined as the psychological stressors present in the work environment or workload (Peeters and Rutte 2005). On the other hand, *Production Processes* are a set of relevant processes that add value to a product (Realyvásquez et al. 2015). Studies have found significant indirect relationships between *Work Demands* and *Production Processes.* Some authors argue that *Work Demands* are a cause of employee burnout, which in turn causes employee depression and little occupational commitment (Hu et al. 2011). Similarly, *Work Demands* have proved to be the cause of emotional fatigue, occupational stress (Peeters and Rutte 2005), and little supervisors’ availability (Kim and Stoner 2008). However, research has also associated appropriate *Work Demands* levels with employee well-being and disposal for learning (Peeters and Rutte 2005). In other words, all the consequences of *Work Demands* have an impact on employee performance, which in turn can affect the quality of the production process. For this reason, we propose the first working hypothesis ($H_{10.1}$) of this chapter from a macroergonomic perspective as follows:

$H_{10.1}$: In manufacturing work systems, the macroergonomic compatibility of *Work Demands* has a positive direct effect on *Production Processes.*

10.2.1.2 The Effects of *Work Demands* on *Customers*

In the manufacturing industry, *Work Demands* play a crucial role in *Customer* satisfaction, as employee–customer interactions are influenced by such demands. Research has provided evidence that *Work Demands* have effects of *Customers* from different perspectives. For instance, Bakker et al. (2008) point out at a strong relationship between *Work Demands* and family conflicts, mainly between spouses (which can be viewed as customers, considered the definition of a customer discussed in previous chapters). Moreover, Hakanen et al. (2008) highlight that high *Work Demands* are a cause of employee burnout, which reflects as poor professional accomplishment and a sense of poor performance. Similarly, another study has demonstrated that employee emotional exhaustion caused by high *Work Demands* contributes to the incidence of cynical or depersonalized attitudes toward *Customers* (Xanthopoulou et al. 2013). The effects of *Work Demands* can thus affect the performance and state of mind of employees, who in such conditions can jeopardize the satisfaction of *Customers* regarding the service they are being provided or the product they are purchasing. Following this discussion, the second research hypothesis ($H_{10.2}$) of this chapter can be read as follows:

$H_{10.2}$: In manufacturing work systems, the macroergonomic compatibility of *Work Demands* has a positive direct effect on *Customers*.

10.2.1.3 The Effects of *Work Demands* on *Organizational Performance*

The main goal of a business is to increase its global competitiveness. To achieve this, companies have to take a look at their *Organizational Performance* to see what can be improved or modified. *Organizational Performance* is a complex construct to be evaluated and measured. According to Kim (2004), *Organizational Performance* refers to whether organizations perform administrative and operational functions pursuant to the corporate mission and whether they actually produce actions and outputs in accordance with the corporate mission. Research has demonstrated that high *Work Demands* can affect both individual performance and *Organizational Performance.* Authors (García-Herrero et al. 2013) mention that demands of the job cause stress, which in turn affects organizational functioning. Similarly, another study demonstrated that *Work Demands* were positively associated with emotional exhaustion and negatively with vigor and dedication (Montgomery et al. 2015) and thus had a negative impact on *Organizational Performance*. Likewise, in their work, Gilboa et al. (2008) argued that occupational stress could affect employee performance, commitment, motivation, and discipline. Following this discussion regarding the effects of *Work Demands*, we propose the third research hypothesis ($H_{10.3}$) of this chapter as follows:

$H_{10.3}$: In manufacturing work systems, the macroergonomic compatibility of *Work Demands* has a positive direct effect on *Organizational Performance*.

10.2.1.4 The Effects of *Production Processes* on *Organizational Performance*

Production Process reliability is a key aspect of *Organizational Performance*. Studies have demonstrated that different organizational processes can impact on the overall performance of companies across industrial sectors. In their research, Damanpour et al. (2009) mentioned that services, technology, and administrative processes innovations have a positive impact on the services industry. Similarly, Gunday et al. (2011) argue that innovations are an indispensable component of business strategies in the manufacturing industry, as they increase *Production Process* reliability and thus improve *Organizational Performance*. In this sense, *Production Process* reliability has shown positive impacts on *Organizational Performance* in Mexican manufacturing companies (Realyvásquez et al. 2015). Likewise, authors (Abdulmalek and Rajgopal 2007) have illustrated the effects of reliable *Production Processes* in a manufacturing company. Such findings allow us to formulate the fourth research hypothesis ($H_{10.4}$) of this chapter, reading as follows:

$H_{10.4}$: In manufacturing work systems, *Production Process* efficiency has a positive direct impact on *Organizational Performance*.

10.2.1.5 The Effects of *Customers* on *Organizational Performance*

Customers are the cornerstone of corporate success, and many studies have thus pointed out at the effects of *Customers* on *Organizational Performance*. As an example, *Customer* satisfaction is considered the main source of employment (Oyedele and Tham 2007) and competitiveness. In fact, Oyedele and Tham (2007 and Maister (2012) argue that when companies manage to better understand and meet *Customer* needs and exigencies, these companies increase their competitive advantage. Similarly, authors (Oyedele and Tham 2007) claim that *Customer* evaluations of *Organizational Performance* help improve employee skills and increase employee responsibility. Similarly, according to Ahmad et al. (2012), when *Customers* lack knowledge and experience, corporate projects may fail or produce poor-quality outputs. Therefore, considering the role of *Customers* in the industrial context, the fifth research hypothesis ($H_{10.5}$) of this chapter can be formulated as follows:

$H_{10.5}$: In manufacturing work systems, *Customer* satisfaction has a positive direct impact on *Organizational Performance*.

Figure 10.1 introduces the hypothetical model that relates the aforementioned variables through the five research hypotheses. The model was tested and analyzed using statistical software WarpPLS5®, a software tool widely used to study small samples (García-Alcaraz et al. 2014; Kock 2015). Another advantage of WarpPLS5® is that it relies on partial least squares (PLS) algorithms, instead of conventional nonlinear algorithms, for the data analysis. PLS allow for the effective management of nonlinear models (Ockert 2014; Kock 2015). Also, notice that the

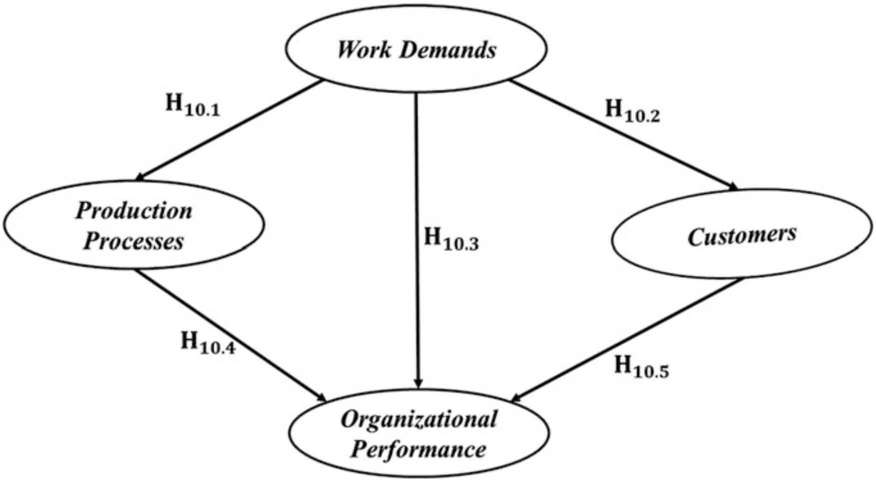

Fig. 10.1 Hypothetical model

model testing does not include fit indices such as chi-squared (X^2), the root-mean-square of error of approximation (RMSEA), or the goodness of fit index (GFI), since they are irrelevant to our research purpose.

The model was tested by estimating three model fit indices: Average Path Coefficient (APC), Average *R*-Squared (ARS), and Average Variance Inflation Factor (AVIF). APC and ARS have *P* values, which were used as a general criterion to accept and or reject the model relationships. That said, the *P* values had to be lower than 0.05, to consider that model relationships as significant at a 95% confidence level. Once the insignificant relationships were removed, we evaluated the factor loadings of items corresponding to each latent variable, and we removed items showing a factor loading value higher in another latent variable than in the one they belonged. As for AVIF, we accepted any value below or equal to five (García-Alcaraz et al. 2014; Kock 2015). Finally, we measured the effects values. Direct effects were used to accept or reject the five research hypotheses, as they indicated or not a direct relationship between two latent variables. Also, we estimated the indirect and total effects between latent variables.

10.3 Results

10.3.1 Model Fit and Quality Indices

Indices APC and ARS showed values of 0.355 and 0.221, correspondingly, and *P* values lower than or equal to 0.001. The Tenenhaus goodness of fit (GoF) index showed a value of 0.479 and demonstrated that the hypothetical model depicted in Fig. 10.1 had great explanatory power and predictive capability (Kock 2015).

Table 10.4 MCQ structural validation for macroergonomic factor tasks

Index	Work demands	Customers	Production processes	Organizational performance
R-Squared (R^2)		0.11	0.16	0.39
Cronbach’s alpha	0.757	0.818	0.774	0.781
Average variance extracted (AVE)	0.578	0.654	0.600	0.697
Q-Squared (Q^2)		0.102	0.146	0.392

As for the MCQ, the test reliability showed Cronbach’s alpha values higher than 0.7 (minimum accepted value) and AVE values higher than 0.5 in every latent variable or dimension, thereby confirming the survey’s reliability and discriminant and convergent validity. Similarly, all the R^2 values of the dependent latent variables were higher than 0.02, and the Q^2 coefficient showed values higher than 0, thus confirming the survey’s high parametric predictive validity. Table 10.4 summarizes the structural validation results of the MCQ for the macroergonomic factor Tasks.

10.3.2 Direct Effects

Figure 10.2 depicts the analyzed model, once the direct effects were estimated. In SEMs, direct effects measure the sensitivity of a dependent latent variable to changes caused by an independent latent variable, while all the other dimensions remain static (Pearl 2001). Also, direct effects are usually expressed in β values as standardized dependence measures and have a corresponding P value to decide on

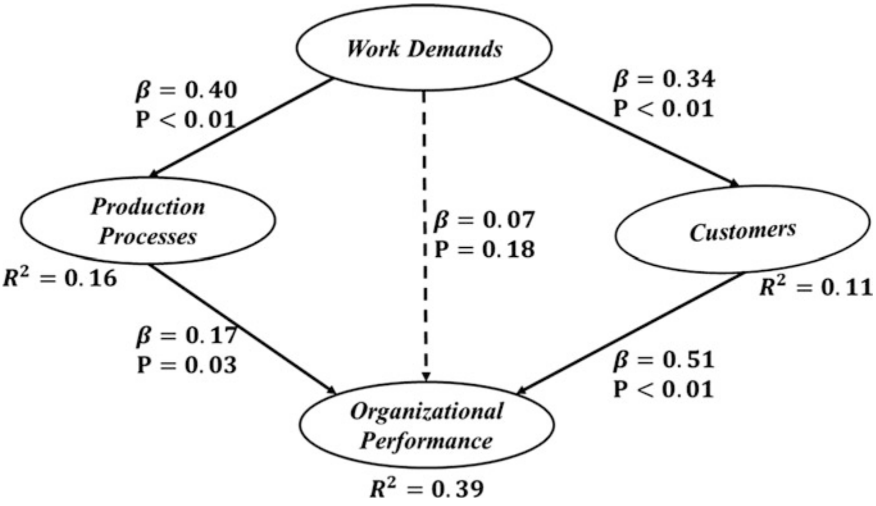

Fig. 10.2 Direct effects between latent variables

their statistical significance (hypothesis testing). In other words, only direct effects showing $P < 0.05$ are considered as significant at a 95% confidence level. For instance, in this model, the relationship between *Work Demands* and *Production Processes* shows $\beta = 0.40$ and $P \leq 0.001$. This implies that it is a significant relationship wherein *Production Processes* increases by 0.40 standard deviations when *Work Demands* increase by one standard deviation.

Notice that the relationships between *Work Demands* and *Organizational Performance* are depicted with dotted lines. Because in this relationship the estimated P value was higher than 0.05 ($P = 18$), its corresponding hypothesis ($H_{10.3}$) was rejected and thus removed from the causal model. On the other hand, note that the largest direct effects were caused by *Customers* on *Organizational Performance* ($\beta = 0.51$), which were then followed by the direct effects that *Work Demands* had on *Production Processes*, in which $\beta = 0.40$. Finally, as mentioned in other chapters, the R^2 values associated with the dependent latent variables represented the contribution of the exogenous latent variables to the variability of the endogenous latent variables. In this sense, the model analysis demonstrated that *Production Processes,* showing $R^2 = 0.16$, were 16% explained by *Work Demands.* However, *Organizational Performance*, having $R^2 = 0.39$, was explained by two independent latent variables: *Customers* (31%) and *Production Processes* (8%). Figure 10.3 illustrates only the significant direct effects between the latent variables.

Considering the direct effects between the latent variables, the structural equations for the dependent latent variables can be proposed as follows:

$$\text{Customers} = 0.34 \times \text{Work demands} + \text{Error} \tag{10.1}$$

$$\text{Production Processes } = 0.40 \times \text{Work Demands} + \text{Error} \tag{10.2}$$

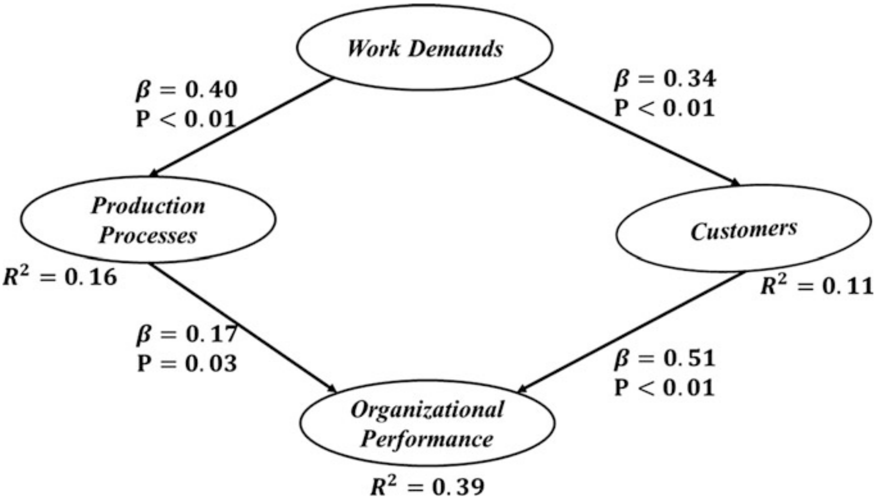

Fig. 10.3 Significant direct effects between latent variables

Table 10.5 Hypothesis testing results

Hypothesis	Independent variable	Dependent variable	Decision
$H_{10.1}$	Work demands	Production processes	Accepted
$H_{10.2}$	Work demands	Customers	Accepted
$H_{10.3}$	Work demands	Organizational performance	Rejected
$H_{10.4}$	Production processes	Organizational performance	Accepted
$H_{10.5}$	Customers	Organizational performance	Accepted

$$\text{Organizational Performance} = 0.51 \times \text{Customers} + 0.17 \times \text{Production Processes} + \text{Error} \tag{10.3}$$

Table 10.5 summarizes the hypothesis testing results. As discussed earlier, only hypothesis $H_{10.3}$ was rejected. This hypothesis directly associated *Work Demands*, as the independent variable, with *Organizational Performance*, as the dependent variable.

10.3.3 Indirect Effects

In SEMs, indirect effects occur between two latent variables through mediating variables. Visually, indirect effects can be tracked using two or more model paths, depending on the number of variables involved (García-Alcaraz et al. 2014; Realyvásquez et al. 2016). Table 10.6 presents the sum of indirect effects found in the model. As can be observed, the analysis detected only one indirect relationship: between *Job Demands* and *Organizational Performance*. The value of this effect implies that both variables are indirectly related in such a way that when *Work Demands* increase by one standard deviation, *Organizational Performance* increases by 0.240 standard deviations. Moreover, because the *P* value was lower than 0.001, this indirect relationship was significant at a 99.9% confidence level.

10.3.4 Total Effects

The total effects of a relationship are the sum of its direct and indirect effects (García-Alcaraz et al. 2014; Realyvásquez et al. 2016). Table 10.7 shows the total effects found in the model. Almost all the total effects were significant at a 99.9%

Table 10.6 Sum of indirect effects

To	From
	Work demands
Organizational performance	0.240*

*Significant at 99.9%

Table 10.7 Total effects

To	From		
	Work demands	Customers	Production processes
Customers	0.340[*]		
Production processes	0.400[*]		
Organizational performance	0.240[*]	0.510[*]	0.170[**]

[*]Significant at 99.9%
[**]Significant at 95%

confidence level, since $P < 0.001$. Only the total effects caused by *Organizational Performance* on *Production Processes* were significant at a 95% confidence level, as $P < 0.05$. Such results confirm that, in Mexican manufacturing work systems, *Work Demands* have a significant and positive direct effect on *Organizational Performance.*

Table 10.7 also demonstrates that the largest total effects were caused by *Customers* on *Organizational Performance*, which confirms that *Customers* are a key to competitiveness. The second largest effects were found from *Organizational Performance* on latent variables *Production Processes*, *Customers*, and *Organizational Performance,* showing values of 0.400, 0.340, and 0.240, respectively. Such findings reveal that in the Mexican manufacturing industry, *Work Demands* have an impact on work system performance.

10.4 Conclusions

Results introduced by Fig. 10.3, Tables 10.6 and 10.7 provide enough evidence regarding the role of *Work Demands* in the Mexican manufacturing system, namely in work system competitiveness. Similarly, in this study, *Work Demands* caused a significant impact on all the dependent latent variables, thereby demonstrating that the macroergonomic compatibility of *Work Demands* brings positive results to manufacturers. As regards *Customers*, we explored their significant direct and total effects on *Organizational Performance*, and we concluded that meeting *Customer* needs and requirements, and thus reaching *Customer* satisfaction, increases business competitiveness in the manufacturing sector, regardless of the types of products manufactured.

As for Fig. 10.2, we can propose the following conclusions for the research hypotheses depicted in Fig. 10.1.

- In manufacturing work systems, the macroergonomic compatibility of *Work Demands* is necessary for *Production Process* efficiency ($H_{10.1}$).
- In manufacturing work systems, the macroergonomic compatibility of *Work Demands* is necessary for *Customer* satisfaction ($H_{10.2}$).
- In manufacturing work systems, *Production Process* efficiency and *Customer* satisfaction are necessary for good *Operational Performance* ($H_{10.4}$, $H_{10.5}$).

Finally, this research presents enough statistical evidence to reject hypothesis $H_{10.3}$, proposed in Sect. 10.2. The hypothesis directly associated *Work Demands* with *Organizational Performance* but showed a *P* value higher than the cutoff. However, notice that the findings obtained and discussed in this chapter are valid merely to companies and employees having participated in the research. To increase the reliability of our model presented in Fig. 10.1, we encourage the scientific community to explore the macroergonomic compatibility of *Work Demands* in manufacturing systems across cultures and regions. That said, the methodology here presented is a new approach to assessing the macroergonomic compatibility of tasks, as a macroergonomic factor, on work system performance, namely on *Customers*, *Production Processes*, and *Organizational Performance*. Regarding the MCQ, we believe it is effective for collecting data on macroergonomic practices in the manufacturing sector. Supported by statistic methods or a mathematical model, the MCQ can effectively measure macroergonomic compatibility.

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Part III
Macroergonomic Compatibility Index for Manufacturing Systems

Chapter 11
Fuzzy Logic Approach and Manufacturing System Evaluation Methodologies

Abstract This chapter presents the most influential theories, models, and methodologies that set the bases for the development of a macroergonomic compatibility index (MCI) for manufacturing work systems. The contribution of fuzzy logic to index generation is highlighted, since it is a logic operation method useful for evaluation capable of simulating human reasoning. Likewise, the role of multiattribute methods in decision making are discussed, as well as the different approaches to characterize manufacturing work systems in terms of sustainability, agility, safety, and ergonomics. The chapter concludes by commentign on the importance of developing accurate measurement indices to meet the exigencies of the modern manufacturing industry.

11.1 Background to Fuzzy Logic

In 1994, the world of fuzzy numbers was state-of-the-art, yet the concept of fuzzy numbers had been used for at least 25 years. In this setting, Lukasiewicz (1988), a Polish scientist, first investigated the logic of vagueness. The first version of Lukasiewicz logic was third-value logic, comprising values 0, ½, and 1, being ½ an unknown value. Later on, the author extended his logic system to infinite-valued logic, thereby allowing for values 0 and 1. Eventually, by proposing membership functions, Zadeh (1968) invented fuzzy logic, which combines crisp logic concepts with the Lukasiewicz's sets. One of Zadeh's major thoughts was that mathematics could be used to link language with human intelligence. Many concepts are better defined when using words instead of numbers. Fuzzy logic and its expression in fuzzy sets constitute a discipline capable of building better reality models. Many years later, Schwartz and Klir (1992) arranged a set of fuzzy words into categories. Quantification terms included *all*, *most*, *many*, *about half*, *few*, and *no*. Usuality terms included *always*, *frequently*, *often*, *occasionally*, *seldom*, and *never*. Finally, likelihood ranged from *certain*, to *likely*, *uncertain*, *unlikely*, and *certainly not*.

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11.2 Triangular Membership Function

Triangular and trapezoidal distributions are commonly discussed in the literature, especially in the evaluation models reviewed for this book. Fuzzy logic is useful when dealing with vague information. In these evaluation models, decision-makers or experts provide a judgment on something using linguistic terms or approximations to linguistic terms. Triangular or trapezoidal numbers can represent these types of expressions better than crisp or precise numbers. Moreover, to experts, decision-makers, and evaluators, triangular and trapezoidal expressions are usually easier to understand (Klir and Yuan 1995; Yeh and Deng 2004; Lin et al. 2007; Kahraman and Çebi 2009). The membership function for a triangular distribution substitutes the probability function to define the design range (DR), the system range (SR), and the common range (CR) areas in axiomatic design (AD).

In this book, we discuss how triangular distribution was employed to represent the judgments or assessments provided by the six experts regarding the importance of a set of macroergonomic practices. Because of its convenience, simplicity, and its ability to represent judgments, triangular distribution seemed to us the most appropriate approach. Likewise, we adapted membership functions and triangular functions to represent the tangible/intangible attributes of the benefits and the tangible/intangible attributes of costs used in the model. Bear in mind that any efficient decision-making model must tolerate ambiguity, as it is a characteristic of real decision-making problems. Decision-makers or experts provide vague responses instead of precise values, and fuzzy representation is more sensitive to this kind of responses (Yu 2002).

The model here proposed to measure the macroergonomic compatibility of manufacturing work systems deals with incomplete or vague information regarding the compliance of designs (equipment) with ergonomic requirements. Triangular distribution has proved to be useful, effective, and reliable when it comes to representing linguistic expressions. A wide range of models, linguistic scales, and evaluation situations similar to our model, with tangible and intangible attributes and sometimes immeasurable units, have relied on triangular distribution. Also, fuzzy theory has been widely used to solve this type of modeling for more than four decades, where the logic of a linguistic approximation subjacent to real values and fuzzy numbers are approximate values.

11.3 Fuzzy Logic in Decision-Making

Fuzzy logic is popularly and successfully utilized in a variety of methods, including decision-making methods. The classical multiattribute decision-making (MADM) methods assume that all the performance score values of alternatives (m_{ij}) and the weight values of attributes (w_j) are crisp values. Alternatives with higher final performance are preferred by the decision-maker. Because the final ratings are real numbers, the preferred alternatives are the ones having higher final utilities. In reality, the performance rating (m_{ij}) can be crisp, fuzzy, and/or linguistic.

Some alternatives may contain unquantifiable attributes that have to be represented by linguistic terms such as *low*, *average*, or *high*. These problems contain a mixture of fuzzy and crisp data. Most MADM problems in the real world are like this. Fuzzy MADM methods propose to solve problems that involve fuzzy data. Bellman and Zadeh (1970) were the first to relate the theory of fuzzy sets to decision-making problems.

During the past three decades, a variety of MADM fuzzy methods have been proposed and reviewed. Some of them can be consulted in Triantaphyllou and Lin (1996), Triantaphyllou (2000), Kulak and Kahraman (2005), Kahraman and Çebi (2009), Figueira et al. (2010), Chen and Hwang (2012). After a careful and systematic review of such approaches, we noticed that most of these methods require complicated calculations; thus, none of them may appropriately solve large-size problems—e.g., more than 10 alternatives associated with more than 10 attributes each. Likewise, the majority of the analyzed MADM methods require that the matrix elements be presented in a fuzzy format, even though they are crisp in nature. This makes fuzzy methods difficult to be used and incapable of solving large-size problems. However, Chen and Hwang (2012) proposed an approach to overcome the aforementioned difficulties and allow a MADM problem to be solved significantly and efficiently in a fuzzy environment. The approach comprises two phases. The first phase involves converting fuzzy data into crisp values, thereby creating a decision matrix of only crisp values. The second phase requires using fuzzy ranking methods to determine the ranking order of alternatives.

In the following paragraphs, we present a collection of methods that are useful to decision-making and the characterization of some properties of manufacturing systems. These methods fueled our initiative regarding the development of a macroergonomic compatibility index for manufacturing work systems.

11.4 Hierarchical Fuzzy Axiomatic Design Methodology for the Ergonomic Compatibility of Advanced Manufacturing Technology

Advanced manufacturing technology (AMT) has played a key role in the evolution of global manufacturing. Generally, AMT involves computer-based technology, such as computer numerical control (CNC), computer-aided design (CAD), and flexible manufacturing, among others (Saraph and Sebastian 1992; Barros et al. 2015). AMT experiences constant, gradual, but also radical changes as the industry finds itself in needs of new tools and strategies for appropriately selecting materials, processes, equipment, and machinery (Rao 2007). In this context, decision-makers must correctly evaluate and select the best alternative among the different possible options to solve a problem.

The reviewed models for AMT planning and selection are considered deficient as regards ergonomic and safety aspects, which are often underestimated, or even neglected and delegated. As a result, decision-makers either are unaware of the ergonomic attributes desired in AMT or lack experience to quantify or evaluate such attributes, since they seem far less tangible than engineering/technical aspects. In this sense, because AMT must comply with multiple ergonomic requirements, its macroergonomic compatibility assessment is considered to be a complex problem that can be addressed from a multiattribute approach to axiomatic design (AD) and complexity.

11.4.1 Applications of Axiomatic Design and Complexity in Ergonomics

As previously mentioned, AD applications in MT selection are as innovative as their incursion in the theory of ergonomics. This section thus addresses the term *complexity* and discusses the most relevant applications having contributed to the MCI generation proposed in this book. As regards complexity, Hirani and Suh (2005) define it as the measure of uncertainty in reaching a desired functional requirement. Uncertainty emerges from poorly designed or incomprehensible systems. Complexity is a function of the relationship between the DS and the SR. As regards this relationship, experts argue that in any design situation, the probability of success is given by what the designer wishes to achieve in terms of tolerance (i.e., DR) and what the system is capable of delivering (i.e., SR) (Kahraman and Çebi 2009).

One of the applications of complexity is AD. AD establishes the customer needs (CNs) that the system must satisfy. Then, the functional requirements (FRs) and constraints (Cs) of the system to be designed are determined to meet CNs. The next step is to match these FRs to design parameters (DPs). This step allows identifying and choosing the proper DPs for the system. Once the DPs are chosen, designers must go to the process domain and identify the process variables (PVs) based on the creation of a new process or the use of an existing process (Suh 1998). DR and SR are established for every FR of the design.

Helander and Lin (2002) were two of the first to apply AD in ergonomics. These authors claim that the industry has become increasingly interested in ergonomics and human factors, especially when new automated industrial systems and products have failed, because they were not designed according to the user’s characteristics, capacities, and limitations. The needs for quantitative ergonomic measures must complement the selection of alternatives that best satisfy the user’s basic and functional requirements. AD has many industrial applications, including the design of a glass bulb (Do and Park 2001), mechanical assembly design (Jung and Billatos 1993; Hashemian and Gu 1996), integrated products and process design (Vallhagen 1996), structural design (Albano and Suh 1992), and reliability design in engineering (Teng and Ho 1995). Likewise, AD applications have been documented for hardware products and software design (Kim et al. 1991) and algorithms design (Pao 1995).

Since the introduction of AD (Suh 1990), AD-related publications have mostly addressed process and product design, yet Helander and Lin (2002) extended AD usefulness to ergonomic problems. To such authors, ergonomic design considers both user capabilities and limitations in many areas, including automobiles, aircraft, spacecraft, workstations, consumer products, human–computer interaction, military, mining, nuclear energy plants, safety and health, and workspaces, among a few.

In their work, Maldonado et al. (2013) applied AD combined with MADM to obtain an ergonomic incompatibility index for AMT. More specifically, the authors proposed a model that included an ergonomic compatibility evaluation survey for AMT and a methodology for supporting the AMT planning and selection process. Based on the Axiomatic Design Theory (ADT) developed by Suh (1990), the authors set the FRs, DRs, and SRs for the ergonomic multiattributes desired in AMT machinery and equipment. To achieve this, they relied on the subjective opinions of AMT experts and thus considered the fuzzy logic theory (FLT) as the ideal approach. The experts were selected considering their industrial expertise and academic background. The model proposed by Maldonado et al. (2013) seeks to deploy the functional requirements (attributes) for the ergonomic compatibility of AMT. Such attributes were retrieved from a comprehensive literature review and a pragmatic perception. Likewise, the authors proposed an appropriate and well-defined scale with fuzzy triangular numbers. From this scale, they evaluated and set the desired DR, SR, and CR.

The model of Maldonado et al. (2013) also sets the ergonomic compatibility attributes (ECA) required in AMT equipment design, considering the interactions among hardware (computer-based technology), organization (organizational structure), information systems, and people (human training and skills). Considering the manual for the ergonomic design for workspaces and machines, proposed by Corlett and Clark (2013), the model of Maldonado et al. (2013) constructs the attributes addressed in the literature that are a key to the evaluation of AMT ergonomic compatibility. Such attributes are classified into five categories: compatibility with skills and training (A11), compatibility with the physical space (A12), usability (A13), equipment emissions requirements (A14), and organizational requirements (A15).

Main attribute A11 includes two subattributes: compatibility with user hardware (A111) and compatibility with training (A112). Attribute A12 includes five subattributes: access to machines and clearances (A121), vertical and horizontal reaches (A122), design adjustability (A123), postural comfort design (A124), and physical work and endurance design (A125). On the other hand, main attribute A13 involves seven subattributes: control design compatibility (A131), control physical distribution (A132), visual work space design (A133), understanding and information load (A134), error tolerance (A135), man–machine functional allocation (A136), and maintainability design (A137). Main attribute A15 comprises four subattributes: temperature (A141), vibration (A142), noise (A143), and residual materials (A144). Finally, main attribute A15 is composed of subattributes work rate (A151) and work content (A152).

The subattributes were classified as tangibles and intangibles; however, from the artifact–human perspective, they were categorized as benefit attributes and cost attributes. Authors talk about benefit subattributes when maximizing their adaptability is ergonomically desirable, or when the desired DR is expressed as a functional ergonomic requirement (FER) and tends to be at the highest range of the linguistic scale. All the benefit attributes in Maldonado et al. (2013) are considered intangible. On the other hand, the authors refer to cost attributes when minimizing their exposition is ergonomically desirable, or when the ideal DR expressed as an FER tends to be at the lowest scale range. The majority of the subattributes were considered as intangible benefit attributes, except for subattributes A125, A141, A142, A143, and A144. Finally, the complete description of the survey and methodology can be consulted in the work of Maldonado et al. (2013) and Maldonado-Macías et al. (2015). This model provided us with the procedural structure necessary to develop the MCI; however, other evaluation models and methods were similarly reviewed and will be summarized in further sections of this chapter.

11.5 Methodologies for the Generation of Evaluation Indices in Manufacturing Work Systems

Several indices have been proposed in diverse areas to evaluate manufacturing systems. Some of them include sustainability indices, supply chain agility indices, and quality indices. In this section, we discuss some of the methodologies for index generation in manufacturing work systems from three approaches: sustainability, agility, and usability. For each methodology, we discuss the time and effort required to apply it, the required expertise from the part of evaluators, the intermediate and final results, and the results deployment. To know more about the methodologies developed for index generation, readers may consult the works mentioned below.

11.5.1 Sustainability Index Generation Methodologies

In manufacturing work systems, sustainability assessment is related to macroergonomic compatibility evaluation in terms of factors and intangible attributes. Moreover, according to the literature review, as macroergonomic compatibility increases, sustainability also increments. Several sustainability indices have been proposed in the manufacturing industry, and some of them contributed with important characteristics to the development of our MCI. For instance, Van De Kerk and Manuel (2008) proposed the sustainable society index (SSI), which encompasses 22 factors grouped into five categories. From a similar perspective, Prescott-Allen (1997) developed the barometer of sustainability that distinguishes two conditions: human well-being and ecosystem well-being. The model relies on a performance scale with five indicators, ranging from unsustainable to sustainable.

Another common sustainability index is the Dow Jones sustainability index (DJSI), an evaluation tool for companies that adopts a financial, social, and environmental approach. Similarly, the Global Initiative Report (GIR) was developed to support decision-making regarding common sustainability goals (Fonseca 2010). In 2002, the Institute of Chemical Engineers introduced the IChemE sustainability metrics (IChemE 2002), in which the interviewee selects the metrics to be applied and reported by the model. However, to ensure that all the sustainability aspects are evaluated equally, the interviewee has limited freedom of selection.

Another popular sustainability evaluation tool is the rapid plant assessment (RPA). RPA includes a questionnaire and a framework to evaluate leanness in manufacturing companies during a relatively short time (Goodson). From a slightly different perspective, Krajnc and Glavič (2005) developed a methodology for obtaining a composite sustainable development index (ICSD) to assess the sustainable performance of an organization. To obtain their ICSD, companies select or develop indicators on their own to assess their sustainable performance in three aspects: social, environmental, and economic. On the other hand, the ITT Flygt sustainability index was developed by Mälardalen University, in Switzerland, for ITT Flygt (Pohl 2006). The relatively small number of indicators (40), as well as the system's scale, guarantees a rapid sustainability evaluation. The set of indicators was developed by ITT Flygt on its own to measure its goals toward sustainability.

In Ford's sustainability measurement, the product sustainability index (PS) is limited to the automobile industry but provides a holistic evaluation of a vehicle's sustainable performance considering three sustainability aspects: social, environmental, and economic (Schmidt and Taylor 2006). The indicator values are obtained using the life cycle assessment (LCA) technique (Ford 2007). Similarly, in 2009, general motors (GM) put forward its sustainability measurement project, which took as a reference pre-existing metrics of sustainable manufacturing (Dreher et al. 2009). The best metrics, including costs and benefits, were implemented and considered as GM metrics for sustainable manufacturing (GM MMS).

In 2009, the European Commission suggested a framework of sustainable assessment (European Commission 2009) to evaluate and monitor how the European Union performed face to common sustainable problems. However, the framework lacks direct application in companies and has to be adapted before being used at organizational level. Such an adaptation allows for comparisons across industrial sectors. One year later, the United States Agency for International Development (USAID) presented the rapid basin-wide hydropower sustainability assessment Tool (RSAT) as its contribution to the sustainable assessment of hydroelectric power plants in a basin-context.

Singh et al. (2007) developed a composite index for sustainable performance assessment. The authors presented a conceptual decision model based on analytic hierarchical process (AHP) to support the evaluation of the impact of an organization's sustainable performance. Likewise, Hassan et al. (2012) proposed an integrated approach to multicriteria decision-making in the context of sustainable products design. The approach combines the morphological analysis (MA) and AHP. Authors Voces et al. (2012) ranked European countries in terms of the sustainability of wood manufacturing industries. Ghadimi et al. (2012) proposed a weighted fuzzy model to assess product sustainability. The approach relies on AHP to weight the attributes and subattributes and fuzzy logic to assess product sustainability based on the obtained weights. Ghadimi et al. (2012) argue that combining weighted fuzzy logic with experts' knowledge increased the model's reliability.

Authors Chang et al. (2013) developed a composite index of corporate sustainability to track the change of corporate sustainability over time. Ziout et al. (2013) developed a multicriteria decision-making model for the selection of end-of-life products recovery alternative from a sustainable perspective. On the other hand, Mayyas et al. (2013) introduced an eco-materials selection approach that relies on a set of quantifiable measures to develop a sustainable model for an automobile structure. Similarly, Egilmez et al. (2013) integrated Data Envelopment Analysis (DEA) and Economic Input–Output Life Cycle Assessment (EIO-LCA) to analyze the eco-efficiency of manufacturing sectors in the United States (US). Additionally, Yeon et al. (2014) introduced the MAS2 model, a sustainable manufacturing integrated approach to life cycle assessment based on modeling and simulation.

Buys et al. (2014) introduced a sustainability scorecard to measure the social, environmental, and economic impact of industries. The scorecard was developed as a Bayesian network model and was proposed as an adaptable tool to enable the evaluation, dialogue, and development of global sustainable strategies. Finally, Chen et al. (2013) created a matrix and classified sustainability methods following four criteria: rapid assessment, generic applicability, application on factory level, and holistic view of sustainability. For more information regarding each one of these sustainability assessment proposals, readers can directly consult these works, which are also summarized in Table 11.1. The table highlights the advantages and disadvantages of every sustainability assessment methodology.

From the aforementioned sustainable assessment methodologies, we can summarize the benefits of evaluation indices as follows:

- Evaluation indices must have a reduced number of variables to be assessed, as long as such variables totally measure the concept under evaluation.
- An evaluation index should be able to compare results among companies of the same industrial sector and across industrial sectors.
- Evaluation results should be regularly updated to determine whether the assessed concept has evolved.
- Companies should create work teams to implement improvement alternatives in the different index variables as a means to improve the assessed concept.

The next section discusses some of the methodologies proposed for agility measurement in the manufacturing sector.

Table 11.1 Advantages and disadvantages of sustainability assessment methodologies

Reference	Method	Advantages	Disadvantages
Van de Kerk and Manuel (2008)	Sustainable society index	Clearly defines the concept to be assessed Regularly updates and issues results Performs comparisons among the participants Appoints a group to monitor the progress of a factor being assessed	
Prescott-Allen (1997)	Barometer of sustainability	Uses a five-stage scale Combines the aggregate indices of the factors being assessed Is flexible, can be adapted to many industrial sectors	
Chen et al. (2013)	Dow Jones sustainability index (DJSI)	Available in several versions: global, European, etc. Considers tangible and intangible aspects Performs the evaluation through questions	Requires voluminous data and performs a long evaluation Does not compare industrial sectors
Fonseca (2010)	Global reporting initiative	Assesses social, environmental, and economic aspects Is flexible, can be adapted to many industrial sectors	Includes 81 factors to be assessed The evaluation is time-consuming The comparison between industrial sectors is limited
(IChemE) (2002)	IChemE	The evaluation comprises tangible and intangible aspects	Comprises 50 assessment factors and more than 300 individual results The evaluation is time-consuming. Exclusive to industrial processes Does not perform comparisons between organizations

(continued)

Table 11.1 (continued)

Reference	Method	Advantages	Disadvantages
Goodson (2002)	Rapid plant assessment (RPA)	Includes 20 yes/no questions Assesses 11 factors The factors are assessed using a six-stage scale	Available only for flow production Only evaluates economic aspects
Krajnc and Glavic (2005)	Composite sustainable development index (ICSD)	Performs evaluations at company level Assesses social, environmental, and economic aspects Companies can select or develop on their own a set of factors to be assessed	The comparison between industrial sectors is limited
Pohl (2006)	ITT Flygt sustainability index	Considers social, environmental, and economic aspects Performs rapid evaluations at company level Limited to only 40 assessment factors	Does not perform comparisons among industrial sectors
Schmidt and Taylor (2006)	Ford’s product sustainability index	Considers social, environmental, and economic aspects Comprises 8 assessment factors	The evaluation is time-consuming. Is exclusive to the automotive industry
Dreher et al. (2009)	General motors sustainable manufacturing index	Considers social, environmental, and economic aspects Comprises 33 indicators Can be applied at corporate level Performs rapid assessments Monitors improvement measures	Is exclusive to the automotive industry
European Commission (2009)	Framework of sustainable development assessment	Considers social, environmental, and economic aspects	Includes more than 100 factors to be assessed The evaluation is time-consuming Is not directly applicable to corporations

(continued)

Table 11.1 (continued)

Reference	Method	Advantages	Disadvantages
United States Agency for International Development 2010	Rapid basin-wide hydropower sustainability assessment tool (RSAT)	Considers social, environmental, and economic aspects	Includes more than 50 factors to be assessed
		Factors assessed using a five-stage scale	Exclusive to hydroelectric power plants
		Performs rapid evaluations	Does not allow for the comparison among industrial sectors
Singh et al. (2007)	Composite index for sustainable performance assessment	Considers social, environmental, and economic aspects, but also technical and governmental aspects	Exclusive to the steel industry
		Performs evaluations at company level	Allows users to compare different steel industries
		Weights the assessed factors	
Hassan et al. (2012)	Integrated MA-AHP approach for selecting the highest sustainability index of a new product	Weights the assessed factors	Exclusive to products assessments
		Identifies the elements and factors affecting sustainability	Not applicable in work systems
		Performs comparisons among different designs for a same product	
Voces et al. (2012)	Sustainability ranking of European wood manufacturing industries	Considers social, environmental, and economic aspects	
		Authors define the concept to be assessed	
		Provides a sustainability ranking of European wood manufacturing industries	
		Compares different countries	
		Can be applicable to other industries	

(continued)

Table 11.1 (continued)

Reference	Method	Advantages	Disadvantages
Ghadimi et al. (2012)	Weighted fuzzy method for sustainability assessment	Weights the assessed factors	Not applicable at corporate level
		Uses fuzzy logic for sustainability assessment	
		Considers experts' knowledge to improve the reliability of the model	
		Allows users to compare sustainability across products and industries	
Chang et al. (2013)	Composite index of corporate sustainability	Offers comparative results of sustainability changes over time	
		Compares different companies	
Ziout et al. (2013)	Multicriteria decision-making model	Applicable to manufacturing work systems	
		Considers environmental, economic, and social aspects	
		The evaluation is performed through questions	
		Weights the factors to be assessed	
		Performs comparisons across manufacturing work systems	
Mayyas et al. (2013)	Eco-materials selection approach	Considers tangible and intangible aspects	Is exclusive to the automotive industry
		Converts intangible values into tangible values to avoid bias	Does not assign weights to the attributes
			Compares materials only for the automotive industry

(continued)

Table 11.1 (continued)

Reference	Method	Advantages	Disadvantages
Egilmez et al. (2013)	Mathematical model for optimization	Applicable to manufacturing sectors Performs comparisons across manufacturing sectors	Only evaluates environmental aspects
Yeon Lee et al. (2014)	MAS^2	Applicable to manufacturing sectors Allows for overtime comparisons Considers environmental, economic, and social aspects Performs comparisons among companies	
Buys et al. (2014)	Sustainability scorecard	Considers environmental, economic, and social aspects Applicable at company level Allows the assessment of, dialogue on, and negotiation of global sustainable strategies Adaptable to local solutions Performs comparisons among companies	

11.5.2 Agility Index Methodologies

Agility is another area of work systems that has gained interest from the scientific community. In the manufacturing industry, the term agility refers to the ability of manufacturers to produce customized products with the costs and efficiency of mass production (Hasan et al. 2011; Hassan et al. 2012). In this context, several models have been proposed to evaluate or assess agility across manufacturing sectors. Many of such models rely on fuzzy logic and AHP, among others.

Authors Yang and Li (2002) developed three indices for agility measurement in mass customization product manufacturing, whereas Arteta and Giachetti (2004) constructed a model for measuring work system agility. Precisely, the authors measured work system complexity as a substitute for work system agility by positing that the least complex company in terms of processes and systems adapts better to changes and is therefore more agile. To test this hypothesis, the authors proposed a complexity measurement model. From a slightly different perspective, Lin et al. (2006) proposed an agility index for supply chains. The authors claim that because agility evaluation is imprecise, most measurements are described subjectively using linguistic terms. Also, according to Lin et al. (2006), ignoring ambiguity when measuring any concept is a limitation. When factors are qualitative and ambiguous, measurements have to be conducted using linguistic terms.

Authors Jain et al. (2008) employed fuzzy logic to assess supply chain agility. Specifically, the authors relied on fuzzy partitioning to find fuzzy association rules and calculated the reliability of such rules to determine their strength. Likewise, Bottani (2009) developed a method for identifying the most appropriate agility enablers to be implemented by companies, starting from the competitive characteristics of the market. To achieve this, the model linked competitive bases, agile attributes, and agile enablers. Hassan et al. (2012) proposed a method for manufacturing companies to rank and select types of layout based on their agility. The proposed method was called the analytic network process (ANP) and it was validated in a case study.

Ganguly et al. (2009) developed an agility measurement methodology after defining the set of agility metrics. The authors proposed to find the metrics with respect to price changes, customer satisfaction, technology changes, and socioeconomic aspects. The approach utilizes fuzzy logic as a tool to deal with subjective aspects and/or translate numerical values of the evaluation into linguistic values, as this makes the evaluation more comprehensible to inexperienced users. Simultaneously that year, Wang (2009) introduced a fuzzy linguistic model to assess agility of mass customization systems using the Top Order of Preference by Similarity to an Ideal Solution (TOPSIS) technique. The author also proposed the formation of decision-making groups in manufacturing companies. Finally, Vinodh et al. (2013) developed a model for supply chain agility evaluation. The model relies on fuzzy logic to assess qualitative and imprecise aspects. Table 11.2 summarizes the advantages and disadvantages of the following methodologies that develop agility indices.

As can be observed, fuzzy logic is common in methodologies for agility index generation, since it is a useful method to deal with problems that involve imprecision and vagueness. That said, because agility depends on qualitative and ambiguous factors that can hardly be described in numerical values, such values have to be defined using linguistic terms (Vinodh et al. 2013). According to the aforementioned methodologies, we conclude that effective agility index generators should have the following characteristics:

- Identify the factors that are necessary for measuring macroergonomic compatibility.
- Evaluate these factors using linguistic terms (fuzzy approach) and provide fuzzy weights for each factor.

Table 11.2 Advantages and disadvantages of agility methodologies

Reference	Method	Advantages	Disadvantages
Yang and Li (2002)	Indices for agility measurement in mass customization product manufacturing	Contains three agility indices: management, product design, and manufacturing process	Each index has a different fuzzy scale
		Contains second-level and third-level indices	Requires several iterations to obtain the final result
		Uses fuzzy evaluation scales with five linguistic terms	
		Relies on the evaluation by experts technique	
		Only five experts are required for the evaluation	
		Weights the assessed factors Uses Petri nets	
Arteta and Giachetti (2004)	Model of system agility	Performs comparisons across sectors	Evaluates complexity only at business process level
Lin et al. (2006)	Supply chain agility index	Relies on fuzzy logic	
		Factors include scores and weights and are aggregated using average fuzzy weights	
		Shows its efficacy in a case study	
		The method: identifies the factors to be assessed, determines the evaluation scales, assesses factors through linguistic terms, obtains the weights of each factor, performs an aggregation, and generates the final result	
		Incorporates expert opinions using the arithmetic mean	
		The final result is associated with a linguistic term to define the identified level of agility	
		Determines the obstacles hindering agility improvements	
		Can be applied in many industrial sectors	
		Allows for overtime comparisons	

(continued)

Table 11.2 (continued)

Reference	Method	Advantages	Disadvantages
Jain et al. (2008)	Fuzzy rules	Is based on fuzzy logic	The number of linguistic terms is inconsistent
		Separates qualitative factors from quantitative factors by partitioning, according to the number of linguistic terms	
		Formulates IF-THEN fuzzy rules	
		Applicable to different industrial sectors	
		Performs comparisons among companies	
Bottani (2009)	Link of competitive bases, agile attributes, and agile enablers	Identifies agile enablers to be implemented by companies	
		Studies the competitive characteristics of the market	
		Is based on the quality function deployment (QFD) methodology	
		Uses fuzzy logic	
		Applicable to different industrial sectors	
		Performs overtime comparisons among companies	
Hassan et al. (2012)	Analytic network process (ANP)	Models interdependences between factors and hierarchical levels	Needs to develop a supermatrix of factor weights
		Weights the assessed factors	The matrix must be raised to a sufficiently high power
		Uses a 1–9 scale	
		Is similar to AHP	
		Is validated in a case study	
		Performs comparisons between companies across industrial sectors	

(continued)

Table 11.2 (continued)

Reference	Method	Advantages	Disadvantages
Ganguly et al. (2009)	Agility metrics evaluation	Defines agility factors, such as cost-effectiveness, response capability, and market share	
		Obtains a numerical value for each metric through an equation	
		Considers aspects such as price, customer satisfaction, technology changes, and socioeconomic aspects	
		Employs a fuzzy scale to obtain a linguistic value of agility	
		Applicable to any industrial sector	
Wang (2009)	Fuzzy linguistic model for agility evaluation in manufacturing work systems	Employs the TOPSIS technique	
		Manufacturing work systems are evaluated by decision-making groups	
		The team proposes agility improvement alternatives and defines linguistic scales for decision-making	
		Defines a scale to assess agility levels	
		Employs experts' knowledge to define ideal and anti-ideal alternatives	
		Ranks alternatives according to the obtained values	
		Transforms numerical values into linguistic terms	
Vinodh et al. (2013)	Model of supply chain agility evaluation	Collects data through qualitative methods, such as interviews, questionnaires, observations, and documents	
		Uses fuzzy logic to evaluate qualitative factors	
		The methodology: defines the factors to be assessed, defines the linguistic terms for the evaluation and the factor weights	

- Identify the macroergonomic compatibility in work systems by associating the numerical value of the macroergonomic compatibility index with an appropriate linguistic term.
- Determine the main obstacles that prevent manufacturing work systems from implementing macroergonomic compatibility improvements.

11.5.3 Usability Index Development Methodologies

According to our review of the literature, relatively few methodologies have been proposed in the manufacturing industry to measure usability, namely to generate usability indices. Also, most of these approaches evaluate the usability of products or Web sites. For instance, Benbunan-Fich (2001) evaluated the usability of a commercial website using protocol analysis, also known as the think aloud technique. This technique requires participants to speak aloud the words in their mind while they complete a task. The verbalization process reveals the suppositions, inferences, and false ideas of users, as well as the problems they encounter as they complete a task. From a different perspective, Kim and Han (2008) proposed a usability index generation methodology for consumer electronic products. The authors highlighted that when developing a model, the simplest is the best. To measure product usability, the authors considered the product, the user, and the tasks performed by such a product. Similarly, Lin et al. (1997) assessed software system usability by taking into account user satisfaction and software design. Table 11.3 summarizes the advantages and disadvantages of the aforementioned usability index development methodologies.

The review of these methodologies provided our methodology for macroergonomic compatibility index generation with a user approach (in this case, users are represented by workers) and guided us through the development of a questionnaire to collect the necessary data.

11.5.4 Safety Evaluation Methodologies in the Manufacturing Industry

As in the previous section, safety evaluation methodologies found in the literature review were fewer than those methodologies proposed to measure agility and develop sustainability and agility indices. This section deserves particular attention, since to generate our macroergonomic compatibility index methodology we sought to embrace the advantages of the reviewed safety evaluation approaches and avoid their disadvantages. In this sense, we found that Adamyan and He (2002) presented a methodology to evaluate reliability and safety in manufacturing work systems by analyzing the impact of sequential failures. On the other hand, Haro and Kleiner

Table 11.3 Advantages and disadvantages of usability methodologies

Source	Method	Advantages	Disadvantages
Benbunan-Fich (2001)	Usability of commercial websites	Relies on protocol analysis	
		Has a user-focused approach	
		Reveals the suppositions, inferences, and false ideas of users, as well as the problems they encounter when completing a task	
		Does not require voluminous data, since it collects a fair amount of rich data	
		Applicable to technology evaluations	
Kim and Han (2008)	Usability index of consumer electronic products	Breaks down the usability concept into more specific components	
		Comprises two usability levels: individual and integrated	
		A transformed and normalized measurement is used as independent variable	
		Demonstrates the method's utility in a case study	
		Considers the product, the user, and the tasks performed by the user	
		Weights factors	
Lin et al. (1997)	Software system usability	Takes into account customer satisfaction and software design to assess effectiveness, efficiency, and learnability	
		Uses only eight evaluation factors	
		Collects data through questionnaires	

(2008) proposed a safety-focused macroergonomic evaluation methodology for manufacturing work systems. In this methodology, the authors considered three factors—people, technology, and environment—and their impact on system complexity centralization, and formalization. Table 11.4 introduces the advantages and disadvantages of these safety evaluation methodologies. Notice that from these approaches, we took into account their ability to identify failures and implement improvements.

Table 11.4 Advantages and disadvantages of safety evaluation methodologies

Reference	Method	Advantages	Disadvantages
Adamyan and He (2002)	Reliability and safety in manufacturing work systems	Identifies sequential failures and assesses the probability of their occurrence	Involves complex functions that may be difficult to understand by corporate men and women
		Relies on Petri net modeling and reachability trees	
		Analyzes and quantifies the impact of sequential failures	Neglects subjective aspects
			The evaluation is time- and effort-consuming
Haro and Kleiner (2008)	Safety in manufacturing work systems, with MAS and MEAD	Evaluates work system safety at macroergonomic level	
		Combines MAS and MEAD	
		Considers three factors—people, technology, and environment—and their impact on system complexity, centralization, and formalization	
		Identifies discrepancies	
		Uses a five-point scale for the subjective assessment of work systems using the MAS technique	
		Applicable to any work system	

11.6 Conclusions

The evaluation of manufacturing work systems was initially led by an increasing interest from the part of experts in characterizing the systems and assessing their performance in terms of productivity, quality, and efficiency. However, the evolution of manufacturing technologies and current challenges in the modern industry call for new evaluation approaches put forward by important aspects such as sustainability, agility, usability, safety, and especially ergonomics. Such factors must be taken into account when evaluating manufacturing work systems, as their integration ensures a complete and holistic evaluation.

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Chapter 12
A Macroergonomic Compatibility Index for Manufacturing Work Systems

Abstract In this chapter, we develop a macroergonomic compatibility index (MCI). The methodology combines employee perceptions regarding the macroergonomic practices implemented in their companies in the five macroergonomic factors previously addressed (person, organization, technologies and tools, tasks, and environment) with the assessment of experts regarding the importance of such macroergonomic practices. The MCI relies on dimensional analysis, which is why the result is a similarity index with respect to an ideal solution. The chapter describes step by step the methodology for the index generation and provides the results of the MCQ validation, which showed 91.3% of statistical reliability.

12.1 Introduction

Macroergonomic compatibility (MC) refers to the degree of positive interaction between humans and different macroergonomic factors and elements to help work systems achieve their goals (Realyvásquez et al. 2016b). Nowadays, MC has become a popular and useful tool among companies to increase competitiveness (Sánchez et al. 2007; Maldonado et al. 2013). As demonstrated in Chaps. 7, 8, 9, and 10, MC as a construct has positive effects—either direct or indirect—on manufacturing work systems; still, a mathematical model that measures corporate MC has not yet been proposed. However, as Karwowski stated, the lack of a universal matrix to quantify and measure human-system compatibility (i.e., MC) is an important obstacle in demonstrating the value of ergonomics as a science and profession (Karwowski 2001, 2006). To overcome this limitation, we propose a methodology for generating a macroergonomic compatibility index and thus measuring human-system compatibility.

The MCI is obtained by assessing the extent to which some macroergonomic practices are implemented in the five macroergonomic factors—Person, Organization, Technologies and tools, Tasks, and Environment—and its corresponding elements. The person can be any employee performing a range of tasks (Holden et al. 2013) and is one of the inseparable components of the system. On the

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other hand, Organization refers to the organizational conditions and structures outside a person (but often established by them), who organizes the time, space, resources, and activities. Technologies and Tools are any objects used by the employees to complete their jobs, whereas Tasks refer to specific actions performed by a person in a broader work process. Finally, Environment comprises the conditions under which a person completes their tasks.

The MCI that we propose for measuring MC relies on dimensional analysis (DA). DA evaluates the status of the variables—macroergonomic factors and elements—and compares them with an ideal solution (IS) (García-Alcaraz et al. 2013). Also, the MCI takes into account the opinions of experts regarding the importance of a set of macroergonomic practices. The experts' opinions or assessments are used in the form of weights. AD traditionally considers two types of values—subjective and objective—yet our methodology only makes use of subjective values. Similarly, AD distinguishes attributes[1] causing a positive impact from those causing a negative impact; however, we believe that CM always causes a positive impact. Therefore, a high MCI reveals good macroergonomic compatibility in a factor or element and thus good system performance.

The remainder of this chapter is organized as follows: Sect. 12.1.1 discusses the advantages and disadvantages of some of the most common ergonomic evaluation methods. Section 12.2 sets the theoretical foundations of AD upon which the MCI is based, whereas Sect. 12.3 discusses the methodology proposed to generate the MCI. Finally, Sect. 12.4 presents a part of the results obtained from applying the MCI, and Sect. 12.5 presents the chapter conclusions.

12.1.1 Ergonomic Evaluation Methods in Manufacturing Work Systems

Ergonomic evaluation tools can be categorized into two groups: microergonomic methods and macroergonomic methods. Microergonomic methods evaluate a single task or a specific workstation and vary in precision. The least precise methods evaluate workstations through the direct observation of employee movements and postures while performing tasks (Sánchez et al. 2007). These methods offer, as a result, a numerical value that measures the risk of suffering from musculoskeletal complaints (MCs) in the evaluated workstation. Four well-known microergonomic methods are the Rapid Upper Limb Assessment (RULA), the Job Strain Index (JSI), the Rapid Entire Body Assessment (REBA), and the Ovako Working Posture Analysis System (OWAS). The main advantage of microergonomic evaluation methods is that they are not time-consuming (Li and Lee 1999; Hignett and McAtamney 2000; Sánchez et al. 2007; Torres and Rodríguez 2007;

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[1] In Macroergonomic Compatibility Index (MCI), the attributes correspond to macroergonomic factors and their elements.

Rodríguez-Ruíz and Guevara-Velasco 2011) or resource-consuming (Sánchez et al. 2007; Torres and Rodríguez 2007; Dockrell et al. 2012). Moreover, they are little or non-invasive and can be used by inexperienced users. Unfortunately, they lack precision.

More precise microergonomic methods capture data through electronic devices applied directly in workers to measure specific performance variables (Sánchez et al. 2007). Electrogoniometry, goniometry, electromyography, and image digitalization are some of the most popular precise microergonomic evaluation methods. They offer more precise results than microergonomic methods of direct observation but are often high-priced and time-consuming. Moreover, the results usually have to be interpreted by specialists (Sánchez et al. 2007; Barrera-Álvarez 2009), since they may be difficult to understand.

All the aforementioned methods employ numerical values to evaluate the level of risk at which employees are exposed in a specific workstation (Sánchez et al. 2007). However, such values are a reference guide to improving a workspace only at microergonomic level, which implies that microergonomic evaluation methods can measure only the human-system compatibility on a small scale, in a given workspace, and they evaluate its effects on one or various employees. For such reasons, macroergonomic compatibility evaluation methods have emerged as a means to assess human-system compatibility on a much larger scale, at organizational level (Stanton et al. 2004).

Participative ergonomics (PE) is perhaps the most popular macroergonomic compatibility evaluation method. PE analyzes work system design and proposes improvement alternatives based on the involvement of all the employees from all the organizational levels (Stanton et al. 2004; Vink et al. 2006; Baumann et al. 2012). Other well-known macroergonomic compatibility evaluation methods are macroergonomic analysis and design (MEAD) and macroergonomic analysis of structure (MAS). MEAD highlights ten specific steps in evaluating work systems, detecting variations in two subsystems (i.e., factors)—organization and environment—and generating improvement proposals (Kleiner 2006). On the other hand, MAS analyzes the effects of three subsystems—technologies and tools, human capital (person), and environment—on the structure of a work system. Overall, EP, MEAD, and MAS support the design of work structures that ensure safe and appropriate work systems (Stanton et al. 2004).

Other macroergonomic compatibility evaluation methods include interviews and focus groups (Newman 2002), antropotechnology, laboratory experiment, field experiment (Stanton et al. 2004), and the Macroergonomic Organizational Questionnaire Survey (MOQS) (Carayon and Hoonakker 2004). However, according to the literature, none of these methods proposes an individual MCI for each one of the five macroergonomic factors, namely Person, Organization, Technologies and Tools, Tasks, and Environment, and neither do they offer a unified MCI for the factors' respective elements or for the work system.

MC has been explored from different contexts and perspectives. Authors Balbinotti and Paupitz (2015) analyzed the relationship between human resources management and production processes in an automotive company, while

Realyvásquez et al. (2015) studied the effects of organizational MC on manufacturing system performance. Similarly, Realyvásquez et al. (2016b) explored the correlation between environmental MC and employee performance in the manufacturing industry. Also, authors Robertson et al. (2015) analyzed the effects of training in macroergonomics and environmental redesign on psychosocial aspects, workplace satisfaction, and corporate culture.

Authors Maldonado et al. (2013) proposed a methodology to evaluate the ergonomic compatibility of advanced manufacturing technology (AMT). Later on, Maldonado-Macías et al. (2017) developed an expert system that simplifies calculations and saves time during the ergonomic compatibility evaluations performed on AMT. Authors Pavlovic-Veselinovic et al. (2016) also developed and expert system to measure the risk of suffering from work-related musculoskeletal disorders, while Bolis and Sznelwar (2015) discussed the importance of improvement committees for enhancing work-related conditions and proposed several alternatives to implement these committees. Finally, Holden et al. (2008) set 30 principles of macroergonomic recommendations for successful change management. Unfortunately, none of such works proposes how to develop a MCI.

12.2 Dimensional Analysis—Theoretical Foundations

Dimensional analysis (DA) is broadly employed in multi-criteria decision-making. DA can be easily applied using Excel® spread sheets, wherein the researcher qualitatively or quantitatively integrates strategical, social, economic, and technological aspects (García-Alcaraz et al. 2006). Some other appealing advantages of AD are listed below (García-Alcaraz et al. 2013):

- Combines heterogeneous attributes.
- Easy to perform and understand.
- Involves a relatively easy process that avoids the high-priced recruitment of multi-criteria experts, as DA can be performed by employees on their own.
- Uses low-cost and accessible software.
- Not a time-consuming process.

DA generates a similarity index (SI) after comparing each alternative with an ideal solution (IS), which is an inherent process of human beings (García-Alcaraz et al. 2013). Precisely, during the AD process, the alternatives are considered as vectors in the Euclidean space. The starting point in the process is the assumption that there is an IS for every assessed attribute. Therefore, an IS is the most appropriate alternative to a given attribute, as it integrates the best nominal values. Then, AD compares every assessed alternative with the IS, thereby generating the SI of an attribute as shown in Eq. (12.1):

$$\mathrm{SI} = \sqrt[W]{\prod_{i=1}^{n}\left[\frac{x_i}{\mathrm{IS}_i}\right]^{w_i^*}} \tag{12.1}$$

where

SI similarity index
IS value of the ideal solution for attribute i
x_i value of attribute i for the evaluated alternative
w_i^* weight or significance level of attribute i provided by experts

Also, W represents the sum of the absolute values of the weights provided by experts, and it is expressed as shown in Eq. (12.2).

$$W = \left|\sum_{i=1}^{n} w_i^*\right| \tag{12.2}$$

To develop our MCI methodology, we considered all the aforementioned advantages and principles of DA. Also, it is important to mention at this point that the purpose of macroergonomics is that work systems (e.g., manufacturing work systems) implement the necessary macroergonomic practices (MPs).

12.3 The MCI Methodology

This methodology is transversal and non-experimental. Similarly, it comprises eight stages, thoroughly discussed in the following subsections.

12.3.1 Stage 1: Designing the Macroergonomic Compatibility Questionnaire (MCQ)

To develop our Macroergonomic Compatibility Questionnaire (MCQ), we conducted a literature review to define the macroergonomic factors and elements contributing to the MC of work systems, namely manufacturing systems (see Table 5.1, from Chap. 5). After a careful and comprehensive analysis and synthesis, we concluded that five macroergonomic factors were necessary to measure the MC of manufacturing work systems, as they were the most commonly explored by the literature. Such factors and their corresponding elements were introduced and discussed in Chap. 5, namely in Fig. 5.1, and are consistent with the set of MC factors an elements proposed in other research works (Carayon et al. 2006). Moreover, they seem to show a detailed structure of the work system components.

Various questionnaires have been employed to collect data on macroergonomic compatibility (Preziosi 1980; Karasek et al. 1998; Morgeson and Humphrey 2003; Carayon and Hoonakker 2004); however, none of such questionnaires assesses all the factors and their corresponding elements, and neither do they measure the MC of work systems. As a result, the MCQ that we developed and propose in this book was a more appropriate instrument to collect the data necessary for our MCI. That said, developing the MCQ demanded a comprehensive review of the literature on macroergonomics. The review explored information behind key terms such as *macroergonomics*, *macroergonomic factors*, *macroergonomic elements*, *macroergonomic methods*, *work systems*, and *sociotechnical systems* (Realyvásquez et al. 2016a).

In most of the research works reviewed, the macroergonomic factors (Kling 1995; Kleiner 1998; Hyer et al. 1999; Berg 1999; Genaidy et al. 2007; Reiman and Oedewald 2007; Drews 2013; Marras and Hancock 2014; Maguire 2014) or elements are not structurally organized (Carayon 2012; Carayon et al. 2014; Karsh et al. 2014; Sherehiy and Karwowski 2014), but the works that do present such factors and elements hierarchically classified (Carayon et al. 2006; Realyvásquez et al. 2016a) contributed to our understanding of how the work system components are interrelated and thus helped us find out how to generate the MCI for the first-level system components (i.e., macroergonomic factors). The MCI of each macroergonomic factor is obtained from the MCI of its corresponding elements, or second-level components. The hierarchical classification of macroergonomic factors and elements also helped us easily identify those components (factors and/or elements) requiring MPs.

Once all the necessary macroergonomic factors and elements were addressed by the MCQ, we adapted some of the questionnaire items, so the involved element or factor could be assessed from a macroergonomic perspective (Preziosi 1980; Karasek et al. 1998; Morgeson and Humphrey 2003; Carayon and Hoonakker 2004; Morgeson and Humphrey 2006). The MCQ comes in three versions, the worker version (MCQ-WV), the health department version (MCQ-HDV), and the experts' version (MCQ-EV). We only employed the MCQ-WV and the MCQ-EV to obtain the numerical values of the MCI and the MCQ-HDV and the MCQ-WV to validate the index.

The MCQ-WV has four sections: demographic data, MPs implementation, MPs benefits, and comments, yet the methodology only focuses on Sects. 12.2 and 12.3. The purpose of Sect. 12.2 was to evaluate the state of a set of MPs in manufacturing work systems, whereas Sect. 12.3 evaluated the benefits obtained from implementing such MPs. We used this last section to validate the MCI. As for the MCQ-HDV, it has two sections: records of occupational risk and current levels and probability of suffering from occupational risks. Both sections were necessary to validate the MCI. Finally, the MCQ-EV was developed to measure the importance level of the set of MPs and relied on the assessments or weights provided by the experts for each MPs of every macroergonomic element. More specifically, in the MCQ-EV, the experts rated each MP, considering its impact and thus importance degree, on work system performance. To consult a sample of each MCQ version, please consult Appendix.

The three MCQ versions include a five-point fuzzy Likert scale (Likert 1932; Glover et al. 2011; Li 2013; García-Alcaraz et al. 2014) that has been previously employed in recent and similar studies (Glover et al. 2011; García-Alcaraz et al. 2014; Realyvásquez et al. 2016b). The MCQ-EV and the MCQ-HDV must be answered with the following scale: (1) strongly disagree, (2) disagree, (3) neutral, (4) agree, (5) strongly agree. This scale system allowed us to measure the employee perceptions regarding the MPs implemented in their companies. Also, note that the subjective questions of the MCQ-HDV are responded in terms of severity and probability, whereas the objective values are obtained from numerical values. Finally, to assess the level of importance of each MP in the manufacturing industry, the MCQ-EV had to be answered using the following five-point Likert scale: (1) not important, (2) slightly important, (3) moderately important, (4) important, (5) very important (Celik et al. 2009; Maldonado-Macías et al. 2013).

12.3.2 Stage 2: Defining the IS of the MCI

Considering the five-point scale of the MCQ-WV, option 5—*Totally Agree*—was set as the ideal answer, thus implying that the IS of the MCI of the assessed macroergonomic elements is the complete consensus from employees regarding the fact that the evaluated MPs are always implemented in the manufacturing systems. Thus, IS can be expressed by Eq. (12.3) as follows:

$$\mathrm{IS} = \text{Totally agree} \tag{12.3}$$

We chose *Totally agree* as the linguistic term to avoid negative questions, for which participants have to reverse their thinking when answering them. The answers to this kind of questions are usually evaluated reversely, so they can be included in the final score, however, this technique may present three difficulties: (1) questions cannot be easily written in an opposite sense without losing some meaning, (2) participants may encounter difficulties with reverse thinking, and (3) a same question can be rated differently depending on the sense in which it is formulated (Hartley 2014). Thus, to avoid calculation errors, all the questions were formulated in the same sense. Also, we paid close attention to and tried to avoid any type of bias derived from incorrectly developing questions (Choi et al. 2010). Common sources of bias in survey development include writing vague, leading, invasive, broad, or open questions and designing incorrect scales. Finally, because the MCQ offers a diagnose of MC in manufacturing systems through employee perceptions, none of the possible answers to the survey questions was considered as right or wrong.

12.3.3 Stage 3: Data Fuzzification and Defuzzification

The answers of the MCQ-WV belonged to a fuzzy scale that allowed us to measure the degree of implementation of MPs in manufacturing work systems. The MCQ-EV also has a fuzzy scale to evaluate de level of importance of the MPs of each macroergonomic element. In both surveys, the data were collected from an ordinal scale and corresponded to triangular fuzzy numbers (TFNs), whereas Eq. (12.1) includes precise values. To be able to use to the data in this equation, they were transformed from fuzzy values into precise values. In other words, the data was defuzzified. To deffuzify the data, we first defined what a TFN is. According to Cheng and Lin (2002) and Chang et al. (2004), a TFN is a triplet (a, b, c) whose membership function $\mu_X(x)$ is defined by Eq. (12.4). Figure 12.1 graphically illustrates a TFN.

$$\mu_X(x) = \begin{cases} 0, & x < a \\ \frac{x-a}{b-a}, & a \leq x \leq b \\ \frac{c-x}{c-b}, & b \leq x \leq c \\ 0, & x > c \end{cases} \tag{12.4}$$

To convert the TFNs into precise values, we employed the Center of the Area (CoA) technique. The defuzzification of TFN $X = (a, b, c)$ using the CoA techniques can be calculated as shown in Eq. (12.5) (Lavasani et al. 2015):

$$x^* = \frac{(a+b+c)}{3} \tag{12.5}$$

where

x^* precise value of TFN X.

Therefore, after using Eq. (12.5) to deffuzify the IS, we obtained the following result:

$$\text{IS} = \frac{0.8+1+1}{3} = 0.93$$

Fig. 12.1 Triangular fuzzy number (TFN)

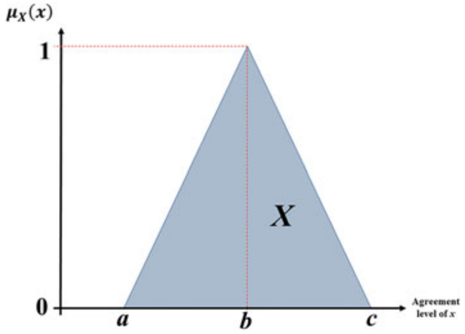

Table 12.1 Correspondence among linguistic terms, fuzzy numbers, and precise numbers

Linguistic term	Type	Fuzzy number	Precise number
Not important	Weight	(0, 0, 0.3)	0.1
Slightly important	Weight	(0, 0.25, 0.5)	0.25
Moderately important	Weight	(0.3, 0.5, 0.7)	0.5
Important	Weight	(0.5, 0.75, 1)	0.75
Very important	Weight	(0.7, 1, 1)	0.9
Totally disagree	Score	(0, 0, 0.4)	0.13
Disagree	Score	(0.2, 0.4, 0.6)	0.4
Neutral	Score	(0.4, 0.6, 0.8)	0.6
Agree	Score	(0.6, 0.8, 1)	0.8
Totally agree	Score	(0.8, 1, 1)	0.93

This procedure was applied to all the fuzzy values presented in Table 12.1 to obtain the corresponding precise values. The value of IS = 0.93 was used to calculate the MCI of all the macroergonomic elements. Once this was achieved, we estimated the MCI of each macroergonomic factor considering IS = 1, since the ideal solution of the MCI of each macroergonomic element was 1. Once all the data were defuzzified, they were treated as continuous data to apply subsequent algorithms.

12.3.4 Stage 4: Aggregating Precise Values

Many data aggregation techniques are nowadays available, such as the arithmetic mean, the median, and the mode. Our methodology relies on the arithmetic mean, since it is a very common technique used to aggregate precise values (Lin et al. 2006). We thus assumed that m workers were surveyed by the MCQ-WV. For each worker, we estimated the precise value $x^*_{i,j}$ as a score of MP$_j$, $j = 0, 1, 2, \ldots, k$. Therefore, the precise average score $\bar{x}^*_j$ of MP$_j$ was calculated as defined in Eq. (12.6).

$$\bar{x}^*_j = \frac{x^*_{1,j} + x^*_{2,j} + \cdots + x^*_{m,j}}{m} \tag{12.6}$$

Because the MCI of a macroergonomic element depends on the precise average score of specific MPs, the $\bar{x}^*_j$ values obtained from Eq. (12.6) were used to calculate the MCI of the macroergonomic elements. The same procedure was followed to aggregate the weights from ergonomics experts. Suppose that there are M experts surveyed by the MCQ-EV. From each expert E, we obtained a precise value $w^*_{E,d}$ to weight the implementation of the assessed MPs in macroergonomic element d, $d = 1, 2, \ldots, l$. Then, the precise average weight $\bar{w}^*_l$ of macroergonomic element

l was calculated using Eq. (12.7). The values of $\bar{w}_l^*$ were used to calculate the MCI of the macroergonomic elements.

$$\overline{w}_l^* = \frac{w_{1,d}^* + w_{2,d}^* + \cdots + w_{M,d}^*}{M} \tag{12.7}$$

12.3.5 Stage 5: Applying the MCI

Because the precise values estimated earlier were used to develop the MCI, we performed DA to measure this index as expressed by Eq. (12.8):

$$\mathrm{MCI} = \sqrt[W]{\prod_{i=1}^{n} \left[\frac{\bar{x}_j^*}{\mathrm{IS}_i}\right]^{\bar{w}_l^*}} \tag{12.8}$$

In this equation, W is the sum of the precise average weights $\bar{w}_l^*$ of a macroergonomic element or factor as expressed by Eq. (12.2). However, to calculate the MCI of a macroergonomic element, we used the weights of that same element, since the MCI of the assessed macroergonomic elements depended on non-weighted questions. Hence, for the macroergonomic elements, we obtained $w = \bar{w}_l^*$. On the other hand, to each macroergonomic factor, W is the sum of the weights of that factor's macroergonomic elements. Finally, for the whole work system, W means the sum of the weights of the five assessed macroergonomic factors. Therefore, Eq. (12.2) can measure only the MCI of macroergonomic factors and work systems (i.e., manufacturing work systems, in this research).

Up to this point, Eq. (12.8) with IS = 0.93 can only calculate the MCI of macroergonomic elements in general. The MCI of a macroergonomic factor thus depends on the MCI of its corresponding elements, for which IS = MCI = 1. Equation (12.9) shows how to estimate the MCI of macroergonomic factors and manufacturing work systems in general, where IS = 1.

$$\mathrm{MCI} = \sqrt[W]{\prod_{i=1}^{n} \left[\bar{x}_j^*\right]^{\bar{w}_l^*}} \tag{12.9}$$

In DA, the best solution is the alternative with the best SI with respect to the IS (García-Alcaraz et al. 2013). We also used a numerical index, since current macroergonomic evaluation methods lack this property. Moreover, a numerical index minimizes subjectivity and simplifies the interpretation of results (Domínguez et al. 2011). However, because the goal of our MCI is to provide feedback to manufacturing work systems regarding their MPs, the MCI goes beyond an absolute value. Our index encourages proactivity by anticipating the risks associated with poor or insufficient MPs. Research has demonstrated that such a proactive approach offers more benefits than the reactive approach (Groza et al. 2011). On the other hand, although the MCI combines experts' opinions, managers do not have to be ergonomics experts to calculate the MCI.

12.3.6 Stage 6: Assigning Linguistic Terms to the MCI

Table 12.2 introduces the scale proposed for the MCI and its corresponding linguistic terms, according to the MCI ranges. The methodology also sets the action levels required from companies according to their obtained MCI values.

Macroergonomic elements or factors or work systems with a LOW MCI are considered as areas of opportunity, which implies that some macroergonomic improvements are necessary in such cases. On the other hand, macroergonomic elements or factors or manufacturing work systems having a MEIDUM or HIGH MCI are considered as acceptable. In such cases, MPs are not necessary, although the involved companies make have the last word.

12.3.7 Stage 7: Validating the MCI

The MCI validation comprised three steps: (1) validating the MCQ, (2) validating the MC construct, and (3) validating the MCI as such. The MCQ validation process and its results are thoroughly presented later in this chapter, whereas Chaps. 7, 8, 9, and 10 address the validation of MC as a construct. In such chapters, the proposed structural equation models demonstrated that MC has positive direct effects on the performance of manufacturing work systems. Finally, the MCI validation is introduced in Chap. 13.

To validate the MCQ, we performed a reliability analysis and a factor analysis. Usually, the reliability of ordinal data is estimated using the Cronbach's alpha index (Ocaña et al. 2013; García-Alcaraz et al. 2014), even though such data are discontinuous and non-normal (Freiberg et al. 2013). In this sense, some experts argue that the Cronbach's alpha can be used in ordinal data as long as the violation of normality and continuity assumptions does not cause statistically significant effects on the results (Freiberg et al. 2013). However, other experts claim that the Cronbach's alpha necessarily involves continuous and normally distributed data (Basto and Pereira 2012; Gaderman et al. 2012; Oliden and Zumbo 2008), which are not characteristics of ordinal data. In this case, the same authors suggest

Table 12.2 MCI ranges, linguistic terms, and action levels

MCI value	Linguistic term	Action level
$0 \leq \mathrm{MCI} < 0.7$	LOW	MPs are required
$0.7 \leq \mathrm{MCI} < 0.9$	MEDIUM	MPs are recommended
$0.9 \leq \mathrm{MCI} \leq 1$	HIGH	

estimating the reliability of ordinal scales by employing the ordinal alpha index, which offers more precise estimations of reliability. Considering this lack of consensus, we employed the ordinal alpha index to test the reliability of our questionnaire, the MCQ, setting 0.7 as the minimum possible value.

The MCQ was analyzed by dimensions or macroergonomic elements through its corresponding items. First, the data were screened, substituting missing values and outliers by the median value of the analyzed dimension. This procedure has been previously adopted for the analysis of ordinal data contained in a Likert scale (García-Alcaraz et al. 2014; Hair et al. 2010, 2006). Afterward, we employed the polychoric correlation technique to obtain the factor loadings of each item corresponding to each macroergonomic element. Then, we estimated the ordinal alpha index for every macroergonomic element using Eq. (12.10) (Oliden and Zumbo 2008; Domínguez 2012).

$$\alpha_{\text{ordinal}} = \frac{n}{n-1}\left[\frac{n\left(\bar{\lambda}\right)^2 - \bar{\lambda}^2}{n\left(\bar{\lambda}\right)^2 + u^2}\right] \tag{12.10}$$

where:

n	number of items in a macroergonomic element
$\bar{\lambda}$	average factor loading of n items
λ^2	average factor loading of the squares of the n factor loadings
$u^2 = 1 - \lambda^2$	average unicity of n items.

The variables having satisfied the reliability analysis remained in the MCQ, whereas those that did not pass the reliability test were preliminary removed. However, if their weights provided by the ergonomics experts were high, these variables were kept in the MCQ despite their low ordinal alpha values and were taken into account for further analyses.

Factor analysis is the most appropriate technique when it comes to identifying the latent variables that explain variation and covariation in a set of items and removing those variables that do not cause any impact. Specifically, factor analysis deals with observed measurements (Brown 2015) and allows the researcher to reduce the study variables when the data are presented in an ordinal scale (Castañeda et al. 2010). For this research, we performed a factor analysis for each macroergonomic element using Bartlett's sphericity test, and we estimated the Kaiser–Meyer–Olkin (KMO) index to determine the feasibility of the analysis (Schulze et al. 2015). The KMO test indicates the proportion of variance in the data that may be caused by subjacent factors. Experts argue that factor analysis is feasible if the KMO index is equal to or above 0.8 (Ferrando and Anguiano-Carrasco 2010). On the other hand, if the KMO index is below 0.5, a factor analysis may not appropriately evaluate data dimensionality (Shumway-Cook et al. 2015). Then, we used varimax rotation, as its goal is to maximize the variance of each of the factors (Wang et al. 2005). Finally, to reduce the dimensionality of the latent variables, we only kept items having shown communality values above 0.5 (Kamboj et al. 2014).

As previously mentioned, we validated MC as a construct using structural equation modeling. The structural equation models (SEMs) developed in Chaps. 7, 8, 9, and 10 helped us measure the effects (direct, indirect, and total) that the macroergonomic compatibility of the elements has on three dependent work system performance variables: customers (customer satisfaction, needs, loyalty), production processes (defects, complaints, inventory levels, productivity), and organizational performance (number of employees, product variety, business volume). The significant effects demonstrated that MC has a positive impact on work system performance, and this is how MC as a construct was validated.

Initially, the MCI was partially validated by analyzing the health and safety data collected by the MCQ-HDV and those obtained with the MCQ-WV regarding the current performance of the surveyed manufacturing companies in terms of customers, production processes, and organizational performance (Dul and Neumann 2009). Such parameters were named benefits. Then, the surveyed manufacturing work systems were ranked in descending order, according to their estimated MCI values. To achieve a reliable partial validation, those manufacturing companies with the highest MCI were supposed to show more positive results in terms of benefits. Because the analyzed benefits did not influence any MCI value, we employed the average technique to aggregate the data (Lin et al. 2006) and thus omitted any defuzzification.

12.4 Results from the MCQ Validation

12.4.1 Reliability

As mentioned earlier, we relied on the ordinal alpha index and used the six experts' weights to test the reliability of the analyzed macroergonomic elements. Table 12.3 shows the reliability of each macroergonomic element, including the ordinal alpha value and the experts' weight. Most of the elements showed an ordinal alpha index above 0.7, which thus confirmed their internal reliability. Only macroergonomic element *Work Schedules* showed an ordinal alpha value below 0.7.

As regards the experts' weights, *Work Schedules* showed the highest weight in the Organization category despite having reported the lowest ordinal alpha value of all the elements. The weight thus justified the element's presence in the MCQ and in the analysis. Also, notice that according to the six ergonomics experts, *Task Variety*, *Workstation Layout*, *Work Demands*, *Noise*, and *Lighting* are the most important macroergonomic elements, yet employee *Social Relationships* and *Psychological Characteristics* showed the lowest weights.

Table 12.3 Ordinal alpha values and average crisp weights of macroergonomic elements

Macroergonomic factor	Macroergonomic element	Ordinal alpha	Experts w^*
Person	Psychological characteristics	0.911	0.580
	Motivation and needs	0.848	0.650
	Physical characteristics	0.834	0.760
	Education, knowledge, and skills	0.783	0.650
Organization	Teamwork	0.857	0.680
	Organizational culture and safety culture	0.855	0.730
	Performance evaluation, rewards, and incentives	0.837	0.610
	Supervision and management styles	0.826	0.760
	Coordination, collaboration, and communication	0.819	0.650
	Social relationships	0.781	0.540
	Work schedules	0.593	0.760
Technologies and tools	Information technology	0.832	0.780
	Human resources characteristics of tools and technologies	0.811	0.700
	Advanced manufacturing technology	0.787	0.780
Tasks	Work content, challenges, use of skills	0.858	0.760
	Autonomy, job control, and participation	0.828	0.680
	Work demands (workload, required attention, etc.)	0.802	0.800
	Task variety	0.751	0.830
Environment	Distribution	0.887	0.730
	Lighting	0.873	0.780
	Workstation layout	0.837	0.810
	Temperature, humidity, air quality	0.821	0.760
	Noise	0.813	0.780

12.4.2 Factor Analysis

The KMO test performed on all the macroergonomic elements demonstrated that the factor analysis was effective, since all the elements showed KMO values above 0.8. Similarly, we obtained communality values above 0.5 in 92 items, thereby validating the MCQ in 91.30%.

12.5 Conclusions

This chapter discusses how we validated the MCQ as a tool capable of evaluating macroergonomic elements and factors and estimating their MCI. Even though *Work Schedules* initially reported an ordinal alpha value below 0.7, we achieved internal consistency in this latent variable after reformulating the items and including more items to assess it. In conclusion, we could validate the MCQ because most of the macroergonomic elements (dimensions) showed an ordinal alpha value higher than 0.7. However, since macroergonomics is an emergent field and new macroergonomic theories may eventually emerge, the MCQ may need further modifications and updates to include new MPs, thereby requiring a new validation analysis.

As regards the advantages of the MCI, we believe that it is a useful and relevant tool in terms of its capability to measure one of the most challenging constructs of science: the level of macroergonomic compatibility for the hierarchies of manufacturing system components, that is, the elements, factors, and the work system as a whole. Also, other benefits of the MCI include:

- It is applicable to any company and thus provides feedback regarding MPs under specific circumstances.
- It can be utilized in any employment sector by means of simple aggregation processes or modifications to the MCQ.
- It measures macroergonomic compatibility at three levels: (1) macroergonomic elements, (2) macroergonomic factors, (3) work systems.
- It associates a linguistic term with each numerical value of the MCI. This property allows companies to understand the index better and detect potential improvement areas.
- It supports and encourages MPs, since the MCI proposes a measuring unit based on a 0–1 scale.
- Can help companies achieve performance and quality goals, such as developing new competitive strategies and meeting the norms and regulations that take into account ergonomic aspects (e.g., Occupational Safety and Health Administration—OSHA—and the ISO 14000 family).

To improve ergonomic conditions, companies interested in implementing MPs can initiate formal ergonomics programs, form ergonomics committees, set continuous improvement policies, and define ergonomic intervention plans and practices. In this sense, participative ergonomics (Guimarães et al. 2015) offers positive results to employees and companies alike. We also recommend work systems to appoint ergonomics experts as improvement group leaders that would monitor and supervise the adopted ergonomic measures. The decisions of such experts would be backed up by the MCI, which is capable of detecting the elements and factors that need urgent macroergonomic intervention. Based upon such results, companies can adopt the macroergonomic methodology that best meets their needs and would help them reach higher macroergonomic compatibility in all the hierarchies. As regards our comments for future work, we encourage the development of software applications for Web platform generation, namely Web evaluation platforms that would promote and monitor MPs in manufacturing companies and other work systems.

Appendix: Samples of MCQ Versions

See Tables 12.4, 12.5 and 12.6.

Table 12.4 Sample of the MCQ-WV

Macroergonomic practices	Perception levels				
	Totally disagree	Disagree	Neutral	Agree	Totally agree
The company regularly evaluates employee performance	1	2	3	4	5
The company motivates its employees to do their best	1	2	3	4	5
The salary is proportional to what employees do	1	2	3	4	5
The company considers human and ergonomic aspects when purchasing new information technology	1	2	3	4	5
The work to be done depends on different information technologies	1	2	3	4	5
The tasks performed with information technologies are completed in risk-safe environments	1	2	3	4	5
Employees are explained how to use information technologies	1	2	3	4	5

Table 12.5 Sample of the MCQ-HDV

Indicator	Perception levels				
	Totally disagree	Disagree	Neutral	Agree	Totally agree
Workers are safe from injuries	1	2	3	4	5
Workers are safe from accidents	1	2	3	4	5
Workers are safe from illnesses	1	2	3	4	5
Work-related injuries have gradually decreased since the company started operating	1	2	3	4	5
Only a few work-related accidents occur	1	2	3	4	5

Table 12.6 Sample of the MCQ-EV

Element on which MPs are applied	Importance				
	Not important	Slightly important	Moderately important	Important	Highly important
Employee autonomy, job control, and participation	1	2	3	4	5
Work demands (workload, mental effort, required attention, etc.)	1	2	3	4	5
Plant distribution	1	2	3	4	5
Noise	1	2	3	4	5
Lighting	1	2	3	4	5
Temperature, humidity, and air quality	1	2	3	4	5
Workstation layout	1	2	3	4	5

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Chapter 13
Macroergonomic Compatibility Index for Manufacturing Work Systems: Case Study

Abstract This chapter presents three case studies to validate the macroergonomic compatibility index (MCI). The studies were conducted in Ciudad Juárez, Chihuahua, Mexico, in three automobile manufacturers. As for the data collection instrument, we administered the Macroergonomic Compatibility Questionnaire (MCQ) discussed in the previous chapters. The collected data were treated as discussed in Chap. 12 to estimate the MCI of each macroergonomic element, macroergonomic factor, and work system. Also, we analyzed the benefits that the three manufacturers reportedly obtain from implementing macroergonomic practices in terms of customers, production processes, organizational performance, and occupational safety. Such information was employed to validate the MCI. As a result, we found that the three automotive companies have a low MCI, thereby implying that such work systems require immediate macroergonomic intervention. Also, the validation of the MCI was satisfactory.

13.1 Introduction

13.1.1 Research Context

The estimated MCI values identify which macroergonomic elements and factors require macroergonomic interventions. To test the reliability of our methodology, we explored macroergonomic compatibility in transnational manufacturing industries located in Ciudad Juárez, Chihuahua. Transnational manufacturing is a key to the economic performance of Mexico. The country congregates more than 5,017 manufacturing plants that yearly employ 2,343,679 people and generate 18,826.54 million USD. More specifically, transnational manufacturing industries located in the state of Chihuahua represent 13.6% of the total income of the Mexican manufacturing industry and employ 323,794 workers in their 482 establishments (Instituto Nacional de Estadística Geografía e Informática (INEGI) 2015).

This chapter presents three case studies that validated our MCI for manufacturing work systems. From now on, the studied manufacturers will be addressed as

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Work System 1, Work System 2, and Work System 3. Work System 1 is a company that started operating in Ciudad Juárez, Chihuahua, in 1985, yet the plant evaluated in the case study launched its operations in 2006. This company manufactures internal combustion engines, turbines, transmissions, unit injectors, railway systems, and electronic modules. The company employs around 1,450 workers. Work System 2 is an electromechanical manufacturer that produces accessories for vehicles such as windshield wipers; it employs 1,367 workers and was established in Ciudad Juárez in 1999. Finally, Work System 3 makes electronic filter assemblies and offers products such as filters, sensors, connectors, potentiometers, and amplifiers, among others. The company settled in Ciudad Juárez in 2000 and employs 352 people.

13.2 Results

This section presents and discusses the results of the MCQ, the three estimated MCI values, and the validation of the MCI methodology.

13.2.1 Survey Administration

Table 13.1 shows the number of surveyed workers in each manufacturing system.

As can be observed, more employees were surveyed in Work System 1, followed by Work System 2, with 41 workers. Work System 3 reported fewer number of participants, with only 34 surveyed workers. The data provided by the sample were used to estimate the MCIs of each work system.

13.2.2 Implementation of Ergonomic Methods

This section presents the ergonomic methods that the studied work systems reportedly implement. To obtain such data, the participants were asked to mention the different ergonomic methods that they thought the companies implemented. To answer this question, the sample had the following options:

1. Participatory ergonomics (PE),
2. Focus group,
3. Macroergonomic and analysis design (MEAD),

Table 13.1 Survey workers

	Work System 1	Work System 2	Work System 3
Number of surveyed workers	42	41	34

4. Macroergonomic analysis of structure (MAS),
5. Laboratory,
6. Field experiment,
7. Questionnaires,
8. Interviews,
9. Microergonomic methods (REBA, RULA, NIOSH, OCRA, Suzanne Rodgers), and
10. Others (specify).

Figure 13.1 shows the ergonomic methods implemented by Work System 1. According to eight of its employees, the company mainly implements PE, whereas seven participants claim that it implements several ergonomic methods. On a smaller scale, we found that Work System 1 relies on microergonomic methods, questionnaires, and MEAD.

Figure 13.2 shows the methods reportedly implemented by Work System 2. According to the MCQ, most of the company participants (12) claim that the company relies on other ergonomic methods. Six participants think that Work System 2 implements microergonomic methods, three participants selected PE, and only one participant considers that the company implements MAS.

As regards Work System 3, 14 participants claim that their company implements several ergonomic methods. Apparently, one of such methods was PE, since six participants selected this approach. Also, two participants think that Work System 3 implements focus groups, and two more believe that it relies on interviews. Only one of the participants thinks the company implements other ergonomic methods that were not mentioned in the MCQ. Figure 13.3 shows the data of Work System 3.

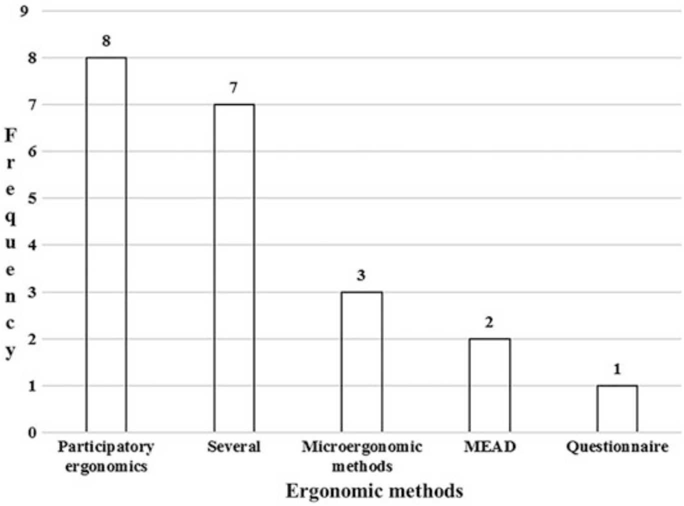

Fig. 13.1 Ergonomic methods implemented in Work System 1

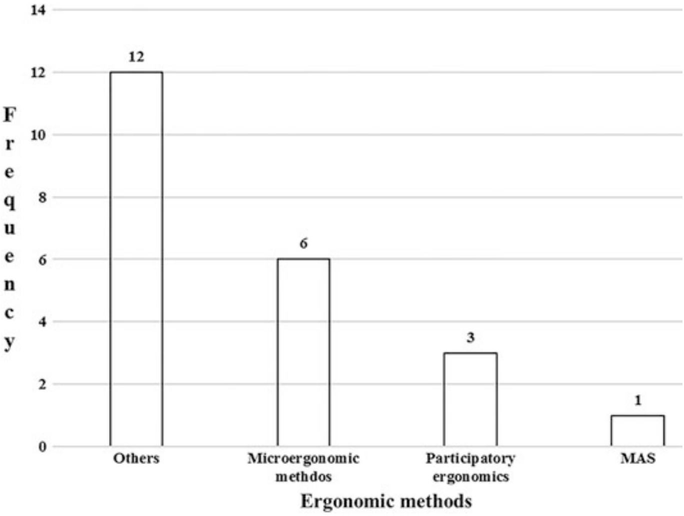

Fig. 13.2 Ergonomic methods implemented in Work System 2

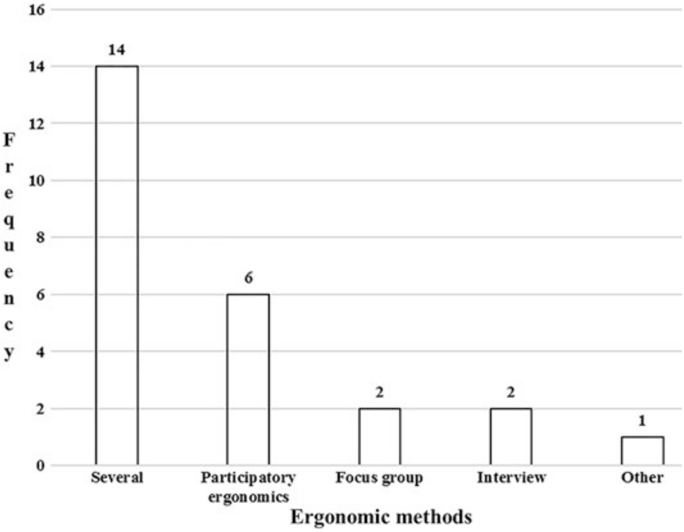

Fig. 13.3 Ergonomic methods implemented in Work System 3

13.2.3 Index of Macroergonomic Compatibility

This section presents the results obtained after applying the methodology proposed in this chapter to estimate the MCI of the three work systems.

13.2.3.1 MCI of Work System 1

To estimate the MCI, we administered the worker version of the MCQ (MCQ-WV) described in Sect. 13.3.1. The obtained data were defuzzified using Eq. (12.5) to obtain precise values. Then, we estimated the average of such values for each macroergonomic practice (MP) using Eq. (12.6). Up to this point, the obtained result is a precise average value of the employee perceptions regarding MP implementation in their companies. We used this value to estimate the MCI of the macroergonomic elements.

The data collected through the experts' version of the MCQ (MCQ-EV) were treated similarly. However, after the defuzzification, we calculated the average of the precise values using Eq. (12.7). We used the precise average values of the MCQ-WV and the MCQ-EV in Eq. (12.8) to obtain the MCI of macroergonomic elements. Similarly, to obtain the MCI of the macroergonomic factors and the work system, we used Eq. (12.9). We followed the same procedure for all the work systems to estimate their MCI. Readers can refer to Chap. 12 to consult the methodology.

Work System 1, the MCIs of the macroergonomic elements are shown in Table 13.2. The table shows that all the elements, except for *Supervision and Management Styles,* fall in the LOW category. That is, all of them showed an MCI below 0.7. For the Person factor, *Education, Knowledge, and Skills* showed the highest MCI (0.669 units), whereas *Psychological Characteristics* showed the lowest MCI, that is, 0.219. As for organizational elements, the highest MCI was reported in *Supervision and Management Styles* (MCI = 0.743), and this value fell into the MEDIUM category. On the other hand, *Social Relationships* showed the lowest MCI (0.281 units). In Technologies and Tools, *Human Factor Characteristics in Technology and Tools* showed the highest MCI (0.670 units), and it was then followed by *Advanced Manufacturing Technology* (MCI = 0.433) and *Information Technology* (MCI = 0.248). For the Tasks factor, *Job Content, Challenges, and Use of Skills* had the highest MCI (0.668 units), while *Autonomy, Work Control, and Participation* had the lowest MCI (0.132 units). Finally, as regards the environment factor, *Lighting* showed the highest MCI (0.658 units) and *Temperature* the lowest (0.307 units). Table 13.2 introduces the MCI and its linguistic terms for each macroergonomic element of Work System 1.

If most of the macroergonomic elements fell in the LOW category, the macroergonomic factors are expected also to fall into the same classification. As previously mentioned, the MCI of every macroergonomic factor was estimated using Eq. (12.9). Table 13.3 shows the MCIs of the macroergonomic factors for Work System 1. As can be observed, all of them actually fell into the LOW category, being Organization the one with the highest MCI (0.476 units) and Tasks the one with the lowest MCI (0.291 units).

Figure 13.4 depicts the MCI values of the macroergonomic factors of Work System 1 and their relationship with the ideal solution (IS). Notice that all the MCI values are relatively far from the IS value.

Table 13.2 MCI and linguistic terms of macroergonomic elements—Work System 1

Macroergonomic factor	Macroergonomic element	MCI	Linguistic term
Person	Education, knowledge, and skills	0.669	LOW
	Physical characteristics	0.651	LOW
	Motivation and needs	0.446	LOW
	Psychological characteristics	0.219	LOW
Organization	Supervision and management styles	0.743	Medium
	Coordination, collaboration, and communication	0.557	LOW
	Work schedules	0.507	LOW
	Teamwork	0.485	LOW
	Performance evaluation, rewards, and incentives	0.450	LOW
	Organizational and safety culture	0.373	LOW
	Social relationships	0.281	LOW
Technologies and tools	Human factor characteristics in technology and tools	0.670	LOW
	Advanced manufacturing technology	0.433	LOW
	Information technology	0.248	LOW
Tasks	Job content, challenges, use of skills	0.668	LOW
	Tasks variety	0.513	LOW
	Work demands	0.144	LOW
	Autonomy, job control, and participation	0.132	LOW
Environment	Lighting	0.658	LOW
	Workstation layout	0.401	LOW
	Noise	0.395	LOW
	Distribution	0.338	LOW
	Temperature, humidity, and air quality	0.307	LOW

Table 13.3 MCI and linguistic terms of macroergonomic factors—Work System 1

Macroergonomic factor	MCI	Linguistic term
Organization	0.476	LOW
Person	0.469	LOW
Technologies and tools	0.409	LOW
Environment	0.406	LOW
Tasks	0.291	LOW

The MCI values seen in Table 13.3 were used to obtain the MCI of the whole work system. In the end, Work System 1 reported MCI = 0.401, a value that also fell in the LOW category.

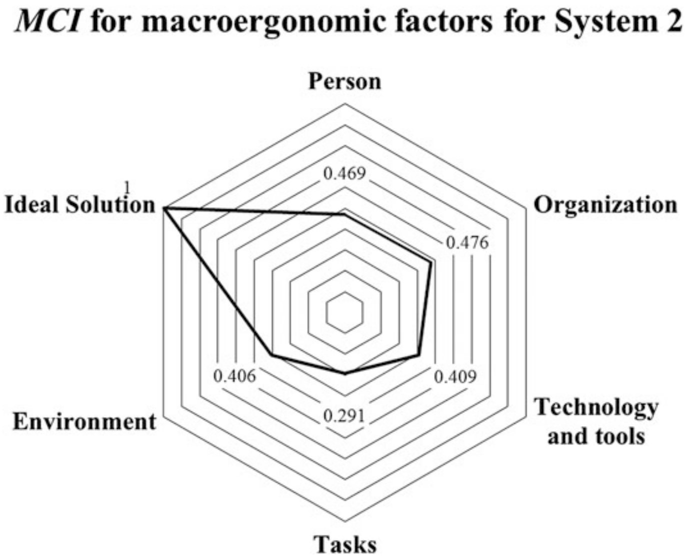

Fig. 13.4 IS and MCI for macroergonomic factors in Work System 1

13.2.3.2 MCI of Work System 2

Unlike Work System 1, Work System 2 reported low MCIs in all its macroergonomic elements. For the Person factor, *Education, Knowledge, and Skills* reported the highest index (MCI = 0.692), while *Motivation and Needs* reported the lowest value (MCI = 0.382). In the Person and Organization factors, the sequence of the macroergonomic elements was the same as in Work System 1. Also in this work system, *Supervision and Management Styles* had the highest MCI (0.616 units), whereas *Social Relationships* was the organizational element with the lowest MCI (0.252 units). For Technologies and Tools, Work System 2 is consistent with Work System 1 in the ranking of the elements. For Work System 2, *Human Factor Characteristics in Technology and Tools* reported MCI = 0.623, *Advanced Manufacturing Technology* reported MCI = 0.340, and *Information Technology* showed MCI = 0.168.

In the Tasks factor, Work System 2 is consistent with Work System 1 in the first two macroergonomic elements. In Work System 2, *Job Content, Challenges, and Use of Skills* showed the highest MCI (0.638 unit) and *Work Demands* the lowest index (MCI = 0.116). Finally, in the Environment factor, Work System 1 and Work System 2 were consistent with each other in the first, fourth, and fifth positions, whereas the second and third positions were interchanged. In Work System 2, *Lighting* showed the highest index (MCI = 0.582), and *Temperature, Humidity, and Air Quality* showed the lowest index (MCI = 0.099). Table 13.4 presents the MCI of each macroergonomic element and its associated linguistic term in Work System 2.

Considering the MCI values of the macroergonomic elements, we expected equally low values in the macroergonomic factors. Table 13.5 shows the MCI

Table 13.4 MCI and linguistic terms of macroergonomic elements—Work System 2

Macroergonomic factor	Macroergonomic element	MCI	Linguistic term
Person	Education, knowledge, and skills	0.692	LOW
	Physical characteristics	0.548	LOW
	Motivation and needs	0.382	LOW
	Psychological characteristics	0.136	LOW
Organization	Supervision and management styles	0.616	LOW
	Coordination, collaboration, and communication	0.481	LOW
	Work schedules	0.390	LOW
	Teamwork	0.367	LOW
	Performance evaluation, rewards, and incentives	0.288	LOW
	Organization and safety culture	0.279	LOW
	Social relationships	0.252	LOW
Technologies and tools	Human factor characteristics in technology and tools	0.623	LOW
	Advanced manufacturing technology	0.340	LOW
	Information technologies	0.168	LOW
Tasks	Job content, challenges, use of skills	0.638	LOW
	Task variety	0.494	LOW
	Autonomy, job control, and participation	0.198	LOW
	Work demands	0.116	LOW
Environment	Lighting	0.582	LOW
	Noise	0.294	LOW
	Workstation layout	0.283	LOW
	Distribution	0.254	LOW
	Temperature, humidity, and air quality	0.099	LOW

Table 13.5 MCI and linguistic terms of the macroergonomic factors—Work System 2

Macroergonomic factor	MCI	Linguistic term
Person	0.391	LOW
Organization	0.372	LOW
Technology and tools	0.321	LOW
Tasks	0.295	LOW
Environment	0.263	LOW

values of the five macroergonomic factors of Work System 2. As can be observed, all of them fell into the LOW category, yet the Person factor reported the highest MCI (0.391) and the Environment factor reported the lowest MCI (0.263).

Additionally, Fig. 13.5 illustrates the MCI values of the factors for Work System 2 as well as their relationship with the IS. Note that all the MCI values are relatively far from the IS value.

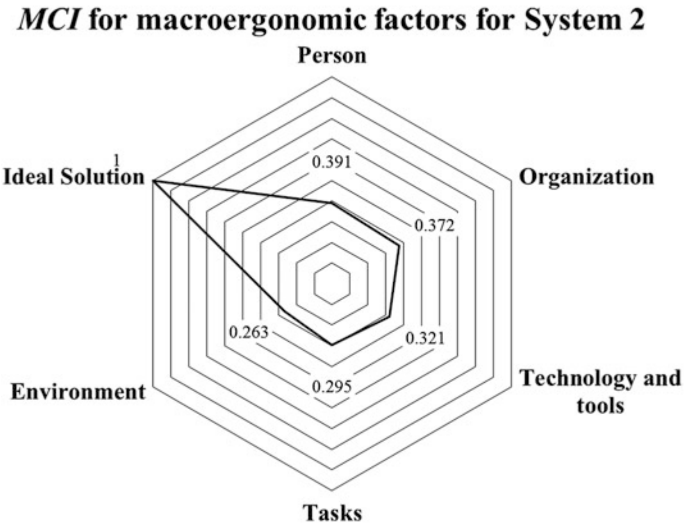

Fig. 13.5 IS and MCI for macroergonomic factors in Work System 2

The MCI values seen in Table 13.5 were used to obtain the MCI of the whole work system. That is, Work System 2 reported MCI = 0.322, a value that also fell in the LOW category.

13.2.3.3 MCI of Work System 3

As in Work System 1 and Work System 2, all the MCI values of the macroergonomic elements in Work System 3 were lower than 0.7 and thus fell into the LOW category. For the Person factor, *Education, Knowledge, and Skills* showed the highest MCI value (0.697 units), and *Psychological Characteristics* reported the lowest index (MCI = 0.180). In this factor, the macroergonomic elements had the same positions in the three work systems as defined by the MCI. As for Organization, Work System 3 is generally consistent with the other two systems, only *Organizational Culture and Safety Culture* and *Performance Evaluation, Rewards, and Incentives* switch positions. Again, *Supervision and Management styles* showed the highest MCI (0.625 units), and *Social Relationships* reported the lowest value (0.174 units).

As far as the Technologies and Tools factor is concerned, the three systems are consistent with one another in terms of the ranking of the macroergonomic elements. *Human Factor Characteristics in Technology and Tools* showed the highest value (0.662), and it was then followed by *Advanced Manufacturing Technology* (MCI = 0.373) and *Information Technology* (MCI = 0.209). For the Tasks factor, Work System 1 and Work System 3 have the same ranking of macroergonomic elements. The highest MCI was reported in *Work Content, Challenges, Use of Skills* (0.638 units), whereas *Autonomy, Job Control, and Participation* showed the lowest MCI (0.160). Finally, Work System 3 and Work System 2 had the same ranking of macroergonomic elements in the Environment factor. The highest MCI was reported by *Lighting* (0.642 units), whereas *Temperature, Humidity, and Air Quality* showed the lowest value (MCI = 0.228). Table 13.6 presents the MCI values of the macroergonomic elements with the corresponding linguistic terms.

Table 13.7 presents the MCI values for the macroergonomic factors of Work System 3. All of them fell into the LOW category, although Person showed the highest MCI (0.424 units) and Tasks reported the lowest (MCI = 0.331).

Figure 13.6 depicts the MCI values of the macroergonomic factors of Work System 3 and their relationship with the ideal solution (IS). As in the previous two case studies, all the MCI values are far from the IS value.

The MCI values presented in Table 13.5 were used to obtain the MCI of the work system. That is, Work System 3 reported MCI = 0.368, a value that also falls in the LOW category.

Table 13.6 MCI and linguistic terms of macroergonomic elements—Work System 3

Macroergonomic factor	Macroergonomic element	MCI	Linguistic term
Person	Education, knowledge, and skills	0.697	LOW
	Physical characteristics	0.535	LOW
	Motivation and needs	0.427	LOW
	Psychological characteristics	0.180	LOW
Organization	Supervision and management styles	0.625	LOW
	Coordination, collaboration, and communication	0.523	LOW
	Work schedules	0.489	LOW
	Teamwork	0.469	LOW
	Organizational culture and safety culture	0.319	LOW
	Performance evaluation, rewards, and incentives	0.240	LOW
	Social relationships	0.174	LOW
Technology and tools	Human factor characteristics in technology and tools	0.662	LOW
	Advanced manufacturing technology	0.373	LOW
	Information technology	0.209	LOW
Tasks	Job content, challenges, use of skills	0.683	LOW
	Task variety	0.517	LOW
	Work demands	0.193	LOW
	Autonomy, job control, and participation	0.160	LOW
Environment	Lighting	0.642	LOW
	Noise	0.401	LOW
	Workstation layout	0.317	LOW
	Distribution	0.272	LOW
	Temperature, humidity, and air quality	0.228	LOW

Table 13.7 MCI and linguistic terms of macroergonomic elements—Work System 3

Macroergonomic factor	MCI	Linguistic term
Person	0.424	LOW
Organization	0.387	LOW
Technologies and tools	0.364	LOW
Tasks	0.331	LOW
Environment	0.349	LOW

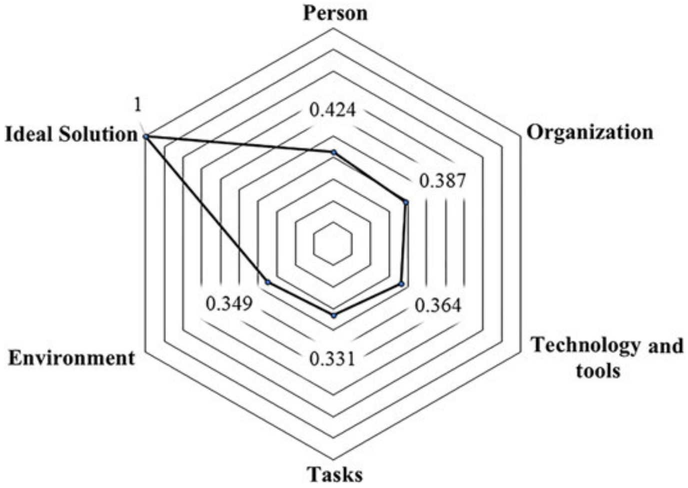

Fig. 13.6 IS and MCI for macroergonomic factors in Work System 3

13.2.4 Interpretation of Results

The MCI values indicate whether macroergonomic elements, macroergonomic factors, or the work system need macroergonomic interventions. As shown in Table 13.2, any element, factor, or system with a low MCI (MCI < 0.7) needs to implement macroergonomic practices, whereas any element, factor, or system with a MEDIUM MCI ($0.7 \leq$ MCI < 0.9) does not necessarily need macroergonomic interventions, although we recommend implementing new macroergonomic practices or periodically audit the ones already implemented as well as the company's safety conditions to keep the MCI stable. Finally, any MCI value that falls into the HIGH category implies that the involved macroergonomic element, macroergonomic factor, or the work system does not need to implement any macroergonomic practices. However, in any case, the company makes the final decision.

For cases that require implementing macroergonomic practices, we propose the following general recommendations:

- Review the data of the MCQ-WV and the MCQ-EV to know which macroergonomic elements and factors fell into the LOW category of the MCI and implement—as soon as possible—the necessary macroergonomic practices.
- Form an ergonomics committee whose members supervise the MPs implemented in every macroergonomic element. The committee should also include a leader of each macroergonomic factor and a top team leader.
- Make a well-detailed work plan including the goals to be reached and the tasks to be completed to reach such goals. Specify dates and time.
- Consult (Stanton et al. 2004), who discuss different macroergonomic methods, their implementation, advantages, and disadvantages.

13.2.5 Validating the Macroergonomic Compatibility Index

The MCI was validated under the assumption that any work system that implements macroergonomic practices has a better MCI and more positive results (benefits) in terms of customer satisfaction and loyalty (*Customers*), inventory levels and customer complaints (*Production Processes*), fewer occupational accidents, injuries, and illnesses in the last year (*Occupational Health and Safety*), and greater business volume and customer volume (*Organizational Performance*). Table 13.8 presents the results of the partial validation of the MCI. As can be observed, Work System 1 showed the highest MCI and was then followed by Work System 3 and Work System 2. As for the benefits, we used the third section of the MCQ-WV to collect the data. As mentioned in this chapter 13, such data do not affect the MCI and were thus aggregated using the average technique, thereby omitting any defuzzification. As seen in Table 13.8, not only did Work System 2 have the lowest MCI, but it also reported the least positive benefits. This is how we partially validated the MCI.

Note that Work System 1 and Work System 3 reported similar results in terms of benefits. For instance, the difference in customer-related benefits was 0.1, whereas the difference in production processes was 0.001. As for occupational health and safety, the three systems reported 0 occupational risks, and in organizational performance, the difference was 0.12. Overall, the difference between Work System 1 and Work System 3 was 0.038, which is relatively small. Finally, the average

Table 13.8 MCI validation results

Work system	MCI	Customers	Production processes	Health and safety	Organizational performance	Average of benefits
1	0.401	4.14	3.43	0	3.88	2.863
3	0.368	4.04	3.44	0	4	2.870
2	0.322	3.68	3.15	0	3.81	2.660

difference in the benefits between Work System 1 and Work System 3 is 0.007. Initially, such results may reject the hypothesis previously proposed, since they are too small; however, because the MCI depends on both benefits and employee perceptions, we concluded that the MCI was validated.

13.3 Conclusions

The MCI is a reliable tool, as it can effectively measure the macroergonomic compatibility of work systems. However, we recommend that more case studies be conducted across countries to increment the reliability of the methodology. As for the implementation of ergonomic methods in manufacturing work systems, we concluded that less than 50% of the participants in each of the three work systems were really convinced that their companies implemented the selected methods. Such results suggest that employees are not familiar with the existence and implementation procedures of such methods or the benefits that such methods bring at individual and branch levels. For this reason, it is important to introduce ergonomics concepts, principles, and practices in companies with the support of educational institutions or through independent projects.

Another aspect that can contribute to the introduction of theoretical and practical knowledge on ergonomics in manufacturing work systems is the Mexican official norm (NOM)-036, through which the Secretariat of Labor and Social Prevision (STPS, by its Spanish acronym) asks senior managers to identify and evaluate occupational risk factors and adopt the pertinent control measures to minimize and reduce such factors. If the Mexican companies that already comply with this norm apply the MCI, the index would probably reach values close to 1. This can encourage further comparative analyses between the Mexican manufacturing work systems that comply with the norm and those that do not comply with it, yet. The results of such analyses could increase the validation reliability of the MCI.

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