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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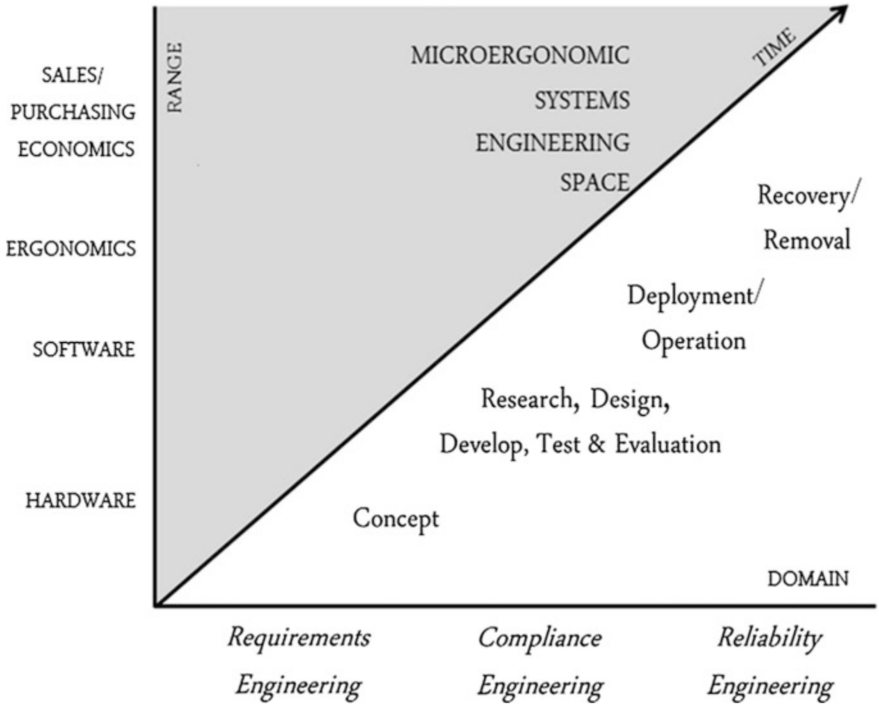

Fig. 3.1 Microergonomic space of systems engineering. Adapted from: Samaras and Horst (2005)

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.

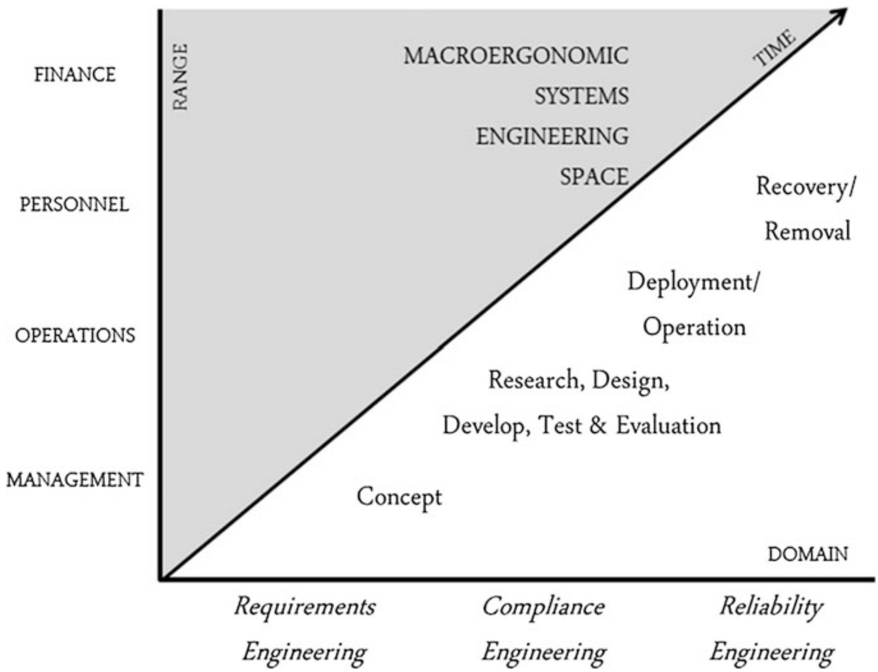

Fig. 3.2 Macroergonomic space of engineering systems. Adapted from: Samaras and Horst (2005)

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

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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

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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

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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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