

DOKUZ EYLÜL UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

**AN INDICATOR-BASED
SYSTEMATIC ERGONOMICS
PERFORMANCE EVALUATION APPROACH
FROM SUSTAINABILITY PERSPECTIVE**

by
İrem SARBAT

February, 2022
İZMİR

**AN INDICATOR-BASED
SYSTEMATIC ERGONOMICS
PERFORMANCE EVALUATION APPROACH
FROM SUSTAINABILITY PERSPECTIVE**

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**by
İrem SARBAT**

**February, 2022
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Ph.D. THESIS EXAMINATION RESULT FORM

We have read the thesis entitled “**AN INDICATOR-BASED SYSTEMATIC ERGONOMICS PERFORMANCE EVALUATION APPROACH FROM SUSTAINABILITY PERSPECTIVE**” completed by **İREM SARBAT** under supervision of **ASSIST. PROF. DR. SEREN ÖZMEHMET TAŞAN** and we certify that in our opinion it is fully adequate, in scope and in quality, as a thesis for the degree of Doctor of Philosophy.

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AN INDICATOR-BASED SYSTEMATIC ERGONOMICS PERFORMANCE EVALUATION APPROACH FROM SUSTAINABILITY PERSPECTIVE

ABSTRACT

Ergonomics is a discipline that has been trying to provide human well-being for many years, nearly since the existence of humanity. It is undeniable that providing better perpetual working and living conditions for people is more challenging for ergonomics considering today's rapidly changing global world. Therefore, new concepts to assist ergonomics and work coherently for achieving this aim are needed.

To fill this research gap, this thesis was built on the research and implementation on querying the effect, contribution, and adaptation of the sustainability concept to ergonomics by developing a systematic approach for sustainable process performance measurement in ergonomics. Accordingly, new sustainability sub-dimensions for ergonomics and also ergonomics indicators were proposed based on a comprehensive literature search and structured in a framework integrating ergonomics and sustainability. Furthermore, two surveys were designed, developed and applied for this thesis for the validity and reliability of implementation. Subsequently, a hybrid multi-criteria analysis including BWM and PROMETHEE was performed using the data gathered from surveys to prioritize the proposed ergonomics indicators, and the ones ranked high were determined as examples to be used for such an approach.

The systematic approach developed in this thesis is for the organizations, in which there are unfavourable working conditions in an economic, ecological, or social manner, to identify and prevent risks caused by these conditions through monitoring and evaluating their processes holistically. Hence, managing risks and providing ergonomically well-operated processes can be achieved with this developed systematic approach comprising the proposed structural framework and ergonomics indicators.

Keywords: Ergonomics, sustainability, indicator, process performance measurement, framework, survey, statistical analysis, multi-criteria analysis, BWM, PROMETHEE

SÜRDÜRÜLEBİLİRLİK BAKIŞ AÇISIYLA BİR GÖSTERGE TABANLI SİSTEMATİK ERGONOMİK PERFORMANS DEĞERLENDİRME YAKLAŞIMI

ÖZ

Ergonomi, neredeyse insanlığın varoluşundan bu yana, uzun yıllardır insanın iyilik halini sağlamaya çalışan bir disiplindir. Günümüzün hızla değişen küresel dünyası göz önüne alındığında, insanlar için daha iyi sürekli çalışma ve yaşam koşulları sağlamanın ergonomi için daha zorlu olduğu yadsınamaz. Bu nedenle, ergonomiye yardımcı olacak ve bu amaca ulaşmak için uyumlu çalışacak yeni kavramlara ihtiyaç vardır.

Bu araştırma boşluğunu doldurmak için bu tez, ergonomide sürdürülebilir süreç performans ölçümü için sistematik bir yaklaşım geliştirilerek sürdürülebilirlik kavramının ergonomiye etkisini, katkısını ve adaptasyonunu sorgulamaya yönelik araştırma ve uygulama üzerine inşa edilmiştir. Bu doğrultuda, kapsamlı bir literatür taramasına dayalı olarak ergonomi için yeni sürdürülebilirlik alt boyutları ve ergonomi göstergeleri önerilmiş ve ergonomi ile sürdürülebilirliği bütünleştiren bir çerçevede yapılandırılmıştır. Ayrıca, uygulamanın geçerliliğini ve güvenilirliği adına bu tez için iki anket tasarlanmış, geliştirilmiş ve uygulanmıştır. Ardından, önerilen ergonomi göstergelerinin önceliklendirilmesi için anketlerden elde edilen veriler kullanılarak BWM ve PROMETHEE'yi içeren bir hibrit çok kriterli analiz yapılmış ve bu tür bir yaklaşım için kullanılabilecek örnekler olarak üst sıralarda olanlar belirlenmiştir.

Bu tezde geliştirilen sistematik yaklaşım, ekonomik, ekolojik veya sosyal açıdan olumsuz çalışma koşullarının bulunduğu kuruluşların süreçlerini bütüncül olarak izleyerek ve değerlendirerek bu koşullardan kaynaklanan riskleri tespit etmek ve önlemek içindir. Dolayısıyla, önerilen yapısal çerçeve ve ergonomi göstergelerini içeren söz konusu geliştirilen sistematik yaklaşım ile, risklerin yönetilmesi ve ergonomik açıdan iyi işleyen süreçlerin elde edilmesi sağlanabilir.

Anahtar kelimeler: Ergonomi, sürdürülebilirlik, gösterge, süreç performans ölçümü, çerçeve, anket, istatistiksel analiz, çok kriterli analiz, BWM, PROMETHEE

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CHAPTER ONE

INTRODUCTION

This chapter comprises the motivation and original contributions, aims and research questions, and research methodology of this thesis with the presentation of the outline and the papers produced from the thesis.

1.1 Motivation and Original Contributions

Considering today's rapidly changing global world, providing better living conditions for people has become difficult. Essentially, the changes in every part of life, such as purchasing power, income level, and technology, and the increased responsibilities and efforts for time management can be presented as the main reasons why it is getting harder to cope with these difficulties. By looking at these difficulties from a global point-of-view, Reiman & Väyrynen (2018), Siemieniuch, Sinclair, & Henshaw (2015), and Zink (2011) state that megatrends (i.e. globalization, food and energy security, digitalization, demographic development, community security and safety, market dynamics, change of values, and technological progress) affect society, organizations, and individuals broadly.

Similarly, from an organizational point-of-view for these difficulties, Krykun (2016) indicates that enhancing quality of life and living standards, giving importance to ecology, and preserving profitability are the aims of organizations. However, it can be denoted that money is one of the most prominent output that is tried to be gained under today's rapidly changing conditions mentioned, and, unfortunately, providing favourable working conditions for employees may be ignored during rapid production and consumption conversions. Furthermore, companies usually are not attentive enough to their employees' needs during these profit-making processes. It can be stated that the health and safety issues in organizations reflect these insufficient attitudes clearly. About this, Haslam, O'Hara, Kazi, Twumasi, & Haslam (2016) denote that the deserved priority of health and safety is not given by many organizations although there is an explicit need for the management of them.

Therefore, by considering all these profit-oriented organizations, it is not difficult to say that giving importance to people's lives has been decreased, meaning that providing human well-being becomes more challenging in today's globalizing world.

Ergonomics is a discipline comprising various proposed methods and approaches to provide human well-being both physically and mentally. Wilson (2000) denotes that the well-being of individuals, organizations, and national economies is provided by ergonomics, and this aim can be achieved with the help of theory as well as practice, models, and methods. Nevertheless, the physical, cognitive, social, organizational, and environmental aspects of work and its positive or negative potential impacts on employees should be regarded for a successful application of ergonomics (Scott, Kogi, & McPhee, 2010). Basically, it can be indicated that such applications have become more essential. The base that lies behind this can be detailed as follows: Given today's many internal and external influences that constitute ergonomics risk factors (e.g. repetitive movements, awkward postures, physical workload, heavy loads, job dissatisfaction, monotonous work, lack of management's support, time pressure, and job stress), the management of better perpetual processes in ergonomics to provide human well-being has been challenging. In the long term, however, these risk factors are likely giving some physical and mental harm to people. Accordingly, economic and ecological effects can be caused by these potential harms directly or indirectly. Unfortunately, sufficient and sustainable solutions may not be achieved anymore by handling these influences and trying to prevent them with only ergonomics.

The existing efforts in ergonomics show that a structural framework is needed. By considering the fundamental aim of ergonomics, providing human well-being, it can be stated that this framework should meet needs of the employee, who is located in the intersection of job/task, workplace & equipment, and work organization, while outside economic and social influences are also considered. Scott et al. (2010) define this relation by presenting fundamental elements of ergonomics (i.e. job/task, workplace & equipment, work organization, and employee) and their interactions. Then, an ergonomically well-designed process should be within an employee's individual capabilities and limitations as well as the satisfaction of social needs and aspirations.

Importantly, to develop an ergonomically well-designed process, the main point is the determination of whether the consideration of only fundamental elements of ergonomics is sufficient or not; the relations between the fundamental elements of ergonomics and the economic and social influences outside require a more structural framework. Basically, ergonomics has not reached its potential for associating with tasks, products, jobs, technology, organizations, and environment interacting with human's abilities, needs, and limitations (Dirkse Van Schalkwyk & Steenkamp, 2017). By starting from this, it can be stated that the concepts such as sustainability may assist in proposing more permanent solutions, i.e., developing such a framework at the base level, against ergonomically improperly designed processes.

Bolis, Brunoro, & Sznclwar (2014b) consider that the aims of ergonomics are somehow related to sustainability. Zink (2014) remarks on the necessity of sustainability for developing assessments and designs related to work systems, because, it is dangerous for sustainability to become only a vogue term. Miller et al. (2014) state that sustainability searches for the answer to the question about how various communities at different scales envision and maintain social and natural well-being. Additionally, Johnston, Everard, Santillo, & Robèrt (2007) suggest that defining sustainability to be more associated with the human environment is essential.

Recently, there has been a growing emphasis on the necessity of considering sustainability for the processes, which human is one of the main drivers. Siemieniuch et al. (2015) denote that manufacturing processes may be fundamental to sustainability. Moreover, ergonomics has an essential role in sustainability due to the increasing roles of people in manufacturing processes such as design, knowledge, control, strategy, and resilience (Siemieniuch et al., 2015). Brown & Legg (2011) also suggest that many systems should be redesigned to achieve sustainability, and ergonomics may help for this redesign. Hence, it is stated that considering ergonomics within a sustainability point-of-view can give an opportunity to the stakeholders, who are the ergonomists and managers in organizations, for designing more traceable, measurable, flexible, and manageable processes. Moreover, sustainability can help ergonomics to evaluate processes in an economic, ecological, and social way.

To accomplish all these issues for presenting the integration of ergonomics and sustainability, firstly, a suitable presentation of the relations between ergonomics and sustainability should be given. This presentation can be mainly divided into two parts: The first part is the precise definition of dimensions, sub-dimensions, and indicators for presenting the relations between ergonomics and sustainability. Accordingly, the second part is the arrangement of all these components within a framework for ease of understanding and performance by whole stakeholders in related processes. Despite the existence of many frameworks and their adaptations to various areas for measuring sustainability in the literature, it has been realized that there is a lack of research addressing ergonomics and sustainability together within a structural framework, comprising new dimensions, sub-dimensions, and indicators proposed for ergonomics under a sustainability point-of-view. Fundamentally, the starting point of this thesis is this research gap summarized above, indicating that the development of such a structural framework to assist in providing sustainable processes in ergonomics.

To fill this research gap, as *the first original contribution* of this thesis, a structural framework for the integration of ergonomics and sustainability was proposed. The dimensions, sub-dimensions, and indicators, which were brought together to present the relations between ergonomics and sustainability, constitutes the proposed framework. The aim of this part of the thesis, presented in detail in Chapter 2, is to propose a practical and easily adaptable framework for organizations to facilitate having processes satisfying the needs of stakeholders and putting cost-effective as well as environmentally-friendly interventions into practice. Essentially, more traceable, measurable, and flexible processes should be provided at first to achieve this aim. It is proposed in this thesis that this base framework, comprising ergonomics, sustainability, and the potential integration of these two, can enable achieving this aim by assisting in periodic control and management of processes. Importantly, it should be noted here that the term *indicator* has been used in this thesis interchangeably with the term *measure* by considering the terms mentioned originally in the cited references. Moreover, the terms *ecology* and *ecological* have also been used in this thesis interchangeably with the terms *environment* and *environmental* due to the scope of this thesis, including the conditions related to working or living areas that relate to humans.

In addition to all these efforts made for proposing such a framework, it is more efficient to utilize this framework basically within a performance measurement system to monitor and evaluate processes of organizations holistically. Such a system can be used as the fundamental part of a systematic approach that integrates ergonomics and sustainability through the proposed ergonomics indicators for sustainable process performance measurement in ergonomics. The efforts made for developing such a systematic approach is *the second original contribution* of this thesis, and its fundamental part (i.e. performance measurement system comprising the proposed ergonomics indicators) is presented in detail in Chapter 3. Before this, the need for such a system is explained in the following part of this subsection.

Similar to the challenges in providing human well-being considering today's rapidly changing global world explained in the first part, from an organizational point-of-view, it can be stated that the management of business processes is an increasing challenge today. What makes this challenge remarkable for organizations is the influence of business processes. According to González, Rubio, González, & Velthuis (2010), product quality and customer satisfaction are influenced strongly by business processes, and both are mainly important for achieving market share. Since the measures used in business processes enable estimating, controlling, and improving processes in organizations, these measures have great importance in business process management (González et al., 2010).

Undoubtedly, to overcome this challenge and guide well-operated processes as well, the establishment of a performance measurement system is needed. Such a system enables ergonomists or managers as the stakeholders responsible for having well-operated processes to monitor and evaluate these processes properly. Specifically, it can be assumed that this responsibility leads ergonomists to work as an advisory board for managerial decisions. For example, Berlin, Neumann, Theberge, & Örtengren's (2017) findings show that ergonomists' advice on determining the limit values of measurements can assist in fulfilling legal requirements. Moreover, Bititci, Carrie, & McDevitt (1997) highlight that a performance measurement system structured effectively and rigorously can be a basis for managing operational, tactical,

and strategic decisions in organizations. Through this viewpoint, it can be stated that the measurement and evaluation of any process affect managerial decisions such as operational, ecological, organizational, and financial ones relating whole organization. In this regard, Ryan & Wilson (2013) suggest that there is a need for developing tools enabling various risks to become visible for managers. These tools may assist in considering the trade-offs based on economic, environmental, social, and performance parameters in the decision-making processes of organizations (Ryan & Wilson, 2013).

Chapanis (1995) state that ergonomists use their knowledge by applying it to “the design of tools, machines, systems, tasks, jobs and environments for safe, comfortable and effective human use” (p. 1626). Accordingly, the role of an ergonomist is guiding the evaluation, analysis, and design of these components, and the inclusion of sustainable ideas and practices are part of this guidance (Martin, Legg, & Brown, 2013). Similarly, Village, Searcy, Salustri, & Neumann (2015) remark on the need for tools for ergonomics specialists for being sustainable in designing processes. Village et al. (2015) state that these tools may ensure quantitative measures and targets, which can be used for continuous improvement, communication, benchmarking, and comparison. These values, enabling systematic and periodic evaluation of processes, can also be used for identifying risky conditions. Hence, ergonomists or managers can prevent unfavourable working conditions through tracking or acting on these values.

Since indicators represent components or processes of real-world systems (Braat, 1991), indicators can be used in measuring the performance of a process. Jägerbrand (2015) states that indicators are used as a tool for policymaking and decision support to provide the measurement, monitoring, and fulfilment of various aims and targets. Furthermore, indicators are frequently used for sustainability assessment. Gallopin (1997) emphasizes this by describing indicators as fundamental components for the assessment of the progress towards sustainable development. Additionally, Braat (1991) defines sustainability indicators as “indicators which provide information, directly or indirectly, about the future sustainability of specified levels of social objectives such as material welfare, environmental quality and natural systems amenity” (p. 57). By starting from this definition, it can be stated that the indicators

used for sustainability assessment point towards a sustainable future in terms of welfare, materiality, ecology, and well-being for society. As Jägerbrand (2015) states, many sustainability indicators usually belong to a framework, and, these frameworks may have specific aims.

On the other hand, finding the metrics, models, and tools to specify unsustainable activities and move away from them is a widely recognized need by individuals, organizations, and societies (Bebbington, Brown, & Frame, 2007; Santiago-Brown, Metcalfe, Jerram, & Collins, 2015). A similar need can also appear for ergonomics. More specifically, it is indicated that humans are an essential part of business processes, and Sobhani, Wahab, & Neumann (2016) underline this as the involvement of human in many phases of operation systems. To accomplish sustainable performance, human is a fundamental resource of competitive advantage for companies (Pfeffer, 1995; Sobhani et al., 2016). Hence, it is essential that a performance measurement system should support proposals for ergonomically favourable conditions for human well-being.

Despite the existence of several ergonomics risk assessment methods in literature, there is a need for the studies in which the development of a structural framework to manage all processes of a work organization within a holistic point-of-view are discussed. Establishing a performance measurement system using this kind of framework and its indicators to identify potential ergonomics risks along business processes enable assessing these risks systematically and periodically in a sustainable way, providing ergonomists or managers to take precautions and minimize risk levels.

In short, such a performance measurement system, which enables using indicators within a holistic point-of-view for the systematic and periodic evaluation of processes through being used in a systematic approach to be developed, is also needed for ergonomics. To overcome this research gap, new ergonomics indicators were proposed in this thesis by utilizing a systematic literature review conducted on ergonomics and sustainability. Classifications and detailed descriptions constituted for the proposed ergonomics indicators were also presented in this thesis as original contributions.

These efforts were presented as a basis for the development of such a systematic approach comprising a performance measurement system and its proposed ergonomics indicators as the fundamental part of such an approach. Thanks to these indicators, the integration of ergonomics and sustainability can enable the presentation of the coherence between the two.

The aim of this part of the thesis, presented in detail in Chapter 3, is to propose ergonomics indicators to assist in measuring the performance of processes of organizations in a sustainable way. It was envisaged that these indicators, by systematically monitoring and evaluating processes, will aid the management and prevention of the risks caused by unfavourable working conditions. Then, these indicators were planned to satisfy employees' needs as well as society, monetary, and ecology issues, referring to three dimensions of sustainability (i.e. *Economic*, *Ecological*, and *Social*). The reason for using these dimensions as a basis is, as Fischer & Zink (2012) state, balancing the management of ecological, human, economic, and social capital. Thatcher, Nayak, & Waterson (2020) discuss this balance from an organization's perspective by considering the needs of an organization in terms of making a profit, providing decent working conditions for its employees, and not damaging the natural environment. The aims that Thatcher et al. (2020) point out were also considered for the efforts made in this thesis to propose ergonomics indicators.

1.2 Aims and Research Questions

The fundamental aim of this thesis is to develop a systematic approach comprising a performance measurement system and its proposed ergonomics indicators as the fundamental part of such an approach that integrates ergonomics and sustainability to monitor and evaluate processes of organizations holistically. To achieve this aim, the efforts made in this thesis are divided into four parts, as presented in Section 1.1 and given details in Section 1.4: The first part comprises the structural framework proposal (Sarbat & Ozmehmet Tasan, 2020), and the second part represents the ergonomics indicators proposal (Sarbat & Ozmehmet Tasan, 2022). Moreover, two new papers produced from this thesis, as the third and fourth parts, were submitted to a journal.

There are two surveys in this thesis, enabling the data collection part of this thesis to achieve this aim. These surveys were designed and developed for this thesis and labelled by considering their implementation order in the thesis: *Survey-1* is for ensuring the validity of the implementation, while *Survey-2* is for ensuring the reliability of the implementation in this thesis. Although the detailed descriptions of these surveys are given in the related following sections, the aims of these surveys are summarized here as supportive of the fundamental aim of this thesis. *The aim of the Survey-1* is to determine the appropriateness of the ergonomics indicators proposed through a comprehensive literature review as fundamental components of a systematic approach integrating ergonomics and sustainability. Accordingly, *the aim of the Survey-2* is to measure the perception of the applicability of a systematic approach comprising a performance measurement system as the fundamental part of such an approach that integrates ergonomics and sustainability to monitor and evaluate processes of organizations holistically.

Subsequently, three research questions were constructed, enabling the achievement of the fundamental aim of this thesis as well as the aims of Survey-1 and Survey-2:

- *The fundamental research question of this thesis:* What are the necessary components of a systematic approach that integrates ergonomics and sustainability to measure the performance of various processes in organizations and monitor their results?
- *The research question of Survey-1:* Which of the ergonomics indicators proposed through a comprehensive literature review are appropriate for developing a systematic approach that integrates ergonomics and sustainability to measure the performance of various processes in organizations and monitor their results?
- *The research question of Survey-2:* By considering their applicability, which of the proposed ergonomics indicators are necessary for developing a systematic approach that integrates ergonomics and sustainability to measure the performance of various processes in organizations and monitor their results?

1.3 Research Methodology

The research methodology of this thesis was constructed in six phases, namely *Background and Proposal*, *Development*, *Implementation for Validity*, *Implementation for Reliability*, *Multi-Criteria Analysis*, and *Systematization*. All these phases and their research steps are presented in detail in Figure 1.1 and explained in the following paragraphs accordingly.

The first phase (i.e. *Background and Proposal* in Figure 1.1), representing the first paper (Sarbat & Ozmehmet Tasan, 2020) produced from this thesis, is a comprehensive look at the literature related to ergonomics and sustainability to present the relation and coherence between the two. This review comprises the prominent papers in these areas that include the frequently encountered indicators. Accordingly, these papers were used for proposing the structural framework, which consists of three dimensions of sustainability (i.e. *Economic*, *Ecological*, and *Social*), six sustainability sub-dimensions proposed for ergonomics (i.e. *Loss*, *Investment*, *Conditions*, *Contribution*, *Self-Development*, and *Satisfaction*), and the ergonomics indicators proposed for measuring the performance of processes of organizations. This framework was developed to assist in providing sustainable processes in ergonomics by integrating ergonomics and sustainability through indicators.

The second phase (i.e. *Development* in Figure 1.1), representing the second paper (Sarbat & Ozmehmet Tasan, 2022) produced from this thesis, consists of a systematic literature review to enrich Sarbat & Ozmehmet Tasan's (2020) base structure by proposing new ergonomics indicators. This review works not only supporting Sarbat & Ozmehmet Tasan's (2020) findings on ergonomics indicators proposals but also enabling the development of a performance measurement system for various processes in organizations by proposing new indicators. This phase also includes the efforts for presenting the detailed descriptions and classifications of the proposed ergonomics indicators both in Sarbat & Ozmehmet Tasan (2020) ($n = 17$) and Sarbat & Ozmehmet Tasan (2022) ($n = 8$) as a basis for systematic approach development for sustainable process performance measurement in ergonomics.

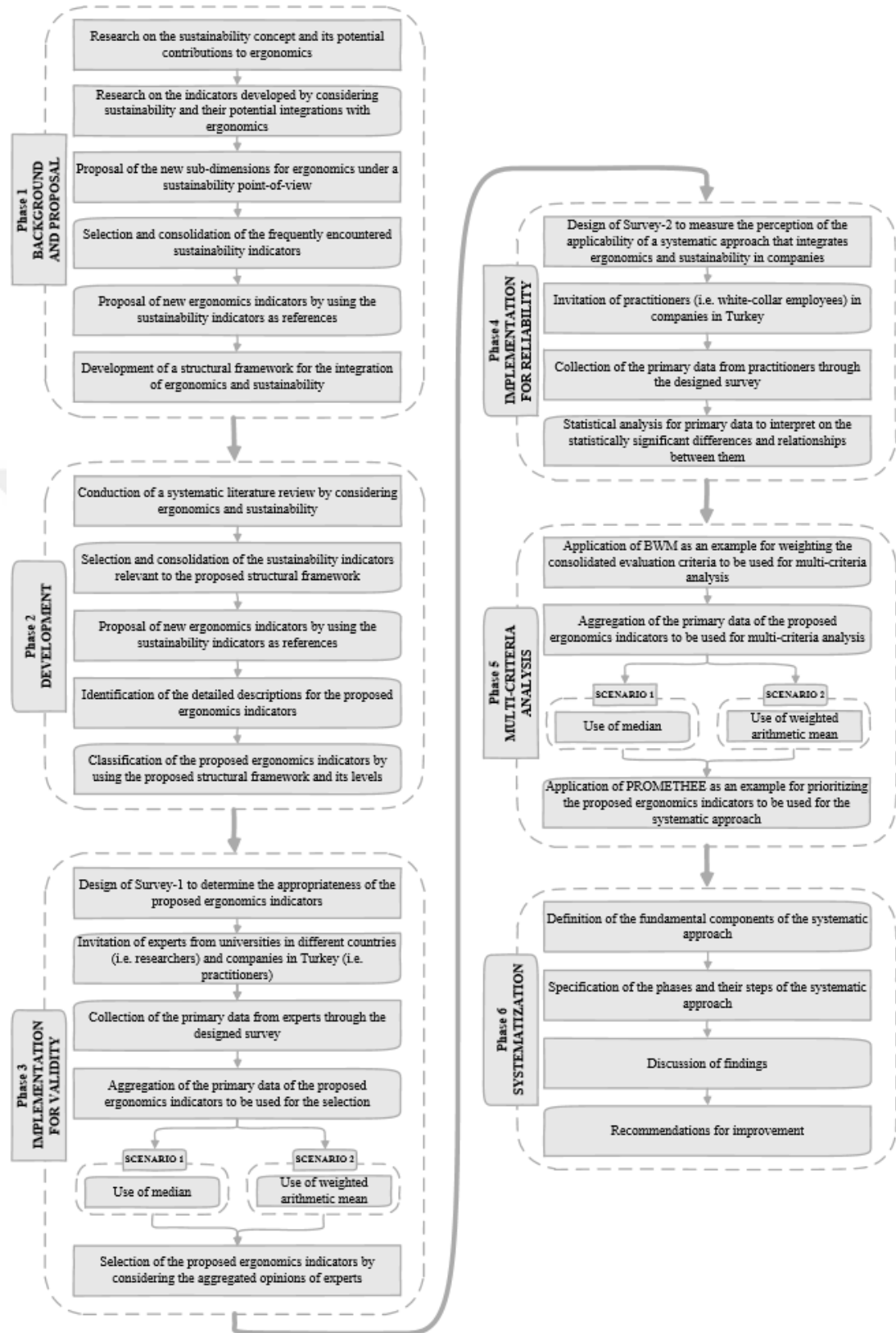


Figure 1.1 The research methodology of this thesis

The third phase (i.e. *Implementation for Validity* in Figure 1.1) is Survey-1, designed and developed to validate the ergonomics indicators ($n = 25$) in the first and second phases. These ergonomics indicators, proposed through a comprehensive literature review, were asked to the experts on ergonomics and sustainability (i.e. the researchers from universities in different countries and the practitioners working in companies in Turkey) through a questionnaire designed for this thesis to determine their appropriateness (i.e. to select the most appropriate of them for further analysis). For this selection, two different scenarios, including the methods (i.e. use of median and use of weighted arithmetic mean) used for the aggregation of the primary data of the proposed ergonomics indicators gathered from the questionnaire, were developed.

The fourth phase (i.e. *Implementation for Reliability* in Figure 1.1) is Survey-2, designed and developed to present the reliability of the proposed ergonomics indicators ($n = 23$) by considering their applicability. The appropriateness of these ergonomics indicators for developing such a systematic approach was validated by experts in the third phase. These ergonomics indicators were asked to the practitioners in companies in Turkey, who are specialized in ergonomics and sustainability and are potential users of such an approach, through a questionnaire designed for this thesis to measure the perception of the applicability of a systematic approach, comprising these indicators, that integrates ergonomics and sustainability in companies. This phase also comprises various statistical analysis for primary data to interpret on.

The fifth phase (i.e. *Multi-Criteria Analysis* in Figure 1.1) comprises a hybrid multi-criteria analysis through two different methods, the Best-Worst Method (BWM) and the Preference Ranking Organization METHod for Enrichment Evaluations (PROMETHEE), using the secondary data gathered from aggregation to present a base study as an example for prioritizing the proposed ergonomics indicators to be used for the systematic approach. In this phase, the same two scenarios were developed, including the methods (i.e. use of median and use of weighted arithmetic mean) used for the aggregation of the primary data of the proposed ergonomics indicators gathered from the questionnaire. It is envisaged that developing two different scenarios for aggregation enables enriching the contributions of this thesis for theory and practice.

The sixth and last phase (i.e. *Systematization* in Figure 1.1) includes the systematic approach developed by integrating ergonomics and sustainability to monitor and evaluate processes of organizations holistically. The fundamental part of this approach is the performance measurement system that includes the proposed ergonomics indicators, which were prioritized and determined as examples in the fifth phase to be used for such a system. The definition of the fundamental components, as well as the specification of the phases and their steps of this systematic approach, were also presented, while the overall look to the development of the systematic approach, including the discussion and recommendations, was summarized in this phase.

1.4 Outline and the Papers Produced from this Thesis

This thesis was formed within nine chapters, which are summarized below:

- Chapter 1 (i.e. *Introduction* in Figure 1.2) comprises motivation and original contributions, aims and research questions, research methodology, and outline and the papers produced from the thesis.
- Chapter 2 (i.e. *Background* in Figure 1.2) comprises a detailed literature search and synthesis related to ergonomics, sustainability, and the potential integration between the two as well as sub-dimensions, indicators, and framework proposals integrating ergonomics and sustainability.
- Chapter 3 (i.e. *Indicator Development* in Figure 1.2) comprises a systematic literature review conducted on ergonomics and sustainability to enrich the efforts made in Chapter 2, while the sustainability indicators selected from the review are consolidated and new ergonomics indicators are proposed, classified, and described in detail to be used for a systematic approach.
- Chapter 4 (i.e. *Theoretical Look at Systematic Approach Development* in Figure 1.2) comprises a theoretical background to develop a systematic approach in terms of the performance measurement systems as the fundamental part of such an approach and their main structures and components.
- Chapter 5 (i.e. *Survey Development, Data Collection, and Methods* in Figure 1.2) comprises problem statement, two surveys (i.e. Survey-1 and Survey-2)

designed and developed for this thesis, and research instruments in terms of primary and secondary data for statistical analysis and multi-criteria analysis.

- Chapter 6 (i.e. *Data Analysis* in Figure 1.2) comprises the analysis for Survey-1 and Survey-2, including the statistical analysis (i.e. various statistical tests performed) for primary data and the hybrid multi-criteria analysis (i.e. BWM for the weighting of the consolidated evaluation criteria and PROMETHEE for the prioritization of the proposed ergonomics indicators) for secondary data.
- Chapter 7 (i.e. *Discussion of Findings* in Figure 1.2) comprises the discussion of findings of this thesis, including indicator selection, data characteristics interpretation, criteria weighting, indicator prioritization, and indicator classification, besides the general evaluation of the implementation part.
- Chapter 8 (i.e. *Systematic Approach Development Integrating Ergonomics and Sustainability* in Figure 1.2) comprises the development phases of the systematic approach, including fundamental components, main structure, and the roadmap proposal representing the systematic approach.
- Chapter 9 (i.e. *Conclusion* in Figure 1.2) comprises summary and concluding remarks, implications for theory and practice, and future research directions.

The papers produced from this thesis are indicated in Figure 1.2: Chapter 2 consists of the first paper produced from this thesis (Sarbat & Ozmehmet Tasan, 2020), while Chapter 3 consists of the second paper produced from this thesis (Sarbat & Ozmehmet Tasan, 2022). Besides covering these papers in one chapter for each, some parts of these papers are presented in different chapters (e.g. Introduction and Conclusion) of this thesis. The required permissions from the journal in which these papers published and from the co-author of these papers (i.e. the supervisor of this thesis) were taken to include these papers in this thesis. Moreover, the third and fourth papers produced from this thesis were submitted to a journal: The third paper produced from this thesis, entitled “Measuring sustainable ergonomics - Part I: An indicator-based systematic approach proposal”, comprises Chapter 4, Chapter 8, and brief parts of Chapter 5, Chapter 6, and Chapter 7, while the fourth paper produced from this thesis, entitled “Measuring sustainable ergonomics - Part II: A hybrid multi-criteria perspective on ergonomics indicators”, comprises Chapter 5, Chapter 6, and Chapter 7.

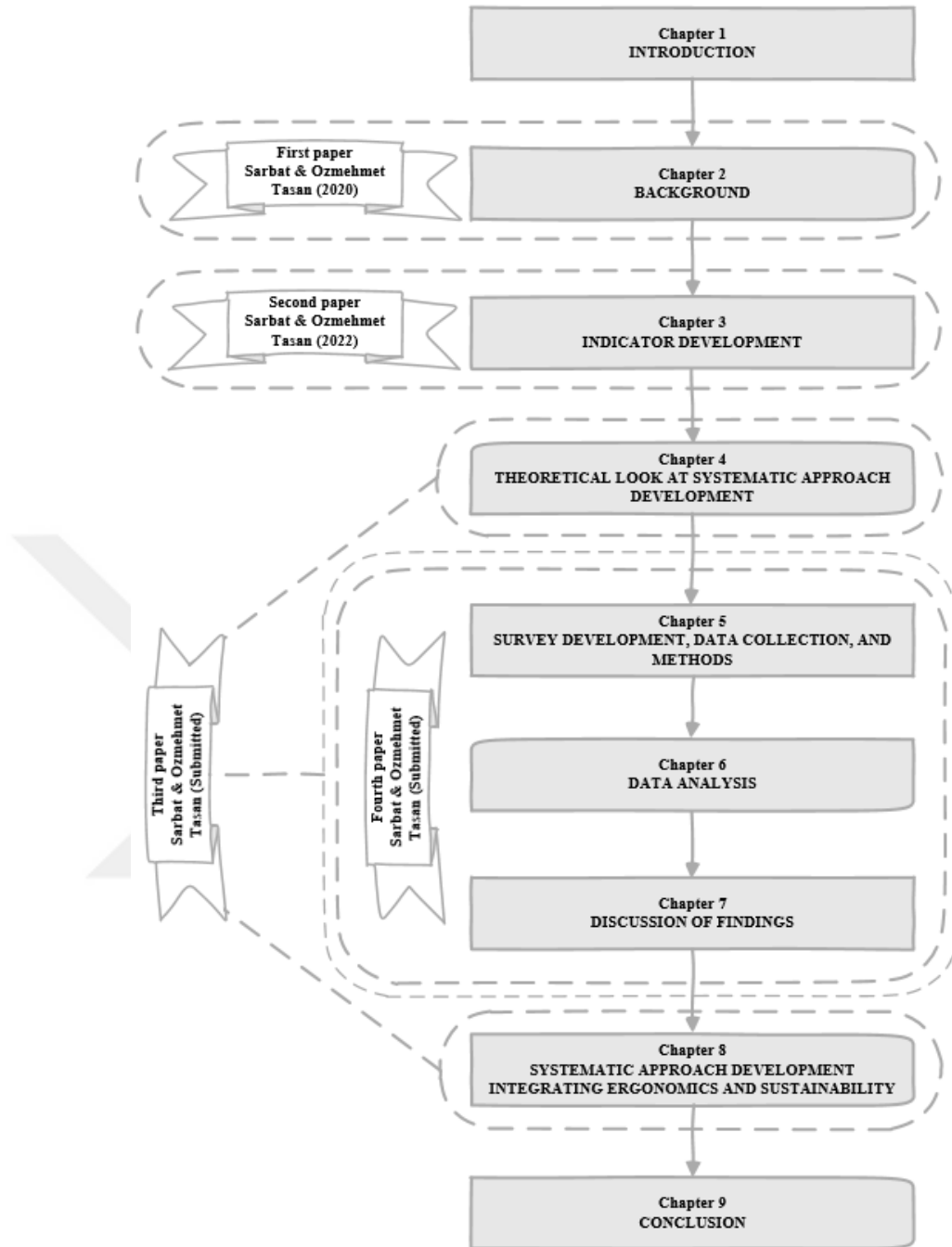


Figure 1.2 The outline of this thesis and the papers produced from this thesis

In the following chapter, a detailed search of the literature and the synthesis related to ergonomics, sustainability, and their potential integration is given, comprising a comprehensive presentation of dimensions, sub-dimensions, indicators. The proposals of sub-dimensions, ergonomics indicators, and structural framework integrating ergonomics and sustainability are also presented in this chapter.

CHAPTER TWO

BACKGROUND

This chapter comprises a detailed literature search and synthesis related to ergonomics, sustainability, and the potential integration between the two; the proposals of sub-dimensions, indicators, and framework integrating ergonomics and sustainability follows them.

2.1 Sustainability as a Key Concept for Providing Well-Operated Processes in Ergonomics

World War II is indicated as the beginning of the modern history of ergonomics (Wilson, 2000). It can be stated that more than eighty years of history mentioned may cause ergonomics to reach maturity by considering the associations, scientific journals, and thousands of studies. However, technologies, quick transformation processes, and advanced information systems of today's globalizing world cause various challenges also for ergonomics. One of these challenges is to provide and preserve the continuity of processes for better jobs, workplaces, and even living conditions. Fundamentally, defining ergonomics risks through ergonomics risk assessment methods can be an effective way to overcome this challenge. By considering the relevant literature, it can be easily stated that many ergonomics risk assessment methods have been developed for decades. Dempsey, McGorry, & Maynard (2005) highlight that ergonomics risk assessment methods have been developed to analyse tasks, equipment, and environment, and method selection is a key step in ergonomics assessment processes. To select one of these methods, Takala et al. (2010) propose four criteria, that is, the aims of the method's usage, the characteristics of the work that is assessed, the person who uses the method, and the resources that are ready to collect and analyse data.

Besides assessing ergonomics risks through these methods, following a structural framework defined clearly can be another effective way to overcome the challenges that emerge in providing and preserving continuity of processes. It can be stated that the proper development and implementation of such frameworks enable identifying

the ergonomics risks easily in the relevant processes. Therefore, a structural framework to be developed should have a holistic point-of-view to prevent potential ergonomics risk factors as well as enable ergonomically well-designed processes. In parallel, the efforts for developing such a framework are presented in the following parts of this chapter.

2.1.1 Comprehensive Look to Sustainability for Ergonomics

Lange-Morales, Thatcher, & García-Acosta (2014) define sustainability in the modern sense as the management of scarce resources that are for the current and future generations' usage. Since sustainability was firstly mentioned in the Middle Ages, it has been spread on the international scale, and this spread has occurred through the concept of sustainable development mainly in the last four decades (Bolis, Brunoro, & Sznclwar, 2014a). As it is widely known, World Commission on Environment and Development (WCED) defines sustainable development as “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (p. 43) (WCED, 1987). With clarification by this definition, it can be stated that when economic, ecological, and social well-being is simultaneously achieved, providing a truly sustainable form of progress is possible (Johnston et al., 2007; WCED, 1987). Accordingly, Hansmann, Mieg, & Frischknecht (2012) state that economic, ecological, and social aspects are considered as three fundamental dimensions of sustainability, which is defined as an integrative concept.

Essentially, sustainability provides all people of the world to live and work healthy, fulfilling, and economically ensured in the absence of jeopardizing the planet and the future welfare and destroying the environment (Johnston et al., 2007). In parallel, Thatcher (2012) underlines that sustainable development is interested in the continuation of the economic viability, environment, and social networks of people as a whole (i.e. the entire system) rather than refer to the continued use of a product over a long period of time. From this point-of-view, sustainability can be presented as a prominent concept for the development of a structural framework also in ergonomics.

Importantly, sustainable development has an anthropocentric view, and it considers not only the environment but also human needs (Zink, Steimle, & Fischer, 2008). Brown & Legg (2011) also denote the intersection of ergonomics and sustainable development by pointing out the aims for each: Sustainable development aims to optimize the relationship between the ecosystem, economic system, and social system, while ergonomics aims to optimize the relationship between humans and other elements of the system. Therefore, it can be stated that human is located in the intersection of ergonomics and sustainability.

Furthermore, work systems can be stated as sociotechnical systems because of their human-centric structure (Carayon, 2009; Reiman & Väyrynen, 2018). Carayon et al. (2015) define the sociotechnical system as “synergistic combination of humans, machines, environments, work activities and organisational structures and processes that comprise a given enterprise” (p. 550). By considering these definitions, it can be stated that human has the centre position in ergonomics processes. Thus, the relations between fundamental elements of ergonomics under the sustainability domain can be used for developing a structural framework by using many other potential elements and their potential interactions. It can be stated that this framework should be sensitive to the needs of human, economy, and environment.

According to Martin et al. (2013), an effective design should accomplish all standards, which are related to ergonomics, environment, production, quality, and occupational health, while this design satisfies the needs of all stakeholders (Figure 2.1). It can be denoted that building such a structure can be possible with a sustainability concept. Accordingly, the framework to be developed for providing sustainable processes in ergonomics is desired to have a holistic point-of-view as in Figure 2.1. Pavlovic-Veselinovic (2014) supports this issue by defining the interest and engagement in sustainability issues as a real need for a holistic, integrated, and systemic approach rather than a desire by ergonomists to be trendy. From this viewpoint, it can be stated that managing the whole complex transformation processes of a work organization becomes easier by using such a framework. The main point is to determine which main areas the framework should contain.

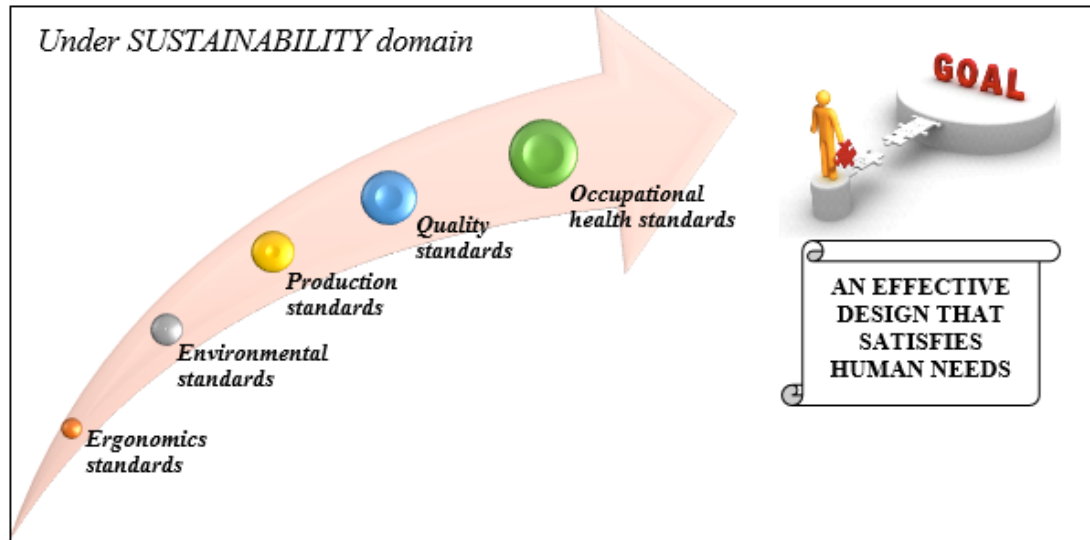


Figure 2.1 Elements of an effective design under sustainability domain (visualized from Martin et al., 2013 and modified from Sarbat & Ozmehmet Tasan, 2020)

In short, sustainable processes not only work for the environment but also protect and maintain human well-being. Besides, to have such sustainable-designed processes and provide their continuity, the processes should be managed within an efficiently operated and periodically reviewed manner. Dul et al. (2012) denote that performance (e.g. productivity, efficiency, effectiveness, quality, innovativeness, flexibility, (systems) safety and security, reliability, and sustainability) and well-being (e.g. health and safety, satisfaction, pleasure, learning, and personal development) can be achieved by fitting the environment to the human and, human factors/ergonomics specialists can balance these two system outcomes and the other ones. To achieve these aims, WCED summarizes the needs for the pursuit of sustainable development in their report with regards to political, economic, social, production, technological, international, and administrative systems (WCED, 1987).

2.1.2 Indicators for Measuring Sustainability

Many proposals, which consist of several definitions and classifications, indicating many indicators or indices, have been made since the late 1980s on how sustainability should be measured. Fundamentally, instead of calculating the values of indicators or

indices for once, calculating them for longer periods and comparing them with previous periods is more effective for understanding and managing the performance of organizations towards sustainability. Mayer (2008) states that, although indices generally present a static overview of a system, if they are calculated periodically, they can specify whether the system is becoming more or less sustainable and can find out the most responsible factors for driving the system. Additionally, Ness, Urbel-Piirsalu, Anderberg, & Olsson (2007) highlight that the tracking of long-term sustainability trends from a retrospective point-of-view is possible by using indicators and indices calculated continuously, therefore, short-term projections and decisions for the future can be made by understanding these trends.

Although there are many indicators and studies about how sustainability can be measured in literature, the unchanging point is the development of a framework that is accepted by all. Regarding this issue, Joung, Carrell, Sarkar, & Feng (2012) denote that instead of using individual indicators, combining them with regards to three dimensions of sustainability (i.e. *Economic, Ecological, and Social*) and evaluating them together bring more practical consequences to measure sustainability. According to Azapagic & Perdan (2000), the main goal of sustainability indicators is to provide stakeholders with the required information of a system to use sustainability indicators in strategy devising for more sustainable development, considering all dimensions of sustainability. Additionally, Mori & Christodoulou (2012) present the following aims of sustainability: Firstly, economic, ecological, and social dimensions of sustainability should be considered; secondly, the equity between current and future generations and nature should be maintained; and, lastly, healthy conditions related to these two aims should be maintained in the long term (Mori & Christodoulou, 2012). Hence, it can be stated that the efforts made for achieving these aims can also provide managing and controlling processes and increasing sustainability performance.

Under these circumstances, many organizations prefer using a generalized and useful framework to measure their performance in terms of sustainability. Using a standardized form of sustainability indicators is also essential to present and benchmark measurement results on a general basis. In this regard, Joung et al. (2012)

compile some of the publicly available indicator sets (Table 2.1). This table summarizes these indicator sets in terms of the number of indicators/categories included, the sustainability dimensions involved, and for whom the indicator sets are developed. Each of the indicator sets is classified in a framework within itself to measure sustainability in many processes.

Table 2.1 The publicly available indicator sets (summarized in a table from Joung et al. 2012 and modified from Sarbat & Ozmehmet Tasan, 2020)

No	Indicator Set	Number of Indicators / Categories	Sustainability Dimensions			Developed for	
			Economic	Ecological	Social	Companies	Regions / Countries
1	Global Reporting Initiative (GRI)	70 indicators	✓	✓	✓	✓	
2	Dow Jones Sustainability Indexes (DJSI)	12 categories	✓	✓	✓	✓	
3	2005 Environmental Sustainability Indicators (ESI)	68 indicators		✓			✓
4	Environment Performance Index (EPI)	19 indicators		✓			✓
5	United Nations-Indicators of Sustainable Development (UN-CSD)	96 indicators	✓	✓	✓		✓
6	Organization for Economic Cooperation and Development (OECD) Core Environmental Indicators (CEI)	46 indicators	✓	✓	✓		✓
7	Ford Product Sustainability Index (Ford PSI)	8 indicators	✓	✓	✓	✓	
8	International Organization for Standardization (ISO) Environment Performance Evaluation (EPE) Standard (ISO 14031)	3 categories		✓		✓	
9	Environmental Pressure Indicators for European Union (EPRI)	60 indicators		✓			✓
10	Japan National Institute of Science and Technology Policy (NISTEP)	71 indicators			✓	✓	
11	European Environmental Agency Core Set of Indicators (EEA-CSI)	37 indicators		✓			✓

Essentially, there are some prominent studies that propose a framework for measuring sustainability in various application areas such as *energy* (Büyükoçkan & Karabulut, 2017; La Rovere, Soares, Oliveira, & Lauria, 2010; Searcy, Karapetrovic, & McCartney, 2005), *production/manufacturing* (Dočekalová & Kocmanová, 2016; Helleno, de Moraes, & Simon, 2017; Joung et al., 2012; Krajnc & Glavič, 2003; Labuschagne, Brent, & Van Erck, 2005; Sangwan, Bhakar, & Digalwar, 2018; Tseng, Divinagracia, & Divinagracia, 2009; Veleva & Ellenbecker, 2001), *biofuel* (Efroymson & Dale, 2015), *steel* (Arena & Azzzone, 2010; Long, Pan, Farooq, & Boer, 2016; Singh, Murty, Gupta, & Dikshit, 2007), *mining and minerals* (Azapagic, 2004), *food* (Gerbens-Leenes, Moll, & Schoot Uiterkamp, 2003; Maxime, Marcotte, & Arcand, 2006), *chemical* (Jia, Li, Wang, & Qian, 2016; Krajnc & Glavič, 2005), and

retailing (Erol, Cakar, Erel, & Sari, 2009). Additionally, there are some generalized frameworks (Ahmed & Sundaram, 2012; Azapagic & Perdan, 2000; Chardine-Baumann & Botta-Genoulaz, 2014; Ness et al., 2007; Roca & Searcy, 2012; Štreimikienė, Girdzijauskas, & Stoškus, 2009; Veleva, Hart, Greiner, & Crumbley, 2001), which are proposed to be used in industries for more sustainable practices.

Nearly all the prominent studies classified above prefer using all three dimensions of sustainability. However, some studies prefer using other different dimensions: Joung et al. (2012) propose a framework with using not only three dimensions of sustainability but also *Technological Advancement* and *Performance Management* as dimensions. La Rovere et al. (2010) use the *Technological* dimension in addition to three dimensions of sustainability. On the other hand, Dočekalová & Kocmanová (2016) consider *Corporate Governance* as a dimension as well as *Economic*, *Ecological*, and *Social* dimensions of sustainability. Similarly, Singh et al. (2007) select *Organizational Governance* and *Technical Aspects* as fourth and fifth dimensions. Contrary to all these studies, Maxime et al.'s (2006), and Efroymson & Dale's (2015) studies concentrate on only one dimension of sustainability (i.e. *Ecological*) while Arena & Azzone (2010) use the *Ecological* and *Social* dimensions.

It is summarized from all the studies discussed above that various sustainability indicators can be used for obtaining proper and efficient results to measure sustainability. During these efforts, many potential relations between ergonomics and sustainability can be established. These relations can be presented through the consolidation of sustainability indicators for the proposal of ergonomics indicators, after the definitions of proposed sub-dimensions and the selection of sustainability indicators are made.

2.2 Framework Proposal Integrating Ergonomics and Sustainability

Since the early 1990s, frequently since 2010, many authors have discussed ergonomics and the role of the human in terms of sustainability and sustainable development. These studies are divided into three categories (Sarbat & Ozmehmet

Tasan, 2020) under ergonomics and sustainability point-of-views to express their contributions and differences: *Reviews, discussions, and foresights* (Martin et al., 2013; Moray, 1995; Radjiyev, Qiu, Xiong, & Nam, 2015; Reiman & Väyrynen, 2018; Siemieniuch et al., 2015; Thatcher, Waterson, Todd, & Moray, 2018), *system design and key elements* (Demirel, Zhang, & Duffy, 2016; Fischer & Zink, 2012; Hanson, 2013; Thatcher, 2013; Thatcher & Yeow, 2016; Zink, 2014), and *interactions and general principles* (Bolis et al., 2014a; Lange-Morales et al., 2014; Zink & Fischer, 2013). These prominent studies are briefly summarized in the following three paragraphs by considering the proposed categories.

Moray (1995) discusses the role and future of ergonomics to solve major ecological and social problems in the 21st century such as water, food, energy, pollution and waste, urbanization, violence and terrorism, health and medicine. According to Moray (1995), to cope with these problems, human behaviour and human interactions with other humans and with the environment must be included in any solving processes and procedures, and, in fact, this reflects the purpose of ergonomics. Martin et al. (2013) present a comprehensive literature review on ergonomics, sustainability, and design to explore the contributions of ergonomics to sustainability and sustainable design. In this study, Martin et al. (2013) find out that despite the congruent aims of ergonomics and sustainability, there is a limited contribution of ergonomics to sustainability and sustainable design. Radjiyev et al. (2015) present a systematic survey that comprises research trends and convergent areas about the potential roles of ergonomics in sustainable development. Consequently, Radjiyev et al. (2015) propose an interconnection map that denotes the relations between sorted categories of ergonomics and sustainable development. Siemieniuch et al. (2015) present the potential effects of global drivers (i.e. population demographics, transportation, energy security, food security, community security and safety, emissions and global climate, resource depletion, and, globalization of economic and social activity) while the role of sustainability engineering to decrease the potential effects of these global drivers is discussed. Siemieniuch et al. (2015) also examine new manufacturing paradigms from a systems ergonomics perspective. Reiman & Väyrynen (2018) present a comprehensive review of holistic well-being defined as a combination of well-being

in both work and non-work domains. Reiman & Vayrynen (2018) discuss sustainability by including this to the balanced work systems and balanced organization theory while new insights and research challenges are also pointed out. Thatcher et al. (2018) present a State of Science article, which evaluates what ergonomics discipline has achieved in addressing the global challenges urged by Moray’s International Ergonomics Association keynote address in 1993. Thatcher et al. (2018) also state their own set of predictions and suggestions for priorities and practices that are required to facilitate a sustainable future for humanity.

Fischer & Zink (2012) discuss sustainability in terms of system theory, and they propose a conceptual model of a sustainable work system that consists of balanced management of human, social, ecological, and economic capital. Hanson (2013) focuses on the design of sustainable systems and presents some of the challenges and opportunities related to environmental sustainability for the professionals who work in ergonomics. Furthermore, Hanson (2013) presents some of the areas for these professionals to contribute such as works in green industries, the designs of products and systems that are environmentally-friendly, and understanding of behavioural changes related to environmental choices. Thatcher (2013) points out the coherent structure of the aims of ergonomics and the aims of design for environmental sustainability. In this regard, Thatcher (2013) proposes a conceptualization of the term green ergonomics to define ergonomics interventions with a pro-nature emphasis, and, he presents bi-directional relationships between human systems and nature within comprehensive research. Zink (2014) defines some of the key issues by presenting a systems approach for the design of sustainable work systems within an ergonomics point-of-view. Zink (2014) also remarks about the potential contradictions about the economic, ecological, and social aims of sustainability while sustainable work systems are considered. According to Zink (2014), new concepts have to be developed while ergonomics can contribute some existing ones. Demirel et al. (2016) use digital human modelling approach for the integration of human into sustainability. Accordingly, Demirel et al. (2016) develop two conceptual digital human modelling toolkits (i.e. Air Quality Index Assessment and Metabolic Energy Expenditure) to evaluate health risks and employee’s performance. Thatcher & Yeow (2016) discuss sustainable

systems in human factors and ergonomics in detail by considering which system requires sustaining and what length of time is considered sustainable.

Zink & Fischer (2013) reveal the interactions of sustainability and ergonomics, and they examine the necessity of sustainability as a new approach for ergonomics. Zink & Fischer (2013) also present some of the general principles for the design of work systems that include sustainability. Bolis et al. (2014a) identify the relationships between work and the themes of sustainability (i.e. sustainable development and corporate sustainability) through an extensive bibliographic analysis. Bolis et al. (2014a) also discuss in which position and on which way ergonomics can contribute to sustainability at work. Lange-Morales et al. (2014) present an extensive analysis of ergoecology and green ergonomics by outlining principles, purposes, and application areas to address the contribution of ergonomics perspective to sustainability. Lange-Morales et al. (2014) also suggest a set of sustainability values (i.e. respect for the Earth, respect for human rights, respect for ethical decision-making, respect for transparency and openness, appreciation of complexity, and respect for diversity) and discuss the results of these values in terms of both theories and practices of ergonomics.

All of these prominent studies present that sustainability has undeniable importance for ergonomics. Meyer, Eweje, & Tappin (2017) reinforce this issue in their review article revealing that ergonomics and sustainability share the same principles, but there is a lack of empirical information to prove the potential between ergonomics and sustainability. Nevertheless, there are ongoing discussions and new framework proposals on ways in which sustainability is most beneficial when adapted to ergonomics. In this regard, Ryan & Wilson (2013) point out possible opportunities for ergonomics evaluations in the sustainability concept. According to Ryan & Wilson (2013), these opportunities may put into practice in various areas such as information collection, organizational processes understanding, behaviours and organizational culture understanding, support for the development of methodologies, tools and interfaces against different kinds of risks. Hence, different new areas, such as those proposed by Ryan & Wilson (2013), can be proposed as potential dimensions for the

integration of ergonomics and sustainability. In this direction, the proposals of the new sub-dimensions for ergonomics under a sustainability point-of-view as well as the ergonomics indicators consolidated from the selected sustainability indicators are given below through this subsection as the scientific contribution of this thesis to the relevant literature.

2.2.1 Introduction of the Dimensions for Classifying Indicators

The relevant literature presents many models to express sustainability and its dimensions. Thatcher (2014) presents the main models in this area as three pillars model (also called the three circles model or the Triple Bottom Line), prism model (sometimes called the four pillars model), nested circles of sustainability (also egg of well-being model or concentric circles model), and two-tiered sustainability equilibria model of sustainable development. These models acknowledge that the coordination of a complex set of interrelating factors is needed for the achievement of sustainable development (Thatcher, 2014).

Considering ergonomics and its fundamental elements (i.e. job/task, workplace & equipment, work organization, and employee as presented in Scott et al., 2010), a kind of model, which represents the intersections between sustainability dimensions, is needed for the framework proposed in this thesis. The reason for selecting the three dimensions of sustainability, which is based on the three circles model (i.e. overlapping circles), is the ability to represent these intersections basically and practically. As stated before, the most important decision should be how and on which way sustainability can contribute to ergonomically well-designed processes.

It can be easily noticed from the relevant literature that many studies classify sustainability indicators by using various dimensions. Moreover, some studies consider these dimensions at more than one level. Additionally, it can be stated that indicators constitute the last level of these dimensions. Before the relevant literature is presented, a hierarchical scheme is depicted to provide clarity in dimensions, sub-dimensions, and indicators (Figure 2.2).

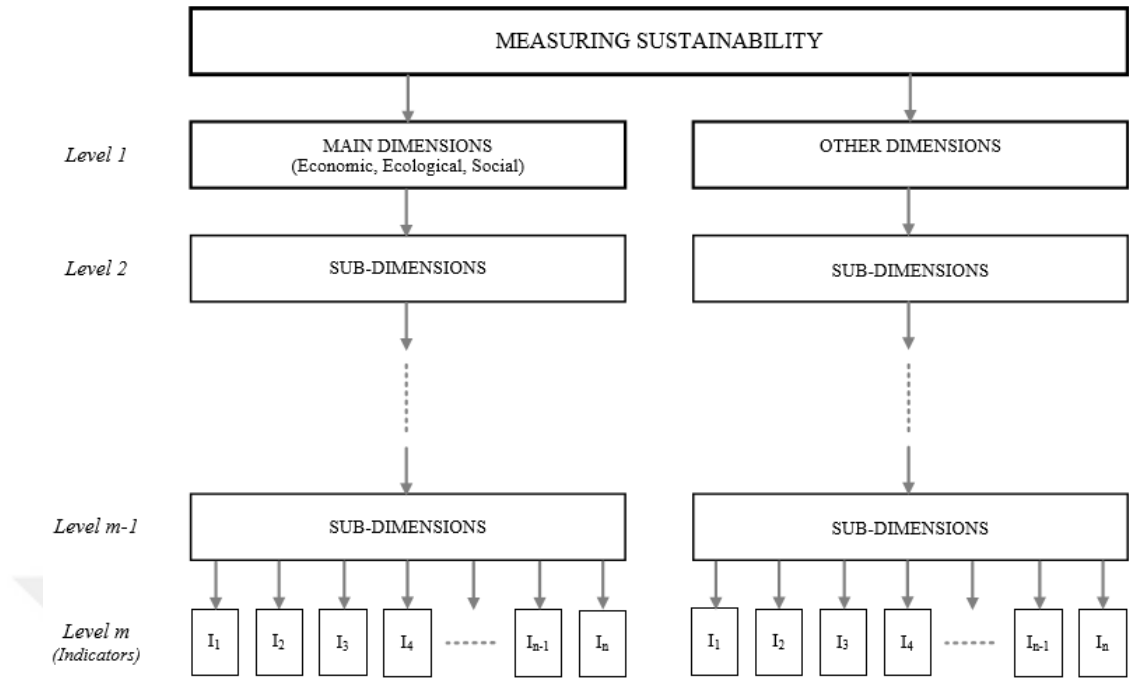


Figure 2.2 A hierarchical representation of sustainability dimensions, sub-dimensions, and indicators (Sarbat & Oz Mehmet Tasan, 2020)

In this hierarchical scheme (Figure 2.2), Level 1 comprises three dimensions of sustainability presented as the *Main Dimensions* in this depiction. *Other Dimensions* that differ from the three dimensions of sustainability are also presented at this level. If there any sub-dimensions after Level 1, they can be presented in Level 2, Level 3, Level 4, ..., Level $m-1$, respectively. The indicators are in the last level of this structure (i.e. Level m), and they are depicted as $I_1, I_2, \dots, I_n$. The following parts of this subsection are presented by considering these definitions.

2.2.1.1 The Dimensions Proposed in the Literature

Besides various framework proposals presented in this chapter, some studies have chosen the way of measuring sustainability by using the frameworks that are presented by different organizations. For example, Azapagic (2004) proposes a framework that is compatible with Global Reporting Initiative (GRI) while sector-specific indicators are also presented in this framework. Additionally, Joung et al. (2012) use the categorization of sustainability indicators, which is proposed by the National Institute

of Standards and Technology (NIST). Moreover, there are other studies, such as Veleva & Ellenbecker (2001), which are based on the framework of Lowell Centre for Sustainable Production (LCSP).

Basically, it can be stated that the prominent studies in this area use different sustainability dimensions and sub-dimensions whether they use such frameworks proposed by these organizations or not. Accordingly, some of these studies use three dimensions of sustainability in Level 1, while other ones focus on different dimensions in this level. Based on this division in Level 1, the prominent studies are presented in Figure 2.3 by using the hierarchical scheme given in Figure 2.2.

As shown in Figure 2.3, it can be stated that some studies (i.e. the studies presented in *Other Dimensions* in Level 1) propose their frameworks within a broader perspective than three dimensions of sustainability. Roca & Searcy (2012) and Dočekalová & Kocmanová (2016) can be given as examples to these studies. Roca & Searcy (2012) present an alternative way to classify the indicators apart from three dimensions of sustainability by dividing the dimensions into fifteen categories in Level 1, namely *Interaction with Community, Emissions and Effluents, Employees, Energy, Financial, Health and Safety, Management, Operations, Purchasing, Research and Development, Reclamation, Satisfaction, Service, Waste, and Water*. On the other hand, Dočekalová & Kocmanová (2016) propose *Corporate Governance* as an additional dimension to the *Economic, Ecological, and Social* dimensions in Level 1.

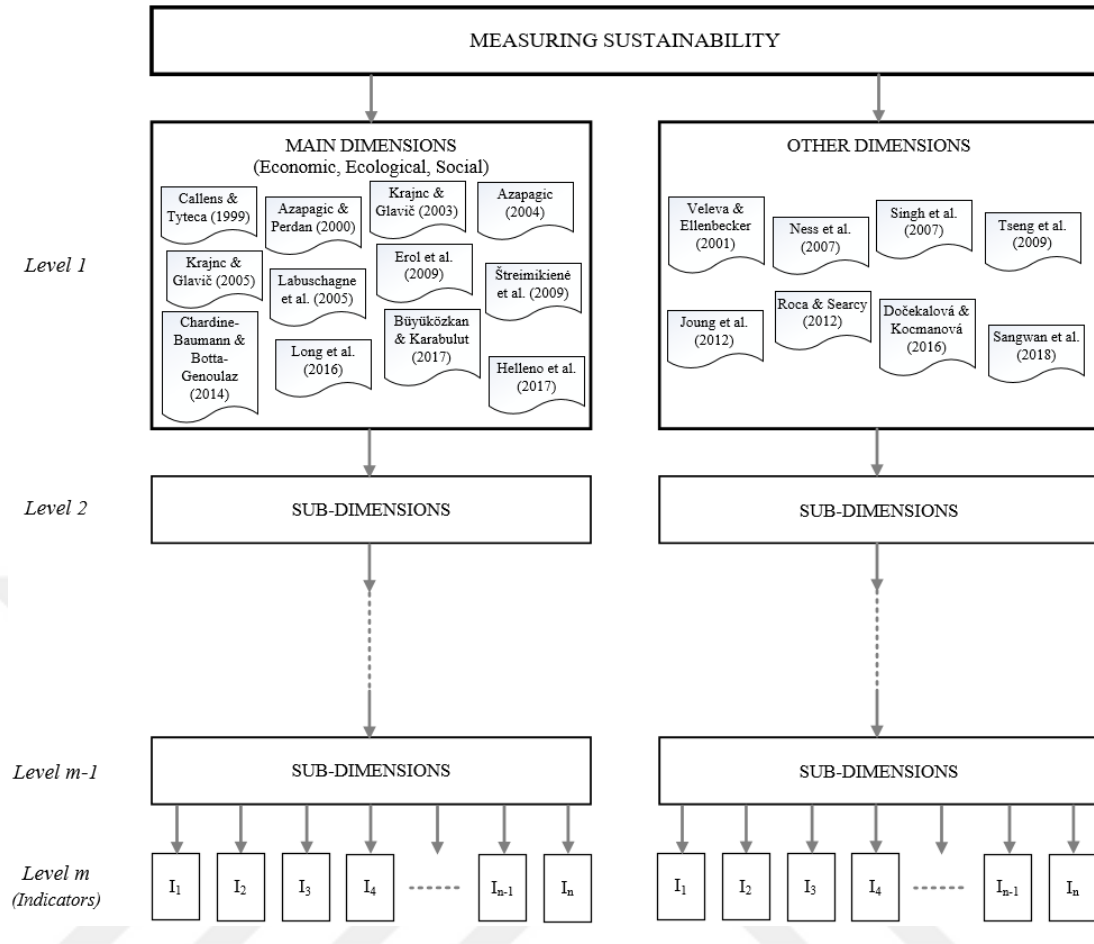


Figure 2.3 The presentation of the dimensions of the relevant studies in literature by using the hierarchical scheme (modified from Sarbat & Oz Mehmet Tasan, 2020)

Rather than proposing new sustainability dimensions, some studies (i.e. the studies presented in *Main Dimensions* in Level 1) prefer using a framework based on three dimensions of sustainability. Each dimension is elaborated in Level 2 by defining sub-dimensions. For example, Chardine-Baumann & Botta-Genoulaz (2014) propose *Reliability*, *Responsiveness*, *Flexibility*, *Financial Performance*, and *Quality* as the sub-dimensions of the *Economic* dimension, while *Environmental Management*, *Use of Resources*, *Pollution*, *Dangerousness*, and *Natural Environment* are proposed as the sub-dimensions of the *Ecological* dimension, and *Work Conditions*, *Human Rights*, *Societal Commitment*, *Customers Issues*, and *Business Practices* are proposed as the sub-dimensions of the *Social* dimension of sustainability. As another example, Büyüközkan & Karabulut (2017) propose the sub-dimensions of *Business Continuity*, *Costs*, *Financial Performance*, and *Product Performance* for the *Economic* dimension,

Pollutants, Resource Efficiency, Biodiversity and Ecological Impacts, and Environmental Management for the *Ecological* dimension, and *Employment, Life Quality and Society, Product Stewardship, and Social Governance* for the *Social* dimension of sustainability. In addition to these studies, Helleno et al. (2017) propose *Cost Management, Corporative Management, Operational Efficiency, Products, Operating Results, Suppliers, Customers, and Infrastructure* as the sub-dimensions of the *Economic* dimension, while *Environmental Management, Environmental Aspects, Responsibility, Consumption, Product Lifecycle, and Recycling* are proposed as the sub-dimensions of the *Ecological* dimension of sustainability. For the *Social* dimensions of sustainability, Helleno et al. (2017) propose *Economic, Satisfaction Level, Quality and Health, Human Resources, and Community* as the sub-dimensions.

2.2.1.2 The Dimensions Proposed in this Thesis

The studies presented so far propose sustainability indicators within a framework that has various dimensions to measure sustainability, and generally, these studies focus on a specific industry/work area. On the other hand, some new dimensions or sub-dimensions in ergonomics under a sustainability point-of-view are needed to classify the ergonomics indicators consolidated from sustainability indicators.

As presented in Figure 2.4, sustainability dimensions were structured within two levels in this thesis. Due to its practical and easily adaptable structure, three dimensions of sustainability were used in Level 1. Essentially, in most publications, indicators are developed considering the economic, ecological, and social dimensions of sustainability (Roca & Searcy, 2012). What distinguishes this thesis from the prominent studies in sustainability as well as in ergonomics is the sub-dimensions in Level 2, which were proposed for ergonomics under the sustainability point-of-view (i.e. *Loss, Investment, Conditions, Contribution, Self-Development, and Satisfaction*). In Level 2, two sub-dimensions were proposed under each dimension of Level 1 for this base framework. Short descriptions of these sub-dimensions are given in Figure 2.4. These descriptions can be used for selecting the related sustainability indicators, which are used as theoretical background for the proposal of ergonomics indicators.

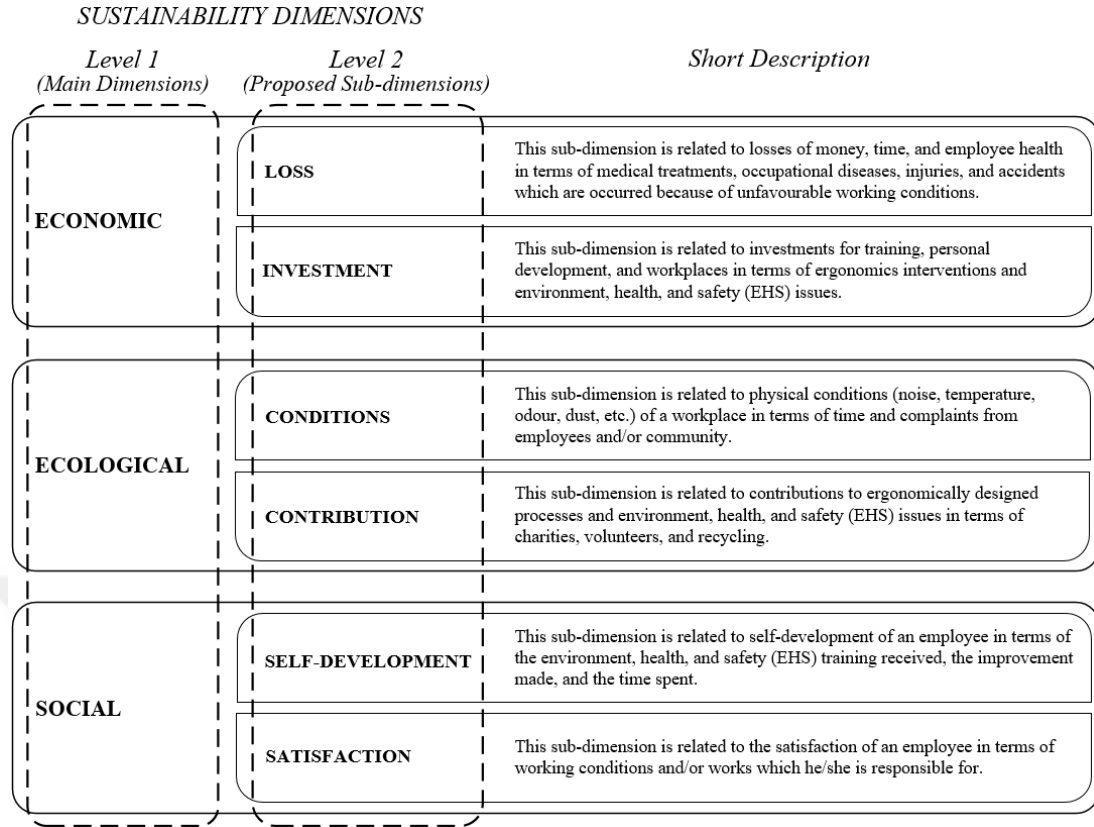


Figure 2.4 The sustainability sub-dimensions proposed for ergonomics to construct the structural framework (modified from Sarbat & Ozmehmet Tasan, 2020)

When Figure 2.4 is examined, it can be easily noticed that there are some similarities between the *Self-Development* sub-dimension and the *Investment* sub-dimension. Both of them consider training and personal development in ergonomics. However, the main differentiation here is the focus points of these sub-dimensions: The *Investment* sub-dimension is for measuring sustainability in an economical way while the *Self-Development* sub-dimension does this in a social way. The hierarchical structure of this framework (i.e. dividing the framework into levels) comes into prominence in explaining this differentiation between the sub-dimensions.

To propose these sub-dimensions in Level 2, employee, work design, and workplace design were considered together, referring to the fundamental elements of ergonomics in Scott et al. (2010). Fundamentally, this framework considers the human as the focal point. Hence, the proposed sub-dimensions should relate to a human

directly or indirectly under a sustainability point-of-view. Additionally, in this framework, it is clear that the substantial amount of the ergonomics indicators to be proposed is related to humans, the needs of humans, the issues that humans affect, or the works that affect humans. Hence, these indicators can be classified easily according to these sub-dimensions.

Dirkse Van Schalkwyk & Steenkamp (2017) define good ergonomics programmes as cost-effective; because these ergonomically well-designed processes help for reducing injuries and incidents, quality and safety errors, and absenteeism, while they provide job enrichment and enable increasing motivation, job satisfaction, and productivity. By starting from these well-summarized benefits of ergonomics, it can be highlighted that this structural framework has such a viewpoint during the formation process of its sub-dimensions. Therefore, presenting the relations between ergonomics and sustainability can be achieved basically by using this framework. It can be stated that the sub-dimensions proposed in this thesis are related to these benefits of ergonomics directly or indirectly under a sustainability point-of-view while the necessity of the central position of humans is also kept into mind.

To expand on the underlying meaning of the viewpoint that was considered during the formation of the sub-dimensions of this structural framework in terms of the *Economic* and *Social* dimensions, sick leave can be given as an example. The factors in the workplace, which are harmful to human's health, are defined as the environmental, task, technological, organizational, and individual factors (Smith & Sainfort, 1989). It can be stated that an ergonomically improperly designed process has many of these factors, and they can cause sick leave. In this context, Pavlovic-Veselinovic (2014) denotes that the impact of an ergonomically designed process on an employee's health is an incontestable fact, and, ergonomics practices can reduce the costs, which are related to human stress, injury, or low productivity. On the other hand, it is inevitable that one of the main causes of sick leave is musculoskeletal or mental disorders (Westgaard & Winkel, 2011). Sick leave threatens the welfare of individuals, companies, and society, while the performance and industrial competitiveness of various organizations are also affected due to the costs related to

absenteeism, labour turnover, reduced productivity, and the quality of life of employees (Marras, 2000; Meyer et al., 2017; Westgaard & Winkel, 2011). In brief, it can be stated that the costs related to ergonomically improperly designed processes has a cumulative effect from the individual to the social level, therefore it should not be ignored by organizations. Some precautions can be taken by making investments for these losses in the ergonomically improperly designed processes to improve working conditions. These improvement efforts may also help for enhancing the satisfaction, motivation, and self-development of employees.

In addition to all these issues related to the *Economic* and *Social* dimensions of sustainability, the interaction and impression of ecology during the formation of the sub-dimensions of this structural framework can be implied in a similar manner. Turker (2009) states that an organization is responsible for not only avoiding environmental harm but also protecting and improving the natural environment. Pavlovic-Veselinovic (2014) supports this statement by defining environmental sustainability as the ability of natural capital to remain intact. Hence, it would be appropriate for the issues covered by the *Ecological* dimension of sustainability to include the conditions related to working or living areas and the contributions to environmental issues in order to preserve the environment within the scope of sustainability.

In summary, it can be stated that the sustainability sub-dimensions in Figure 2.4 were proposed by considering the main issues such as cost, performance, quality, safety, and motivation, which are implied so far. It should be highlighted that the proposed sub-dimensions in this structural framework are also coincident with the benefits of ergonomics (please see Dirkse Van Schalkwyk & Steenkamp, 2017). As Pavlovic-Veselinovic (2014) stresses, ergonomics and environmental protection complement each other, and, they have an enormous impact on the well-being, health, and welfare of individuals and society together with occupational health and safety. Additionally, Pavlovic-Veselinovic (2014) states that ergonomically designed processes and workplaces provide producing quality products with minimum rejection and less use of raw materials, achieving high productivity, maintaining health and

safety at work with less medical costs and absenteeism, and having high satisfaction with work. All of these issues affect the balance between the costs and profits of companies and also the country's economy (Pavlovic-Veselinovic, 2014).

2.2.2 Proposal of the Framework with Components of both Ergonomics and Sustainability

After structuring sustainability dimensions and sub-dimensions for Level 1 and Level 2, sustainability indicators that are classified under each sub-dimension should be selected from the prominent studies in the relevant literature to propose ergonomics indicators. The main criterion for this selection lies behind similar issues with the formation of the sub-dimensions in Level 2: Human, work design, and workplace design. It should be noted that these selected sustainability indicators are the frequently encountered indicators in the prominent studies in this area. In this regard, the selected sustainability indicators and their references are listed in the following figures below by considering the sub-dimensions proposed. The consolidated versions of these indicators (i.e. the proposed ergonomics indicators) are also presented in these figures.

The proposed ergonomics indicators, which were classified within the *Economic* dimension of sustainability, are presented in Figure 2.5. There are four ergonomics indicators in the *Loss* sub-dimension (i.e. *Number of accident-free days per year*, *Number of injury-free days per year*, *Percentage of total lost time due to accidents and injuries relative to the total hours worked per year*, and *Expenditure on medical treatments for accidents, injuries and occupational diseases per year*), while three ergonomics indicators were proposed in the *Investment* sub-dimension (i.e. *Annual investment cost for ergonomics interventions and EHS issues*, *Cost of EHS training of employees per year*, and *Expenditure on employee development per year*). In here, losses of time, money, and employee's health are considered in terms of accidents, injuries, medical treatments, and occupational diseases for the *Loss* sub-dimension, while investments for workplaces, training, and personal development in terms of ergonomics interventions and EHS issues are considered for the *Investment* sub-dimension.

SUSTAINABILITY DIMENSIONS		PROPOSED ERGONOMICS INDICATORS	RELATED SUSTAINABILITY INDICATORS IN THE LITERATURE	
Level 1 (Main Dimensions)	Level 2 (Proposed Sub-dimensions)		Indicator	Reference
ECONOMIC	LOSS	Number of accident-free days per year	- Number of facility accident-free days - Accident rate - Work-related accident frequency - Overall accident rate at work - Fatal accidents rate at work - Number of occupational accidents per hours worked - Number of serious occupational accidents - Number of accidents during typical production activities - Number of accidents while walking or moving around	- Veleva et al. (2001) - Helleno et al. (2017) - Roca & Searcy (2012) - Dočekalová & Kocmanová (2016) - Dočekalová & Kocmanová (2016) - Krajnc & Glavič (2005) - Krajnc & Glavič (2005) - Krajnc & Glavič (2005) - Krajnc & Glavič (2005)
			- Number of employee injury incidents per hours worked - Disabling injury frequency rate - Employee recordable injury frequency rate	- Roca & Searcy (2012) - Roca & Searcy (2012) - Roca & Searcy (2012)
		Percentage of total lost time due to accidents and injuries relative to the total hours worked per year	- Lost workday injuries and illness case rate - Time of employee illness - Lost-time accidents - Lost-time accidents relative to the total hours worked - Percentage of total absence-hours on health and safety grounds relative to the total hours worked - Absenteeism	- Veleva & Ellenbecker (2001) - Krajnc & Glavič (2003) - Azapagic (2004) - Azapagic (2004) - Azapagic (2004) - Helleno et al. (2017)
			- Number of compensated occupational diseases - Medical treatments - Injury risk	- Azapagic (2004) - Roca & Searcy (2012) - Callens & Tyteca (1999)
	INVESTMENT	Annual investment cost for ergonomics interventions and EHS issues	- Value of investments in sustainable development - Investments into community projects (e.g. schools, hospitals, infrastructure) as percentage of net sales - Costs of health protection of employee - Expenditure on health and safety	- Krajnc & Glavič (2003) - Azapagic (2004) - Krajnc & Glavič (2003) - Azapagic & Perdan (2000)
		Cost of EHS training of employees per year	- Investment in employee training and education as percentage of net sales - Investment in learning/training - Expenditure on education and training	- Azapagic (2004) - Roca & Searcy (2012) - Dočekalová & Kocmanová (2016)
		Expenditure on employee development per year	- Investments in employee development - Investment in staff development	- Krajnc & Glavič (2003) - Azapagic & Perdan (2000)

Figure 2.5 The proposed ergonomics indicators for the *Loss* and *Investment* sub-dimensions of the *Economic* dimension (modified from Sarbat & Ozmehmet Tasan, 2020)

The proposed ergonomics indicators, which were classified within the *Ecological* dimension of sustainability, are presented in Figure 2.6. There are three ergonomics indicators in the *Conditions* sub-dimension (i.e. *Number of complaints due to physical conditions (noise, temperature, odour, dust, etc.) per year*, *Number of complaints from community per year*, and *Number of days when there are unfavourable physical conditions (noise, temperature, odour, dust, etc.) per year*), while two ergonomics indicators were proposed in the *Contribution* sub-dimension (i.e. *Number of volunteers for making charitable contributions to EHS issues per year* and *Percentage of recycled products/raw materials used in ergonomically designed processes per year*). In here, the *Conditions* sub-dimension denotes to physical conditions of a workplace in terms of time and complaints from employees and community, while contributions to EHS issues and ergonomically designed processes in terms of charities, volunteers, and recycling are considered for the *Contribution* sub-dimension.

SUSTAINABILITY DIMENSIONS		PROPOSED ERGONOMICS INDICATORS	RELATED SUSTAINABILITY INDICATORS IN THE LITERATURE	
Level 1 (Main Dimensions)	Level 2 (Proposed Sub-dimensions)		Indicator	Reference
ECOLOGICAL	CONDITIONS	Number of complaints due to physical conditions (noise, temperature, odour, dust, etc.) per year	- Number of complaints due to odour - Number of complaints due to noise - Number of complaints due to dust - Total number of external complaints related to noise, road dirt and dust, visual impact and other nuisance	- Krajnc & Glavič (2005) - Krajnc & Glavič (2005) - Krajnc & Glavič (2005) - Azapagic (2004)
		Number of complaints from community per year	- Specific number of complaints of customers - Complaints from community - Number of complaints from neighbours	- Krajnc & Glavič (2003) - Roca & Searcy (2012) - Krajnc & Glavič (2005)
		Number of days when there are unfavourable physical conditions (noise, temperature, odour, dust, etc.) per year	- Noise level - Noise level - Noise	- Krajnc & Glavič (2003) - Helleno et al. (2017) - Callens & Tyteca (1999)
	CONTRIBUTION	Number of volunteers for making charitable contributions to EHS issues per year	- Community spending and charitable contributions as percent of revenues - Fraction of charitable contributions	- Veleva & Ellenbecker (2001) - Krajnc & Glavič (2003)
		Percentage of recycled products/raw materials used in ergonomically designed processes per year	- Percentage of products designed to be easily reused or recycled - Mass fraction of products designed for disassembly, reuse or recycling	- Veleva et al. (2001) - Krajnc & Glavič (2003)

Figure 2.6 The proposed ergonomics indicators for the *Conditions* and *Contribution* sub-dimensions of the *Ecological* dimension (modified from Sarbat & Ozmehmet Tasan, 2020)

The proposed ergonomics indicators, which were classified within the *Social* dimension of sustainability, are presented in Figure 2.7. There are three ergonomics indicators in the *Self-Development* sub-dimension (i.e. *Percentage of employees receiving EHS training per year*, *Percentage of total time spent due to EHS training relative to the total hours worked per year*, and *Number of suggested improvements made by employees per year*), while two ergonomics indicators were proposed in the *Satisfaction* sub-dimension (i.e. *Annual turnover rate of employees* and *Percentage of employees who are satisfied with their work*). In here, the *Self-Development* sub-dimension is related to efforts for the development of an employee in terms of EHS trainings, suggested improvements, and time, while the satisfaction of an employee is considered in terms of working conditions or employee's work for the *Satisfaction* sub-dimension.

SUSTAINABILITY DIMENSIONS		PROPOSED ERGONOMICS INDICATORS	RELATED SUSTAINABILITY INDICATORS IN THE LITERATURE	
Level 1	Level 2	Indicator	Reference	
(Main Dimensions)	(Proposed Sub-dimensions)			
SOCIAL	SELF-DEVELOPMENT	Percentage of employees receiving EHS training per year	- Number of employees receiving hazardous material training - Percentage of suppliers receiving safety training per year - Number of employees that are financially sponsored by the company for further education - Number of employees who received training	- Veleva et al. (2001) - Veleva et al. (2001) - Azapagic (2004) - Roca & Searcy (2012)
		Percentage of total time spent due to EHS training relative to the total hours worked per year	- Average number of hours of employee training - Time of employee education - Percentage of hours of training regarding health and safety relative to the total number of hours worked - Training hours	- Veleva & Ellenbecker (2001) - Krajnc & Glavič (2003) - Azapagic (2004) - Roca & Searcy (2012)
		Number of suggested improvements made by employees per year	- Number of suggested improvements by employee - Percentage of employees that are shareholders in the company - Policy and procedures involving consultation and negotiation with employees over changes in the company (e.g. restructuring, redundancies etc.) - Number of improvement measures initiated	- Krajnc & Glavič (2003) - Azapagic (2004) - Azapagic (2004) - Krajnc & Glavič (2005)
	SATISFACTION	Annual turnover rate of employees	- Turnover rate (or average length of service of employees) - Employee turnover - Staff turnover - Employee turnover expressed as percentage of employees leaving company relative to the total number of new employees	- Veleva & Ellenbecker (2001) - Krajnc & Glavič (2003) - Azapagic & Perdan (2000) - Azapagic (2004)
		Percentage of employees who are satisfied with their work	- Turnover - Employee turnover rate - Fluctuation - Turnover - Personnel rotation rate	- Helleno et al. (2017) - Roca & Searcy (2012) - Dočekalová & Kocmanová (2016) - Callens & Tyteca (1999) - Callens & Tyteca (1999)
		- Fraction of workers satisfied with their work - Work satisfaction - Employee satisfaction	- Krajnc & Glavič (2003) - Azapagic & Perdan (2000) - Roca & Searcy (2012)	

Figure 2.7 The proposed ergonomics indicators for the *Self-Development* and *Satisfaction* sub-dimensions of the *Social* dimension (modified from Sarbat & Oz Mehmet Tasan, 2020)

The efforts made so far (i.e. the selection and consolidation of sustainability indicators and the proposal of ergonomics indicators) mostly constitute the sustainability part of this framework. However, potential integration between ergonomics and sustainability should be presented more clearly. To present the relations between ergonomics and sustainability, i.e., to constitute this framework, the fundamental elements of ergonomics (i.e. job/task, workplace & equipment, work organization, and employee) mentioned previously in Section 1.1 were used. In this framework, it was proposed that the first three of the fundamental elements of ergonomics are associated with the *Economic*, *Ecological*, and *Social* dimensions of sustainability in Level 1. Since the fourth one, i.e., employee, is located in the intersection of the other three elements, it was not presented in this proposed framework separately (Figure 2.8).

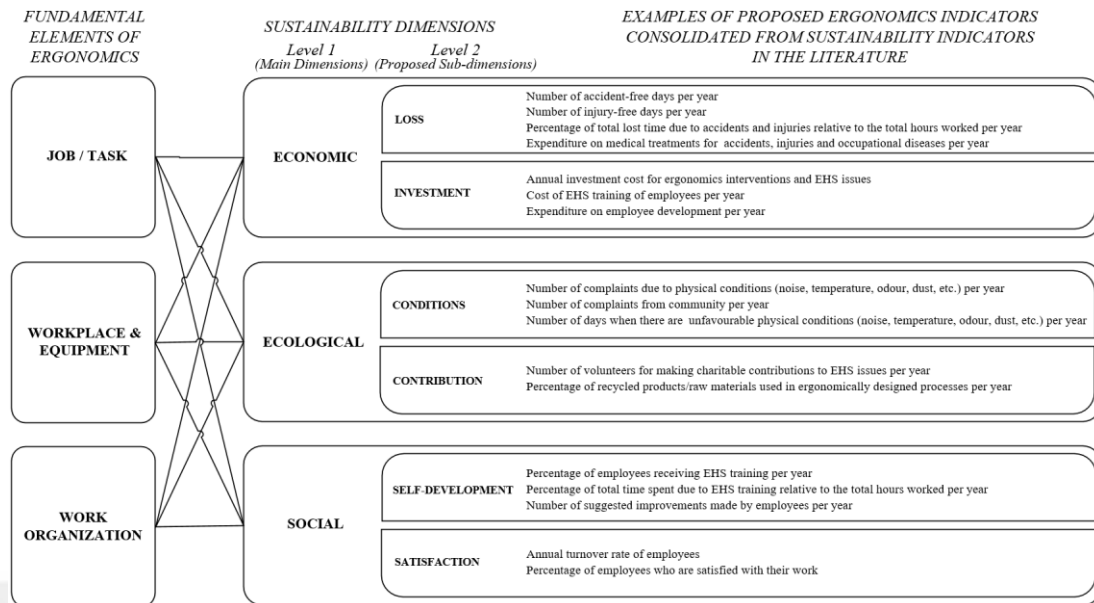


Figure 2.8 The proposed structural framework for the integration of ergonomics and sustainability (modified from Sarbat & Ozmehmet Tasan, 2020)

The proposed structural framework presented in Figure 2.8 consists of four parts, respectively; the fundamental elements of ergonomics presented by Scott et al. (2010), the three dimensions of sustainability in Level 1, the proposed sub-dimensions of sustainability for ergonomics in Level 2, and the proposed ergonomics indicators ($n = 17$) consolidated from the selected sustainability indicators. Ergonomics indicators here were classified according to these proposed sub-dimensions in Level 2.

In this framework, the relations between ergonomics and sustainability were presented between all fundamental elements of ergonomics and all sustainability dimensions (Figure 2.8). The base structure of this framework is the reason for this holistic presentation of relations. Nevertheless, it is thought that it would be more convenient to identify the strength of these relations (i.e. strong or weak) according to the type of processes or organizations that this framework is implemented. Consequently, it was proposed with this structural framework that various organizations can measure sustainability in ergonomics at the base level.

In the following chapter, a systematic literature review conducted on ergonomics and sustainability to enrich this base structure is presented, comprising the proposal of new ergonomics indicators ($n = 8$), besides the classifications and detailed descriptions of these indicators by including the existent ones ($n = 17$), to be used for a performance measurement system as the fundamental part of a systematic approach to be developed for sustainable process performance measurement in ergonomics.



CHAPTER THREE

INDICATOR DEVELOPMENT

This chapter comprises a systematic literature review conducted on ergonomics and sustainability to enrich the efforts made in Chapter 2 by consolidating more sustainability indicators selected from the review and proposing new ergonomics indicators; then, all are classified and described in detail to be used for a performance measurement system as the fundamental part of a systematic approach.

3.1 Systematic Literature Review

As underlined in the previous chapters, the foundation of this thesis is the integration of ergonomics and sustainability to propose ergonomics indicators. It was planned that this integration can be achieved through a literature review conducted comprehensively to select the relevant papers that consider both ergonomics and sustainability. In this regard, a comprehensive overview of the literature was conducted to propose ergonomics indicators from a sustainability point-of-view. This overview comprises papers that appear at the intersection of ergonomics and sustainability while considering the aim of this thesis presented in Section 1.2. It should be noted here that the term *intersection* represents the definitions, classifications, inferences, and proposals related to both ergonomics and sustainability. What is crucial here is the decision of which sustainability indicators should be selected as references to aid the management and prevention of the risks caused by unfavourable working conditions through ergonomics indicators.

Fundamentally, many measures and metrics have been developed through indicators, indices, and frameworks due to wide and new application areas of sustainability assessment (Joung et al., 2012). Moreover, for ergonomics becoming an effectively managed contributor to organizational goals, there is a need for developing tools enabling the evaluation and report of its applications throughout organizations (Greig, Village, Dixon, Salustri, & Neumann, 2019; Neumann, Greig, Village, & Wells, 2013; Neumann & Village, 2012). By starting from this, it can be stated that

this need can be met by proposing a framework in which sustainability indicators can be consolidated to propose ergonomics indicators as a basis for sustainable process performance measurement in ergonomics. It was planned that this framework enables proposing ergonomics indicators by using these sustainability indicators as references.

To achieve this, Sarbat & Ozmehmet Tasan's (2020) structure presented previously in Chapter 2, which comprises six sustainability sub-dimensions proposed for ergonomics (i.e. *Loss, Investment, Conditions, Contribution, Self-Development, and Satisfaction*), was used as the theoretical background of this thesis. This structure consists of three dimensions of sustainability (i.e. *Economic, Ecological, and Social*) as the main dimensions in Level 1. Each main dimension has two proposed sub-dimensions in Level 2, while the proposed ergonomics indicators place in Level 3. The sub-dimensions were proposed by considering human, work design, and workplace design together (Sarbat & Ozmehmet Tasan, 2020). The base that lies behind this proposal consists of the fundamental elements of ergonomics (i.e. job/task, workplace & equipment, work organization, and employee) in Scott et al. (2010). Hence, the efforts made in this thesis to present an integration of ergonomics and sustainability, i.e., the selection of papers to support sustainability indicators for further evaluation, the consolidation of these selected sustainability indicators, and the proposal of new ergonomics indicators, are made possible through this theoretical background by starting from the systematic literature review conducted on ergonomics and sustainability to enrich this base structure.

3.1.1 Literature Search

For reviewing the literature, three online databases, i.e., Web of Science, Scopus, and Google Scholar, were used in this thesis. The Web of Science search was applied in the *Topic* field corresponding to a search of title, abstract, author keywords, and keywords plus, while the Scopus search was applied in the *Article Title, Abstract, Keywords* field. Additionally, the Google Scholar search was applied by considering the titles through *Advanced Search*.

Specifically, the search terms such as *ergonomics*, *human factors*, and *occupational health and safety* were combined with sustainability-related ones such as *sustainability* and *sustainable development*. The term *indicator* presented as the base of this thesis to measure the performance of processes was also included in the combination of search terms. The asterisk (*) was used as a truncation symbol for the Web of Science and Scopus searches. Instead of using an asterisk, different roots of the search terms were run through Google Scholar to include the singular and plural forms as well as variant endings of the terms.

The search was firstly performed at the end of December 2019 through the selected databases by including all years. Later, the same search was revised at the end of December 2020 to include the records belonging to 2020. Consequently, a total of 6568 records belonging to both peer-reviewed papers and publications from grey literature (e.g. technical reports, working papers, and conference proceedings) were collected. After removing 401 duplicates, 6167 records remained.

3.1.2 Paper Selection

A two-step screening to select relevant papers was conducted for the publications ($n = 6167$) obtained from the three online database searches. At first, the publications were evaluated in terms of *language*, *publication year*, and *access to full-text*. Later, the full-text publications were assessed for eligibility by considering their *types*, *qualifications*, and *scopes*. All these evaluations were made through the inclusion and exclusion criteria defined for screening, as explained in the following paragraphs.

Peer-reviewed papers, which had accessible full-text, written only in English, and published between 2015 and 2020, were included for synthesis. The reason for determining the year 2015 as the starting point (i.e. one of the inclusion criteria) for this review is the 2030 Agenda published by the United Nations (UN) in 2015, comprising 17 Sustainable Development Goals having 169 targets based on three dimensions of sustainability (Andries et al., 2019; Chang, Wang, & Wang, 2018; UN, 2015). Therefore, this agenda was adopted as a milestone for this review. Moreover,

only the papers published by journals that were indexed in Science Citation Index (SCI), Science Citation Index Expanded (SCI-E), or Social Sciences Citation Index (SSCI) were selected among the peer-reviewed papers. The reason for selecting the SCI, SCI-E, and SSCI indexes as the other inclusion criteria for this review is related to academic quality. Baumann (2002) underlines this issue by indicating that the inclusion of a paper in SCI or SSCI is frequently associated with academic quality. Beyond that, the papers within the scope of this thesis (i.e. taking place at the intersection of ergonomics and sustainability) and comprising the indicators presented in this scope were included. In addition to the sustainability concept, as underlined previously in Section 3.1, this scope comprises human, work design, and workplace design, referring to the fundamental elements of ergonomics in Scott et al. (2010). Hence, the selection of papers for further evaluation is based on these inclusion criteria.

The exclusion criteria were structured in a similar manner. Publications that were not written in English and did not have accessible full-text were excluded, as well as the ones that published before 2015. Neither conference proceedings, dissertations, working papers, technical reports, books, book chapters nor papers published by journals not indexed in SCI, SCI-E, or SSCI were considered. Moreover, publications that did not present any indicators were excluded, as well as the ones only having indices or any aggregated forms of the indicators.

3.1.3 Results of the Literature Review

The screening enabled the selection of 77 papers from 6167 records for further evaluation. It should be noted that some of these papers ($n = 77$) were obtained from only the Google Scholar search; on the contrary, some of the others did not belong to the Google Scholar search but were obtained from the Web of Science and Scopus searches. The overview of this screening is presented in Figure 3.1, including the representation of the *Literature Search* and *Further Evaluation* phases of the systematic literature review beside the *Paper Selection* phase presented in detail.

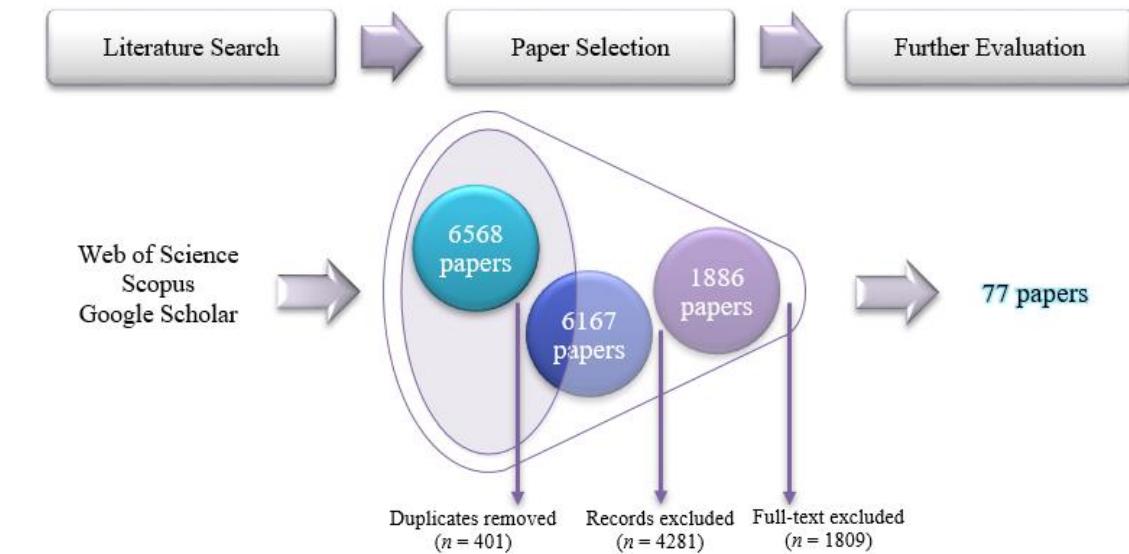


Figure 3.1 The overview of paper selection (modified from Sarbat & Oz Mehmet Tasan, 2022)

At first, based on the inclusion and exclusion criteria explained previously, the screening of 6167 records was conducted, and 4281 of these records were excluded. In this step, some records were excluded based on more than one exclusion criterion. The result after this exclusion ($n = 1886$) can be explained briefly: The number of records *not written in English* was 773, the number of records that did *not have accessible full-text* was 1587, and the number of records that were *published before 2015* was 3742.

Later, the selection of 77 papers to be used for proposing ergonomics indicators was made through the evaluation of the remaining full-text publications ($n = 1886$) by considering the inclusion and exclusion criteria. As presented in Figure 3.2, some of these publications ($n = 1809$) were excluded due to their *types* (i.e. 350 conference proceedings, 77 dissertations, 93 working papers and technical reports, and 92 books and book chapters), *qualifications* (i.e. 564 papers not indexed in SCI, SCI-E, and SSCI), and *scopes* (i.e. 633 papers not related).

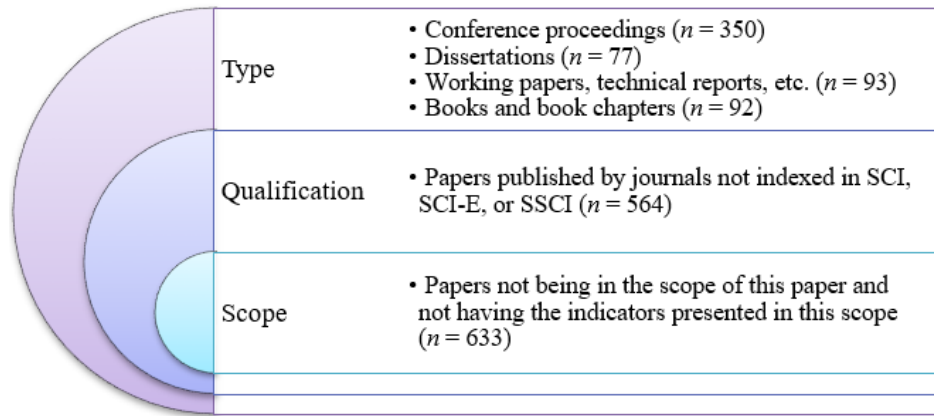


Figure 3.2 The excluded full-text publications in terms of type, qualification, and scope (modified from Sarbat & Ozmehmet Tasan, 2022)

Similar to the theoretical background (i.e. consideration of human, work design, and workplace design) of this thesis, the selected papers ($n = 77$ in Table 3.1 below) were examined in detail in terms of the indicators they proposed. The main point here, as underlined previously in Section 3.1, was the selection and consolidation of the sustainability indicators relevant to this theoretical background to propose ergonomics indicators. In Table 3.1, the *Listed* column represents the total number of sustainability indicators listed in 77 papers, while the *Selected* column highlights the number of sustainability indicators selected from 77 papers and used for consolidation.

The sustainability dimensions that these papers use in Level 1 are also presented in Table 3.1. The *Main* column represents the papers that comprise three dimensions of sustainability. On the other hand, the papers that have an additional dimension (e.g. *Corporate Governance* or *Technological Performance*) to three dimensions of sustainability as well as the papers that use only one of the three dimensions of sustainability (e.g. *Social*) are presented in the *Other* column. Additionally, the papers that use many other dimensions (e.g. *Education and Participation*, *Management Review*, or *Materials and Packaging*) apart from the three dimensions of sustainability are also given in the *Other* column. Lastly, *N/A* column presents the papers that do not explicitly state any dimensions.

Table 3.1 The selected papers ($n = 77$) with the indicators and dimensions they comprise (modified from Sarbat & Ozmehmet Tasan, 2022)

No	Paper	Number of Indicators		Sustainability Dimensions		
		Listed	Selected	Main	Other	N/A
1	Marnika, Christodoulou, & Xenidis (2015)	36	2	✓		
2	Rahdari & Rostamy (2015)	70	5		✓	
3	Heravi, Fathi, & Faeghi (2015)	42	6	✓		
4	Feil, de Quevedo, & Schreiber (2015)	77	13	✓		
5	Rafiei et al. (2015)	9	2			✓
6	Kuleli Pak, Albayrak, & Erensal (2015)	7	1			✓
7	Loeppke et al. (2015)	25	7	✓		
8	Bélanger, Vanasse, Parent, Allard, & Pellerin (2015)	44	4		✓	
9	Pawłowska (2015)	18	16		✓	
10	Valls-Donderis, Vallés, & Galiana (2015)	130	3		✓	
11	Santiago-Brown et al. (2015)	76	5	✓		
12	Dočekalová & Kocmanova (2016)	32	13		✓	
13	Govindan, Garg, Gupta, & Jha (2016)	49	13	✓		
14	Shea, De Cieri, Donohue, Cooper, & Sheehan (2016)	10	5		✓	
15	Antão et al. (2016)	59	13		✓	
16	Valenzuela-Venegas, Salgado, & Díaz-Alvarado (2016)	249	7	✓		
17	Manning & Soon (2016)	73	16	✓		
18	Winroth, Almström, & Andersson (2016)	169	23	✓		
19	Allahyari, Daghighi Masouleh, & Koundinya (2016)	62	4	✓		
20	Iribarren, Martín-Gamboa, O'Mahony, & Dufour (2016)	40	10		✓	
21	Shiau & Chuen-Yu (2016)	35	6		✓	
22	Schöggel, Fritz, & Baumgartner (2016)	69	7		✓	
23	Ciommi, Gigliarano, Emili, Taralli, & Chelli (2017)	41	2		✓	
24	Dočekalová, Doubravský, Dohnal, & Kocmanová (2017)	17	4		✓	
25	Mapar et al. (2017)	80	4		✓	
26	Mahjouri, Ishak, Torabian, Abd Manaf, & Halimoon (2017)	43	3		✓	
27	Bui et al. (2017)	20	5	✓		
28	Helleno et al. (2017)	60	9	✓		
29	Mohammadfam et al. (2017)	43	43		✓	
30	Kocmanova, Dočekalová, & Šimanavičienė (2017)	38	5		✓	
31	Moreira, Vasconcelos, & Santos (2017)	40	10			✓
32	Valenti, Kimpara, Preto, & Moraes-Valenti (2018)	56	2	✓		
33	Van Schoubroeck, Van Dael, Van Passel, & Malina (2018)	85	5	✓		
34	Tsalis, Stylianou, & Nikolaou (2018)	7	5			✓
35	Li & Mathiyazhagan (2018)	15	3	✓		
36	Popovic, Barbosa-Póvoa, Kraslawski, & Carvalho (2018)	31	10		✓	
37	Pan, Linner, Pan, Cheng, & Bock (2018)	75	10		✓	
38	Chan, Si, & Marafa (2018)	68	4		✓	
39	Danso (2018)	25	2	✓		
40	Chang et al. (2018)	19	4	✓		
41	Danielis, Rotaris, & Monte (2018)	16	3	✓		
42	Moreira, Vasconcelos, & Santos (2018)	6	2			✓
43	Davino, Dolce, Taralli, & Vinzi (2018)	40	2		✓	
44	Popovic & Kraslawski (2018)	22	7		✓	
45	Evangelinos et al. (2018)	10	4			✓
46	Ottaviani (2018)	28	2		✓	
47	Demartini, Pinna, Aliakbarian, Tonelli, & Terzi (2018)	14	3		✓	
48	Ameen & Mourshed (2019)	81	5		✓	
49	Van Schoubroeck, Springael, Van Dael, Malina, & Van Passel (2019)	48	3	✓		
50	Hutchins, Richter, Henry, & Sutherland (2019)	17	9		✓	
51	Ahmad & Wong (2019)	57	13	✓		

Table 3.1 Continues

No	Paper	Number of Indicators		Sustainability Dimensions		
		Listed	Selected	Main	Other	N/A
52	González-García et al. (2019)	38	2	✓		
53	Kravchenko, Pigosso, & McAloone (2019)	279	24	✓		
54	Munyaneza, Kurwijila, Mdoe, Baltenweck, & Twine (2019)	57	3	✓		
55	Ahmad, Wong, & Rajoo (2019)	144	14	✓		
56	Gillespie-Marthaler, Nelson, Baroud, & Abkowitz (2019)	46	2	✓		
57	Egenolf & Bringezu (2019)	48	3	✓		
58	Feil, Schreiber, Haetinger, Strasburg, & Barkert (2019)	69	12	✓		
59	Shi et al. (2019)	58	2		✓	
60	Karnauskaitė, Schernewski, Støttrup, & Kataržytė (2019)	89	2		✓	
61	Almost et al. (2019)	9	1		✓	
62	Lin, Belis, & Kuo (2019)	40	10	✓		
63	Hristov & Chirico (2019)	14	5	✓		
64	Merino-Saum, Halla, Superti, Boesch, & Binder (2020)	34	3			✓
65	Janackovic, Stojiljkovic, & Grozdanovic (2020)	48	12		✓	
66	Torabizadeh, Yusof, Ma'aram, & Shaharoun (2020)	33	8	✓		
67	Hojnik, Biloslavo, Cicero, & Cagnina (2020)	45	6	✓		
68	Qiu, Liu, Lu, & Huang (2020)	30	1		✓	
69	Visentin, da Silva Trentin, Braun, & Thomé (2020)	39	3	✓		
70	Roy, Sen, & Pal (2020)	8	2			✓
71	Yadegaridehkordi et al. (2020)	54	3		✓	
72	Kumar & Ramesh (2020)	25	2	✓		
73	Rafiaani et al. (2020)	46	4	✓		
74	Narimissa, Kangarani-Farahani, & Molla-Alizadeh-Zavardehi (2020)	88	10	✓		
75	Bhanot, Qaiser, Alkahtani, & Rehman (2020)	13	3	✓		
76	Lin, Belis, Caesaron, Jiang, & Kuo (2020)	33	15		✓	
77	Taddese, Durieux, & Duc (2020)	68	9	✓		
<i>Total</i>		3938	525			

The starting point of the efforts made in this part of the thesis is the sustainability indicators ($n = 3938$) listed in 77 papers as presented in Table 3.1. Due to their relevance to scope, only 13% of the listed sustainability indicators (525 out of 3938) were selected to structure ergonomics indicators. Indeed, this is not an unexpected result. One of the reasons for this result is the theoretical background of this thesis. It should be regarded that the selection of sustainability indicators, as well as the descriptions of sub-dimensions, are based on human, work design, and workplace design to tackle the integration of ergonomics and sustainability. Later, the variety of application areas in the selected papers ($n = 77$) can be presented as another reason. Selecting those papers was not restricted by considering their application areas. Therefore, various indicators proposed for different application areas (e.g. agriculture, urbanization, wastewater treatment, chemistry, aquaculture, and marine management) were included in this review. Nevertheless, this rate (13%) indicates that there is a lot

more work to be done for researchers and practitioners in these areas: Many other indicators may be selected through other dimensions and sub-dimensions by selecting different theoretical backgrounds and inclusion criteria. Accordingly, it should be highlighted that this selection rate (13%) is a descriptive statistic that presents the result of the review rather than being a measure of success.

The papers in Table 3.1 can also be compared by considering the selection rates of sustainability indicators in terms of their dimensions stated in these papers ($n = 77$). The results are not surprising considering the potential strict relation of the *Social* dimension of sustainability with ergonomics (Figure 3.3).

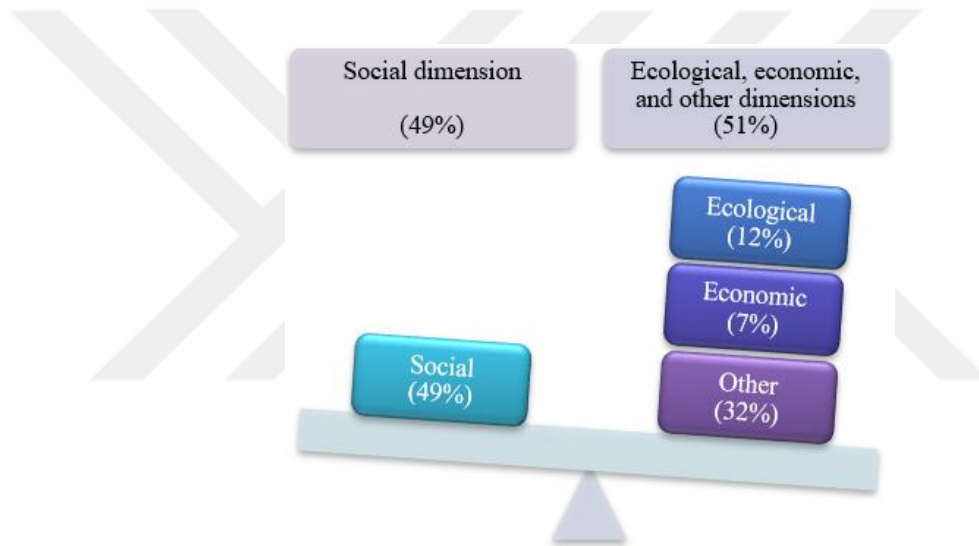


Figure 3.3 The comparison between the selection rates of sustainability indicators in terms of their dimensions (modified from Sarbat & Ozmehmet Tasan, 2022)

Figure 3.3 shows that almost half of the selected sustainability indicators (49%; 258 out of 525) in the reference papers were classified under the *Social* dimension. Nevertheless, the selected sustainability indicators, classified under the *Ecological* dimension (12%; 65 out of 525) and the *Economic* dimension (7%; 35 out of 525), constituted 19% of all selected sustainability indicators. The remaining sustainability indicators, i.e., the ones that were classified under various dimensions in the reference papers, constitute 32% (167 out of 525) of all selected sustainability indicators.

3.2 Proposal of Ergonomics Indicators

As underlined in Section 3.1.1, indicators are the basis of this thesis to develop a systematic approach that integrates ergonomics and sustainability. Establishing a performance measurement system using the ergonomics indicators proposed in this thesis is the fundamental part of such an approach for sustainable process performance measurement in ergonomics. Through this viewpoint, in this subsection, definitions of indicators are given; before the efforts (i.e. the consolidation of the selected sustainability indicators, the presentation of the hierarchical scheme, and the classifications and detailed descriptions of the proposed ergonomics indicators) made for proposing the ergonomics indicators to be used for such a systematic approach are presented. It should be noted that, previously in this thesis, the indicators were stated in Section 1.1 as an introduction and Section 2.1.2 as a detailed review. Moreover, the definitions presented below enable reminding and underline the essential position and benefit of indicators for this thesis.

Fundamentally, indicators are the “measures that provide specific information about the property or state of a system” (Cottrill & Derrible, 2015, p. 47). According to Mascarenhas, Nunes, & Ramos (2014), indicators are generally used as a tool to transform information from complex to simplified form. Cottrill & Derrible (2015) state that contrary to often regarded, indicators can be used not only for system performance assessment but also for many other applications such as verification of the ongoing project, real-time evaluation, overall comparison, completion of the project, calibration of the model, evaluation of the project design, and scenario development.

Essentially, indicators can be used successfully through their major functions. Gallopin (1996) summarizes these functions as the assessment of trends and conditions related to aims and targets, the anticipation of trends and future conditions, the comparison across situations and places, and the providing of early warning information. In short, it can be stated that the functional characteristics of the indicators enable revealing the current situation of an evaluated process.

3.2.1 Consolidation of the Selected Sustainability Indicators

The proposal of ergonomics indicators in this thesis starts from the consolidation of the sustainability indicators in the papers ($n = 77$) in Table 3.1. Accordingly, to consolidate the sustainability indicators ($n = 525$) selected from the systematic literature review, i.e., to propose the ergonomics indicators through using these indicators as references, the merging of multiple indicators was used in this thesis. Essentially, many researchers have been using this merging approach. Karji, Woldeesenbet, Khanzadi, & Tafazzoli (2019) merge indicators with similar content to provide a single comprehensive indicator. Similarly, Opon & Henry (2019) combine the indicators, which have synonymous meanings, to a single thematic indicator to minimize the complexity of the indicator list by representing their collective meaning. Moreover, Chan & Lee (2019) merge the reviewed indicators that have parallel descriptions. Finally, Sarbat & Ozmehmet Tasan (2020), which is the theoretical background of this thesis and presented in Chapter 2, also merge frequently encountered indicators in prominent studies.

Under these circumstances, all selected sustainability indicators ($n = 525$) were consolidated by considering their similarities to propose ergonomics indicators. This consolidation is divided into two parts:

- The *first part* is the consolidation by considering the relevant ergonomics indicators ($n = 17$) proposed by Sarbat & Ozmehmet Tasan (2020) (Appendix-1), supporting the efforts made in Chapter 2 through enriching the references (i.e. the selected sustainability indicators) for the proposal of these ergonomics indicators.
- The *second part* is the proposal of new ergonomics indicators ($n = 8$) by Sarbat & Ozmehmet Tasan (2022) (Appendix-2), consolidating the remaining selected sustainability indicators through merging them by utilizing their similarities, enhancing the efforts made in Chapter 2.

It should be noted here that the numbers in parentheses in the bulleted lists in both Appendix-1 and Appendix-2 represent the paper numbers in Table 3.1, indicating the papers having those sustainability indicators. During consolidation, not only their definitions but also their expressions and formulas were considered for the assignments of the selected sustainability indicators to the relevant ergonomics indicators. Hence, some sustainability indicators can be assigned to more than one ergonomics indicator.

3.2.2 Presentation of the Hierarchical Scheme with Dimensions and Indicators Proposed for Ergonomics

Subsequently, the ergonomics indicators proposed both in the first part ($n = 17$) (i.e. Chapter 2) and the second part ($n = 8$) (i.e. this chapter) are presented by using a hierarchical scheme (Figure 3.4). This base scheme, previously depicted by Sarbat & Ozmehmet Tasan (2020) and presented in Figure 2.2, enables presenting dimensions, sub-dimensions, and indicators on different levels holistically. It should be noted that all ergonomics indicators ($n = 25$) were assigned to the proposed sub-dimensions by considering the short descriptions of these sub-dimensions (please see Figure 2.4 for details) defined in Sarbat & Ozmehmet Tasan (2020).

By considering Figure 3.4, the proposed ergonomics indicators can be briefly introduced as follows: There are nine ergonomics indicators proposed under the *Economic* dimension; five of them (i.e. *Number of accident-free days per year*, *Number of injury-free days per year*, *Percentage of total lost time due to accidents and injuries relative to the total hours worked per year*, *Expenditure on medical treatments for accidents, injuries and occupational diseases per year*, and *Number of cases of occupational diseases per year*) took place in the *Loss* sub-dimension, while four of them (i.e. *Annual investment cost for ergonomics interventions and EHS issues*, *Cost of EHS training of employees per year*, *Expenditure on employee development per year*, and *Expenditure on research and development, technology, and innovation per year to enhance ergonomically and environmentally-friendly designed processes*) took place in the *Investment* sub-dimension.

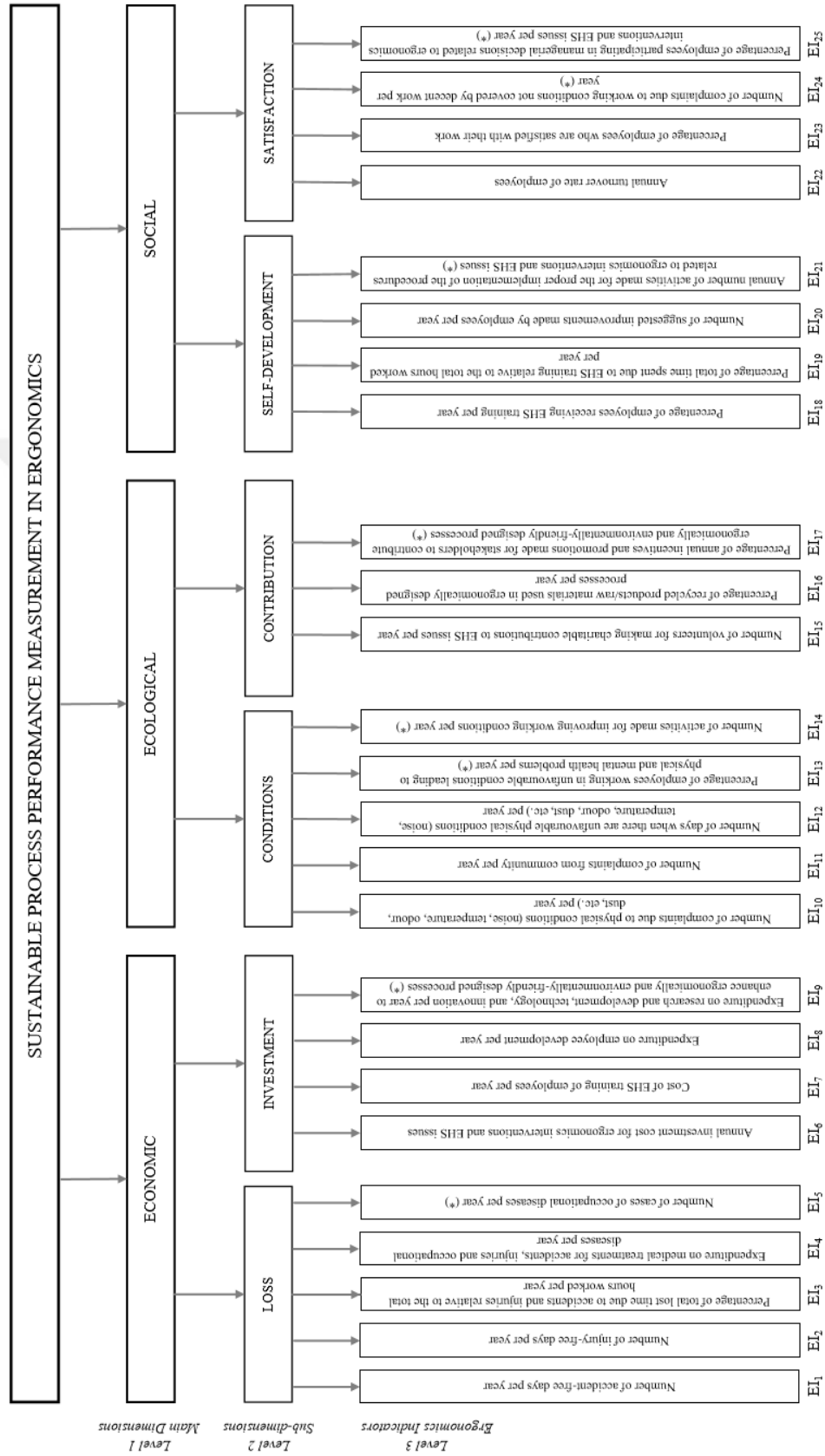


Figure 3.4 The hierarchical scheme presenting the dimensions, sub-dimensions, and ergonomics indicators (modified from Sarbat & Ozmehmet Tasan, 2020 and Sarbat & Ozmehmet Tasan, 2022) (The ergonomics indicators that have an asterisk in the figure are proposed in this chapter, and EI represents ergonomics indicators)

Eight ergonomics indicators are proposed under the *Ecological* dimension; five of them (i.e. *Number of complaints due to physical conditions (noise, temperature, odour, dust, etc.) per year*, *Number of complaints from community per year*, *Number of days when there are unfavourable physical conditions (noise, temperature, odour, dust, etc.) per year*, *Percentage of employees working in unfavourable conditions leading to physical and mental health problems per year*, and *Number of activities made for improving working conditions per year*) were put in the *Conditions* sub-dimension, while three of them (*Number of volunteers for making charitable contributions to EHS issues per year*, *Percentage of recycled products/raw materials used in ergonomically designed processes per year*, and *Percentage of annual incentives and promotions made for stakeholders to contribute ergonomically and environmentally-friendly designed processes*) were put in the *Contribution* sub-dimension.

In addition to the above, the remaining eight ergonomics indicators are structured in the *Social* dimension; four of them (i.e. *Percentage of employees receiving EHS training per year*, *Percentage of total time spent due to EHS training relative to the total hours worked per year*, *Number of suggested improvements made by employees per year*, and *Annual number of activities made for the proper implementation of the procedures related to ergonomics interventions and EHS issues*) were classified under the *Self-Development* sub-dimension, while the remaining four (i.e. *Annual turnover rate of employees*, *Percentage of employees who are satisfied with their work*, *Number of complaints due to working conditions not covered by decent work per year*, and *Percentage of employees participating in managerial decisions related to ergonomics interventions and EHS issues per year*) were classified under the *Satisfaction* sub-dimension. The ergonomics indicators proposed in this chapter ($n = 8$) were distinguished by using an asterisk (*) for each (Figure 3.4).

It should be underlined that the new ergonomics indicators proposed in this chapter enable improvement of Sarbat & Oz Mehmet Tasan's (2020) base structure presented in Chapter 2. For example, the ergonomics indicator *Number of cases of occupational diseases per year* under the *Loss* sub-dimension can work for measuring the long-term effects of unfavourable working conditions on employees by focusing on occupational

diseases. Similarly, the ergonomics indicator *Expenditure on research and development, technology, and innovation per year to enhance ergonomically and environmentally-friendly designed processes* under the *Investment* sub-dimension points to the importance of activities related to research and development, technology, and innovation as a need of our century. This indicator can also assist in linking these activities with ergonomics and sustainability.

Moreover, the two ergonomics indicators proposed under the *Conditions* sub-dimension (i.e. *Percentage of employees working in unfavourable conditions leading to physical and mental health problems per year* and *Number of activities made for improving working conditions per year*) enable this sub-dimension to consist of not only complaints. These two indicators denote the effects of unfavourable working conditions on employees as well as the activities to improve them. In addition to charities and recycling issues formerly proposed in the *Contribution* sub-dimension, the ergonomics indicator *Percentage of annual incentives and promotions made for stakeholders to contribute ergonomically and environmentally-friendly designed processes* can assist in measuring the motivational ways such as incentives and promotions made for the stakeholders to take active roles in designing processes.

Considering that being part of the processes related to ergonomics interventions and EHS issues can contribute to self-development, the ergonomics indicator proposed under the *Self-Development* sub-dimension (i.e. *Annual number of activities made for the proper implementation of the procedures related to ergonomics interventions and EHS issues*) enables querying the activities that are made for implementing the relevant procedures properly. Finally, the last two ergonomics indicators (i.e. *Number of complaints due to working conditions not covered by decent work per year* and *Percentage of employees participating in managerial decisions related to ergonomics interventions and EHS issues per year*) investigate the satisfaction of employees from work and working conditions in terms of decent work and employee empowerment, respectively.

3.2.3 Another Classification of the Proposed Ergonomics Indicators

Apart from the classification of the twenty-five ergonomics indicators through the proposed three-dimensional structure (Figure 3.4), furthermore, these indicators were also classified in this thesis as lagging or leading indicators (Table 3.2). Before the presentation of this classification, definitions for lagging and leading indicators are given. According to Grabowski, Ayyalasomayajula, Merrick, Harrald, & Roberts (2007), lagging indicators measure occurrences and outcomes of a system by being taken after events. These indicators may not predict future losses necessarily; instead, they reflect what has occurred (Wurzelbacher & Jin, 2011). The accident frequency rates, the number of occupational diseases, the number of accidents at work, and the number of absent days due to accidents at work can be examples for lagging indicators (Pawłowska, 2015).

On the other hand, leading indicators usually indicate self-assessment ratings of a company's exposure to ergonomic, safety, or medical managerial activities and musculoskeletal disorder risk factors, or safety hazards (Wurzelbacher & Jin, 2011). Contrary to lagging indicators frequently called reactive indicators, leading indicators are proactive indicators (Kravchenko et al., 2019), because they enable monitoring the effectiveness of systems and warn of any weaknesses before their appearance (Pojasek, 2009). The number of suggestions from workplace inspections and accident investigations, and the percentage of planned training completed are examples of leading indicators (Almost et al., 2019).

Recently, there is an increasing emphasis on the usage of leading indicators in providing information to anticipate and develop organizational performance (Reiman & Pietikäinen, 2012). Nevertheless, Neumann & Village's (2012) observation shows that few companies have leading indicators of human factors aspects. Hence, the classification presented in Table 3.2 below can contribute to the endeavour in the relevant literature on this basis.

Table 3.2. Another classification of the ergonomics indicators ($n = 25$) proposed in this thesis as lagging or leading indicators (modified from Sarbat & Ozmehmet Tasan, 2022)

Main Dimension	Proposed Sub-Dimension	No	Proposed Ergonomics Indicator	Indicator Type		
				Lagging	Leading	
Economic	Loss	EI ₁	Number of accident-free days per year	✓		
		EI ₂	Number of injury-free days per year	✓		
		EI ₃	Percentage of total lost time due to accidents and injuries relative to the total hours worked per year	✓		
		EI ₄	Expenditure on medical treatments for accidents, injuries and occupational diseases per year	✓		
		EI ₅	Number of cases of occupational diseases per year	✓		
	Investment	EI ₆	Annual investment cost for ergonomics interventions and EHS issues		✓	
		EI ₇	Cost of EHS training of employees per year		✓	
		EI ₈	Expenditure on employee development per year		✓	
		EI ₉	Expenditure on research and development, technology, and innovation per year to enhance ergonomically and environmentally-friendly designed processes		✓	
Ecological	Conditions	EI ₁₀	Number of complaints due to physical conditions (noise, temperature, odour, dust, etc.) per year	✓		
		EI ₁₁	Number of complaints from community per year	✓		
		EI ₁₂	Number of days when there are unfavourable physical conditions (noise, temperature, odour, dust, etc.) per year	✓		
		EI ₁₃	Percentage of employees working in unfavourable conditions leading to physical and mental health problems per year	✓		
		EI ₁₄	Number of activities made for improving working conditions per year		✓	
	Contribution	EI ₁₅	Number of volunteers for making charitable contributions to EHS issues per year		✓	
		EI ₁₆	Percentage of recycled products/raw materials used in ergonomically designed processes per year		✓	
		EI ₁₇	Percentage of annual incentives and promotions made for stakeholders to contribute ergonomically and environmentally-friendly designed processes		✓	
	Social	Self-Development	EI ₁₈	Percentage of employees receiving EHS training per year		✓
			EI ₁₉	Percentage of total time spent due to EHS training relative to the total hours worked per year		✓
EI ₂₀			Number of suggested improvements made by employees per year		✓	
EI ₂₁			Annual number of activities made for the proper implementation of the procedures related to ergonomics interventions and EHS issues		✓	
Satisfaction		EI ₂₂	Annual turnover rate of employees	✓		
		EI ₂₃	Percentage of employees who are satisfied with their work		✓	
		EI ₂₄	Number of complaints due to working conditions not covered by decent work per year	✓		
		EI ₂₅	Percentage of employees participating in managerial decisions related to ergonomics interventions and EHS issues per year		✓	

It can be clearly stated through Table 3.2 that 56% of the proposed ergonomics indicators in this thesis (14 out of 25) were classified as leading indicators, while the remaining ones (44%; 11 out of 25) were classified as lagging indicators. Additionally, a remarkable result was obtained from Table 3.2 by considering the two classifications together made in this thesis (i.e. the *Proposed Sub-Dimension* and *Indicator Type* columns) for the proposed ergonomics indicators: All indicators classified in the *Investment*, *Contribution*, and *Self-Development* sub-dimensions were classified as leading indicators, while all indicators classified in the *Loss* sub-dimension and nearly all indicators classified in the *Conditions* sub-dimension were classified as lagging indicators. Nevertheless, it should be underlined that the indicator types in Table 3.2 were not associated with the sub-dimensions of these indicators; these sub-dimensions were not considered during their classifications as lagging or leading indicators. Accordingly, the only basis in this classification is the definitions for lagging and leading indicators given in this subsection before Table 3.2.

3.2.4 Detailed Descriptions of the Proposed Ergonomics Indicators

To elaborate on this work, finally, the detailed descriptions of the ergonomics indicators ($n = 25$) proposed in this thesis (i.e. both in Chapter 2 and this chapter) were constituted (Appendix-3) to be used for a performance measurement system. The need for such a system as well as the importance of it for ergonomics, emphasizing the systematic approach of which this system is the fundamental part, was already discussed in Chapter 1. To achieve this, a standard template of the International Organization for Standardization (ISO) (ISO, 2014; Popovic et al., 2018) was used in this thesis to provide the detailed information for the proposed ergonomics indicators.

Importantly, the template used in this thesis was modified by adding three new parts, namely *Type*, *Related main dimension*, and *Related sub-dimension*: In this modified template, *Type* represents the indicator as lagging or leading, depending on the classification presented in Table 3.2, while *Related main dimension* and *Related sub-dimension* represent the indicator's dimensions in Level 1 and Level 2, depending on the classification presented in Figure 3.4.

The *Formula* of each proposed ergonomics indicator was generated in this modified template by considering the formulas and descriptions presented in the prominent papers in ergonomics and sustainability. Additionally, the *Notes*, which comprises essential details for each indicator, were formed attentively in this thesis. It enables this template to guide a researcher or practitioner for the data collection phase of any project in which these indicators could be used in measuring the performance of processes of organizations by utilizing ergonomics, sustainability, and the coherence between the two.

As underlined before, this structure, i.e., the systematic approach comprising the performance measurement system and its proposed ergonomics indicators as the fundamental part of such an approach, can be defined as a generalized framework comprising the three dimensions of sustainability and six sustainability sub-dimensions proposed for ergonomics. It should be highlighted that the detailed descriptions of the proposed ergonomics indicators in this thesis (Appendix-3), when used in a performance measurement system to monitor and evaluate processes of organizations holistically, were proposed as a basis for systematic approach development for sustainable process performance measurement in ergonomics. In the following chapter, the theoretical background for developing such a systematic approach is presented, comprising the performance measurement systems as the fundamental part of such an approach and their main structures and components.

CHAPTER FOUR

THEORETICAL LOOK AT SYSTEMATIC APPROACH DEVELOPMENT

This chapter comprises a theoretical background for developing a systematic approach in terms of the performance measurement systems as the fundamental part of such an approach; the main structures and components of such systems are also presented.

4.1 Definitions and Key Issues

As stated in the previous chapters, a systematic approach to be developed by integrating ergonomics and sustainability to monitor and evaluate processes of organizations holistically is the result of this thesis. Besides, the performance measurement system comprising the proposed ergonomics indicators was planned as the fundamental part of this approach. Therefore, definitions and key issues for a performance measurement system with its suggested steps comprising its elements are given in this chapter to present a theoretical look at such a system.

To describe a performance measurement system, as well as a systematic approach comprising such a system, firstly, the definitions of performance and performance measurement should be given. According to Laitinen (2002), performance is “the ability of an object to produce results in a dimension determined a priori, in relation to a target” (p. 66). Teeratansirikool, Siengthai, Badir, & Charoenngam (2013) highlight the key role of performance measurement in developing, implementing, and monitoring a strategic plan in organizations. Accordingly, performance measurement enables managers to evaluate the achievement of organizational objectives as well as monitor the direction of the organization whether it is as planned or not (Teeratansirikool et al., 2013). Tucker & Pitt (2009) support this by defining the performance measurement, which is a process of setting key drivers for assessing and changing organizational objectives, as integral to implementing continuous improvement and added value within business effectively.

Essentially, Neely, Gregory, & Platts (1995) define a performance measurement system as the set of measures used to determine both effectiveness and efficiency of actions. Tangen (2005) expands this definition by stating that a successful performance measurement system consists of a set of performance measures, which provides useful information to a company for assisting in controlling, managing, planning, and performing organizational activities. By considering all these definitions and key issues, it can be indicated that performance measurement plays a vital role for organizations having many business processes, and developing a performance measurement system working properly is essential.

As stated before, such a system needs well-defined indicators to measure the performance of processes of organizations systematically. In this regard, Bourne, Mills, Wilcox, Neely, & Platts (2000) state that performance measurement systems use measures to evaluate strategy implementation and challenge strategic assumptions. Greig et al. (2019) support this by indicating these systems as a helper for providing organizational direction and creating change whenever is needed. By considering the mentioned relevant effects of well-defined indicators from the lowest level (i.e. operations) to the highest level (i.e. strategy and vision) in organizational management, it can be stated that the benefits of these indicators for organizations are undeniable.

According to Wisner & Fawcett (1991), an effective performance measurement system should guide the integration of engineering, marketing, accounting, operations, and finance to act as a value-adding system coordinately; also, its measures should encourage the integration and co-existence of the technological and human systems in organizations. This system should have a long-term orientation; consequently, continuous improvement in both the processes and products, leading to sustainable competitive advantage, can be achieved (Wisner & Fawcett, 1991). When the aim of this thesis presented clearly in Section 1.2 is considered, it is obvious that the system that Wisner & Fawcett (1991) describe corresponds to such a performance measurement system to be developed within a holistic point-of-view in this thesis. In parallel to Wisner & Fawcett (1991), Brown (1996) summarizes the characteristics of an effective measurement system as follows:

- Having vital few key measures are better than trivial many.
- Measures should be linked to the key success factors, values, and vision of organization.
- Measures should focus on the past, present, and future.
- Measures should be linked to the needs of employees, customers, and shareholders.
- Measures should be related to all levels and functions of organization and should be consistent.
- Multiple measures should be combinable into several indices.
- Measures should be changeable as strategy and situation change.
- Measures should have goals or targets based on research.

Besides, using a performance measurement system comprising such indicators has many advantages that benefit various functional areas of organizations related to financial, strategic, quality, operational, managerial, and employment issues. These advantages are summarized as follows (De Waal & Kourtit, 2013; Papulová, Gažová, Šlenker, & Papula, 2021):

- Profit and revenue increase,
- Cost reduction,
- Internal strategy communication improvement,
- Higher understanding and achievement of organizational goals and results,
- Careful focus on what is important for the organization,
- Higher quality of products and services,
- Higher operational efficiency, performance information quality and management control,
- Improvement in decision making, management quality and business processes,
- Clearer vision of organizational members about their roles, contribution and goals to be achieved,
- Higher employee commitment and satisfaction.

4.2 Frameworks Comprising Main Structures and Components

The main structures of performance measurement systems comprising their components and fundamental steps, which are summarized in the prominent papers in this research area, are presented in this subsection as a theoretical background for developing such a systematic approach. It should be underlined here that the frameworks presented in the following figures can constitute a basis for developing a systematic approach integrating ergonomics and sustainability through indicators to assist in sustainable process performance measurement in ergonomics.

Cross & Lynch (1988) develop the *Strategic Measurement Analysis and Reporting Technique (SMART)*, which enables clarifying measures, building horizontal integration across business functions and departments, and establishing operational measurements. The framework of this technique is represented by a four-level structure, namely the *Performance Pyramid* (Figure 4.1), presenting the hierarchy of organizations through the relevant measures in each level by translating strategic objectives from first to the fourth level and rolling measures in the opposite direction.

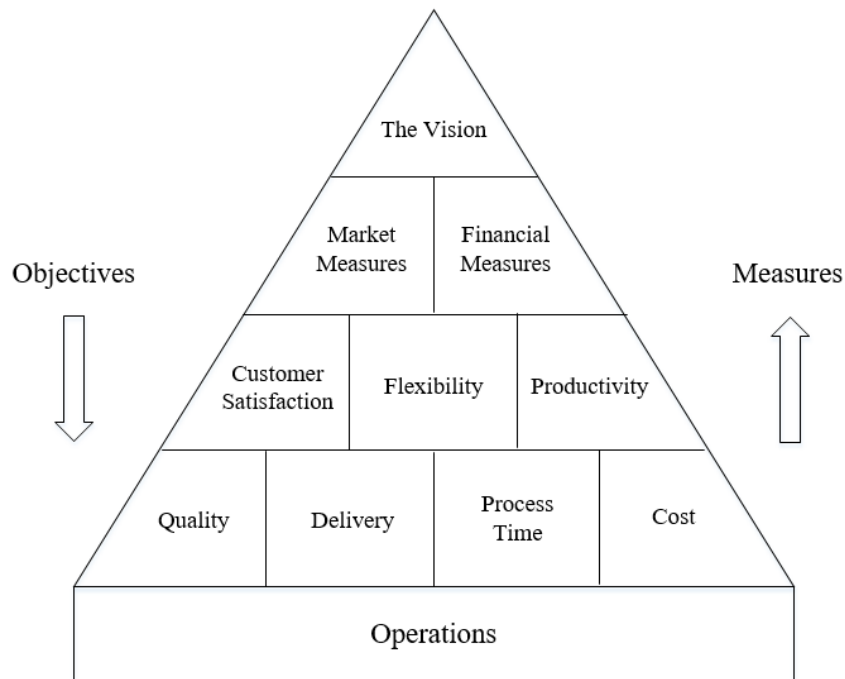


Figure 4.1 The Performance Pyramid representing SMART (redrawn from Cross & Lynch, 1988)

Keegan, Eiler, & Jones (1989) propose the *Performance Measurement Matrix*, dividing the measurement of performance of organizations into four different categories within two viewpoints, namely, *Cost* and *Noncost*, and *Internal* and *External* (Figure 4.2). The performance measures are then listed in a balanced manner through these four categories. This balance is represented by two double-headed arrows drawn in the middle of the framework in Figure 4.2.

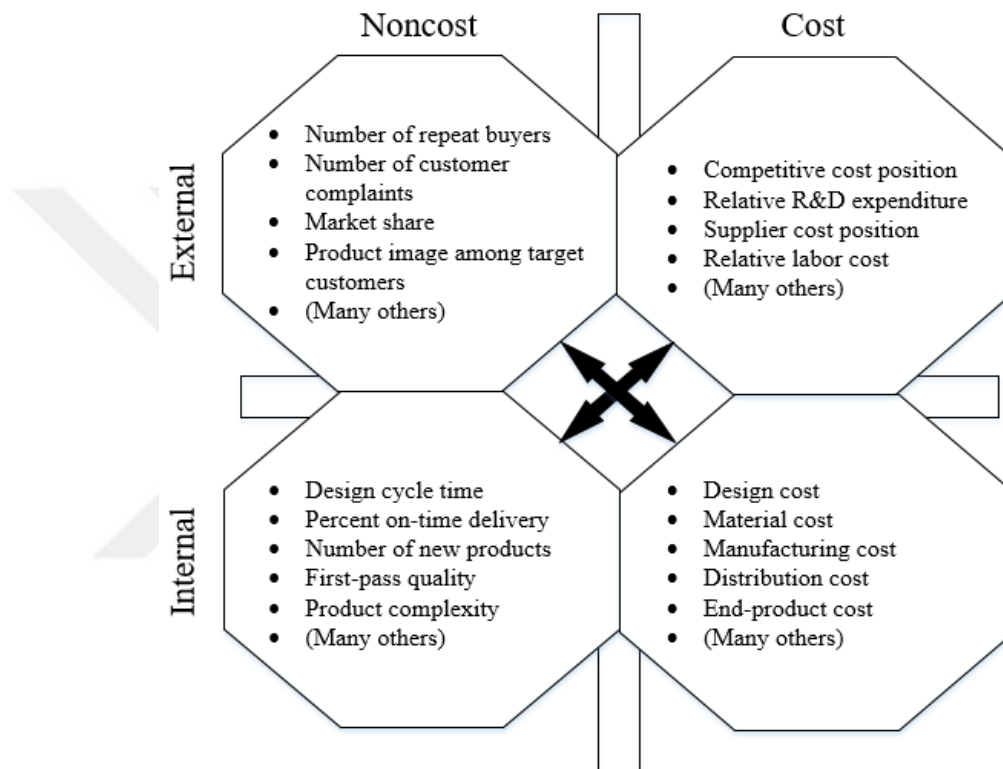


Figure 4.2 The Performance Measurement Matrix (redrawn from Keegan et al., 1989)

Fitzgerald, Johnston, Brignall, Silvestro, & Voss (1991) examine performance measurement from a different perspective by presenting the *Results and Determinants Framework*, comprising six dimensions (i.e. *Competitiveness*, *Financial Performance*, *Quality of Service*, *Flexibility*, *Resource Utilisation*, and *Innovation*) for performance measures divided into two main categories, namely *Results* and *Determinants* (Figure 4.3). The essential point here is that the indicators listed in the *Results* category represent lagging indicators, while the remaining ones (i.e. listed in the *Determinants* category) represent leading indicators.

	Dimensions of performance	Types of measure
Results	Competitiveness	Relative market share and position Sales growth Measures of the customer base
	Financial performance	Profitability Liquidity Capital structure Market ratios
Determinants	Quality of service	Reliability Responsiveness Aesthetics/appearance Cleanliness/tidiness Comfort Friendliness Communication Courtesy Competence Access Availability Security
	Flexibility	Volume flexibility Delivery speed flexibility Specification flexibility
	Resource utilisation	Productivity Efficiency
	Innovation	Performance of the innovation process Performance of individual innovations

Figure 4.3 The Results and Determinants Framework (redrawn from Fitzgerald et al., 1991)

Kaplan & Norton (1992) propose the *Balanced Scorecard*, which enables organizations to measure their performance from four different perspectives, namely *Financial*, *Internal Business*, *Innovation and Learning*, and *Customer* by considering the goals, strategy, and vision of organizations (Figure 4.4). This framework divides the measures into two main categories, namely financial and operational measures. Similar to Fitzgerald et al.'s (1991) framework (Figure 4.3), the measures categorized in the *Financial* perspective can be defined as lagging indicators, while the remaining measures (i.e. operational measures categorized in the *Internal Business*, *Innovation and Learning*, and *Customer* perspectives) can be defined as leading indicators. This framework is also balanced, and this balance is represented by double-headed arrows between every two perspectives to symbolize a recurring process.

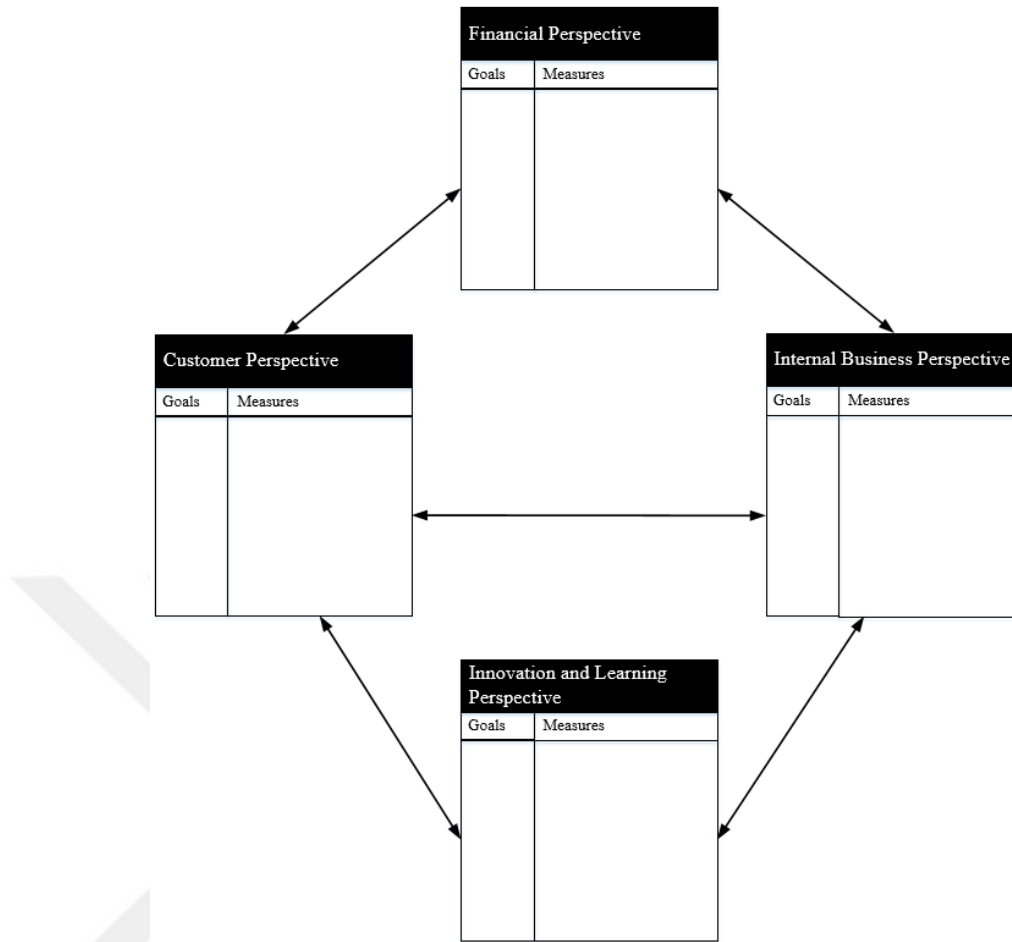


Figure 4.4 The Balanced Scorecard (redrawn from Kaplan & Norton, 1992)

Brown (1996) develop the *Macro Process Model*, which represents a horizontal flow of business processes divided into five phases, namely *Inputs*, *Processing System*, *Outputs*, *Outcomes*, and *Goal* (Figure 4.5). Additionally, there are four types of measures (i.e. input, process, output, and outcome) in this framework. These measures are placed between every two adjacent phases respectively to measure the performance of the related phase in terms of various issues such as satisfaction, financial, operational, safety, environmental, and quality. Similar to Kaplan & Norton's (1992) Balanced Scorecard (Figure 4.4), the Macro Process Model (Figure 4.5) is constituted as a recurring process, meaning that an arrow is depicted wherever a review and feedback is needed in the framework. Accordingly, the *Goal* should be considered in each previous phase, while each measure should be regarded at the beginning of the flow (i.e. first phase).

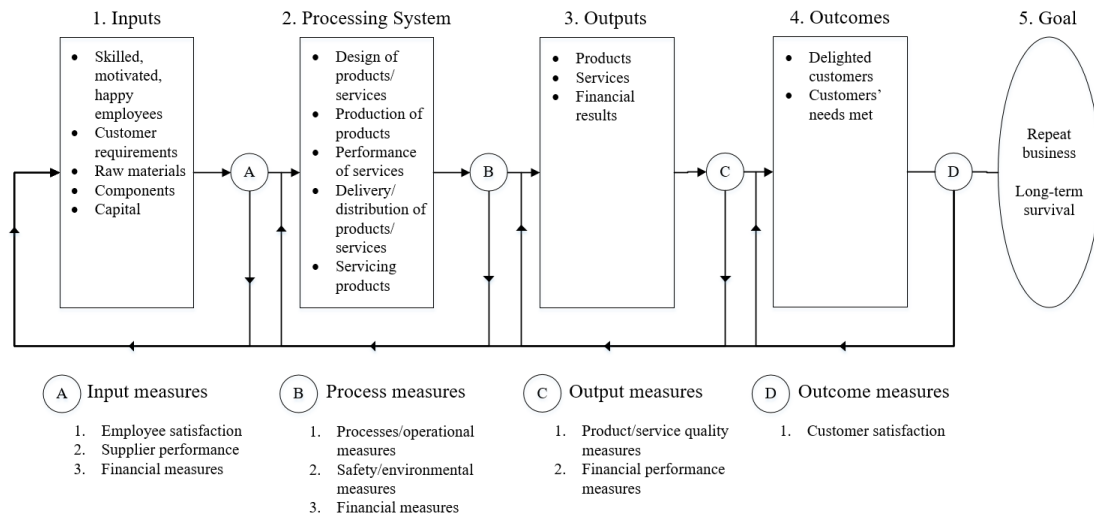


Figure 4.5 The Macro Process Model (redrawn from Brown, 1996)

Neely & Adams (2000) propose a three-dimensional framework that is called the *Performance Prism*, having five facets, namely *Stakeholder Satisfaction* as the top facet, *Stakeholder Contribution* as the bottom facet, and *Strategies*, *Processes* and *Capabilities* as the three side facets (Figure 4.6). This framework includes stakeholders with their satisfaction and contribution in the measurement of performance of business processes through a stakeholder-centric structure, while it focuses on the stakeholders of organizations and the fulfilment of their needs in terms of strategies, processes, and capabilities of organizations.

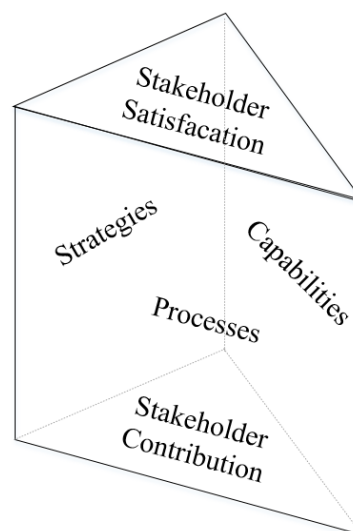


Figure 4.6 The Performance Prism (redrawn from Neely & Adams, 2000)

In addition to the frameworks comprising main structures and components of performance measurement systems, there are some frameworks in the relevant literature that present the fundamental steps of such systems. Wisner & Fawcett's (1991) flow diagram can be given as an example of these frameworks. Similar to the flow in Brown's (1996) Macro Process Model (Figure 4.5), Wisner & Fawcett (1991) present a flow diagram to develop an effective performance measurement system. This framework consists of nine steps, including a company's mission, strategic objectives, functional areas, and performance measures related to the performance measurement system to be developed (Figure 4.7). It should be easily stated that these steps, if properly conducted, can lead a company to achieve a competitive advantage. Similar to Brown's (1996) Macro Process Model (Figure 4.5), this framework also has a recurring process, comprising an arrow from the last step to the first step for providing continuous review and feedback.

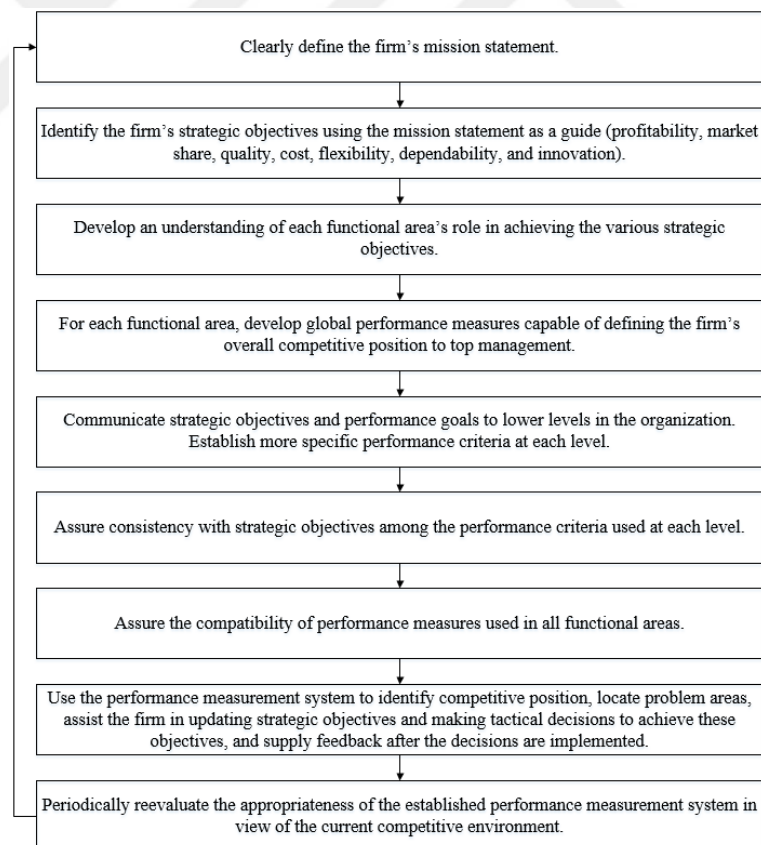


Figure 4.7 The steps to develop and maintain an effective performance measurement system (redrawn from Wisner & Fawcett, 1991)

Bourne et al. (2000) depict the development of a performance measurement system, which is presented below in Figure 4.8, divided into three main phases, namely *Design*, *Implementation*, and *Use*, in terms of the performance measures (i.e. indicators). Additionally, the last phase (i.e. *Use*) is divided into two phases, comprising the use of measures for assessing strategy implementation and for challenging strategic assumptions. Similar to the frameworks presented in Figure 4.4, Figure 4.5, and Figure 4.7, this framework also has a recurring process, comprising arrows from one phase to another wherever is needed for providing continuous review and feedback.

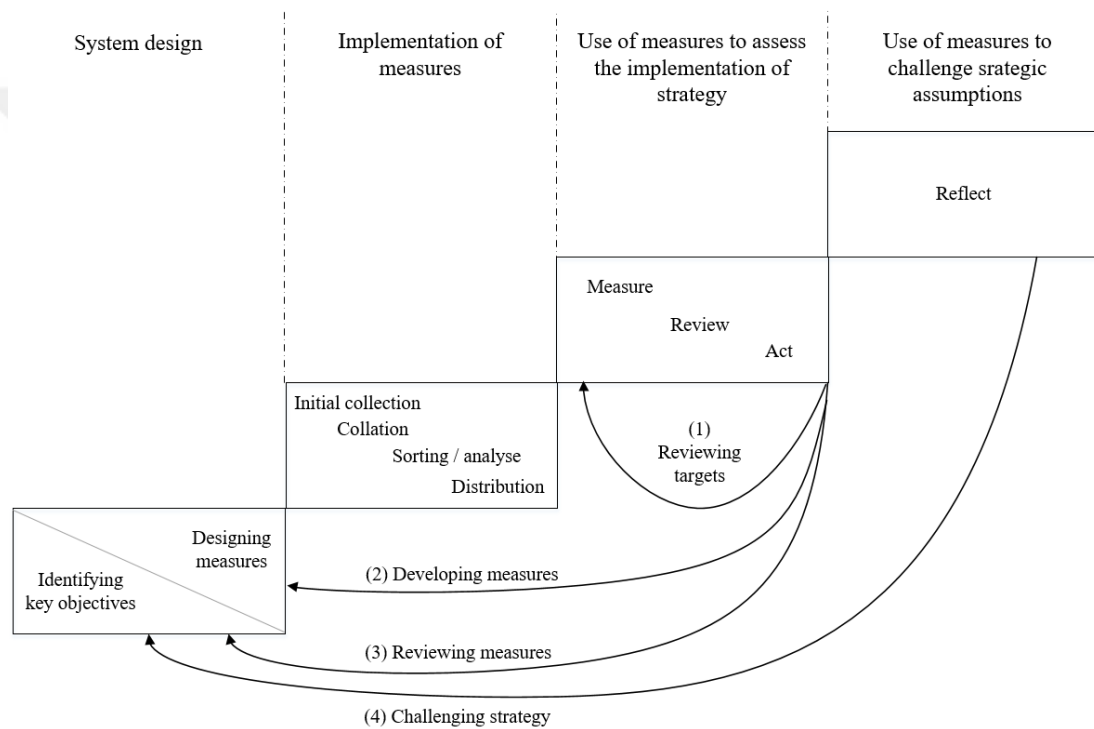


Figure 4.8 The phases of development of a performance measurement system (redrawn from Bourne et al., 2000)

Beyond all these prominent frameworks summarized in this subsection, some of the frameworks proposed for guiding researchers in the literature related to performance measurement are developed through a sustainability point-of-view. Fiksel, McDaniel, & Mendenhall's (1999) generalized framework for performance measurement in a company can be presented as an example of these frameworks. Their framework is presented within three phases, namely *Plan*, *Implement*, and *Review*; and they visualize

these three phases in eleven steps (Figure 4.9). By considering Fiksel et al.'s (1999) framework, it can be indicated that if these eleven steps are implemented properly, a continuous improvement could be achieved.

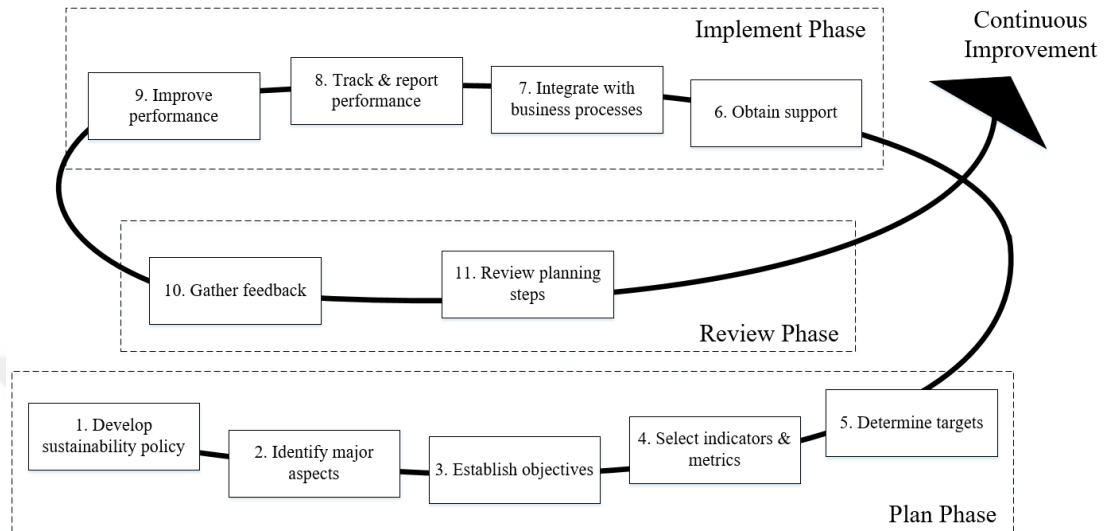


Figure 4.9 The steps to develop a performance measurement system through the sustainability point-of-view (redrawn from Fiksel et al., 1999)

Similar to Fiksel et al.'s (1999) framework (Figure 4.9), Searcy (2011) presents a conceptual framework to structure the evolution of a performance measurement system through a sustainability point-of-view (Figure 4.10). This framework, which is called *Sustainability Performance Measurement System (SPMS)*, also has three phases, namely *Planning*, *Assessment*, and *Follow-Up*, comprising three steps for each. It can be stated that this framework presents guidance on planning, assessing, and updating such a system in organizations.



Figure 4.10 The conceptual framework to structure a sustainability performance measurement system (redrawn from Searcy, 2011)

By considering all these definitions, key issues, and frameworks comprising the main structures and components given in this chapter for presenting a theoretical look at developing a systematic approach of which a performance measurement system is its fundamental part, such an approach to be developed as the result of this thesis is presented in Chapter 8. Before presenting this, in the following chapter, the efforts made for survey development and data collection are presented, comprising problem statement and two surveys designed and developed for this thesis, while research instruments in terms of primary and secondary data for statistical analysis and multi-criteria analysis are also given in this chapter.

CHAPTER FIVE

SURVEY DEVELOPMENT, DATA COLLECTION, AND METHODS

This chapter comprises the problem statement, two surveys designed and developed for this thesis, and research instruments used for the analysis; all represent the efforts made for survey development and data collection.

5.1 Problem Statement

As stated in Chapter 1, *the theoretical background* and accordingly *the original contributions of this thesis* were constituted twofold: Firstly, a structural framework, comprising dimensions, sub-dimensions, and indicators, which were gathered to present the relations between ergonomics and sustainability, for the integration of ergonomics and sustainability was proposed in this thesis as *the first original contribution*. The aim of this first part was to propose a practical and easily adaptable framework for organizations to facilitate having processes satisfying the needs of stakeholders and putting cost-effective as well as environmentally-friendly interventions into practice. Secondly, a systematic approach, comprising a performance measurement system that consists of the proposed ergonomics indicators as the fundamental part of such an approach, by integrating ergonomics and sustainability through the proposed ergonomics indicators for sustainable process performance measurement in ergonomics will be developed in this thesis as *the second original contribution*. The aim of this second part was to propose ergonomics indicators to assist in measuring the performance of processes of organizations in a sustainable way. It was envisaged that these indicators, by systematically monitoring and evaluating processes, will aid the management and prevention of the risks caused by unfavourable working conditions. Then, these indicators were planned to satisfy employees' needs as well as society, monetary, and ecology issues, referring to three dimensions of sustainability (i.e. *Economic, Ecological, and Social*). Essentially, all these efforts are for achieving *the fundamental aim of this thesis*, which was to develop a systematic approach comprising a performance measurement system and its proposed ergonomics indicators as the fundamental part of such an approach that

integrates ergonomics and sustainability to monitor and evaluate processes of organizations holistically. Through this viewpoint, all efforts have been made to accomplish these original contributions, and it should be noted that the research in this thesis was approved by the Ethics Board of Dokuz Eylul University. Consequently, it can be summarized that *the scope of this thesis* is ergonomics, sustainability, and the coherence between the two: By considering ergonomics within a sustainability point-of-view, proposing ergonomics indicators to assist in measuring the performance of processes of organizations as well as developing a systematic approach comprising these indicators as a result of the integration of ergonomics and sustainability.

As ordinarily indicated in all researches, this thesis also has some assumptions and limitations. In this part of this subsection, these are listed respectively. At first, *the assumptions of this thesis* are presented as follows, by considering all phases in the research methodology of this thesis (Figure 1.1):

- The papers published between 2015 and 2020 are selected from the systematic literature review presented in Chapter 3 for further evaluation, justifying the 2030 Agenda. Similarly, the papers published by journals indexed in SCI, SCI-E, or SSCI are selected, justifying academic quality.
- The methods used in the multi-criteria analysis are selected representatively for weighting the consolidated evaluation criteria and prioritizing the proposed ergonomics indicators to be used for the systematic approach.
- All data is deterministic and crisp.
- All primary data gathered from both designed questionnaires is equally weighted (i.e. no weights are assigned to the respondents) for aggregation.
- The significance level (i.e. alpha) is selected 0.05 for all statistical analysis.
- All criteria and alternatives in the multi-criteria analysis are predefined, and there are a finite set of criteria and a finite set of alternatives.
- All respondents of Survey-1 act together as a unit due to having the same viewpoint through the clearly explained aims of the survey and having similar specializations and competence in ergonomics and sustainability. This is also

the same for all respondents of Survey-2, except for the aggregation of weights of evaluation criteria due to the data collection principle of the method used.

- The weights of the evaluation criteria in the multi-criteria analysis are unique.
- There is no interaction between criteria as well as between alternatives.

Subsequently, *the limitations of this thesis* are presented as follows within three parts, considering all phases in the research methodology of this thesis (Figure 1.1):

- *For the proposal of ergonomics indicators:* Despite comprehensive and attentive literature review through selected online databases, some related papers may not be included due to used search terms, selected online databases and their limitations. Additionally, the papers not written in English, not have accessible full-text, published before 2015, published by journals not indexed in SCI, SCI-E, or SSCI, and not present any indicators as well as only having indices or any aggregated forms of indicators are excluded. Grey publications (e.g. conference proceedings, dissertations, working papers, and technical reports) and also books and book chapters are other limitations of this thesis.
- *For surveys:* Although all voluntary respondents (i.e. the researchers from universities in different countries and the practitioners working in companies in Turkey) of both surveys are invited after a detailed and careful investigation and comprehensive meetings, the results of this thesis are limited to their opinions (i.e. responses) gathered through the questionnaires designed for this thesis. Additionally, the companies accepted to participate in the survey voluntarily are other limitations of this thesis.
- *For the methods used in multi-criteria analysis:* Due to the suitability of the method with the data and problem statement of this thesis, BWM and PROMETHEE are selected as examples for weighting the consolidated evaluation criteria and prioritizing the proposed ergonomics indicators to be used for the systematic approach. The results, i.e., the prioritized indicators, are limited to these methods, while their parameters are also another limitation. Different methods through different parameters may provide to decide on using different ergonomics indicators to be used for such a systematic approach.

5.2 Questionnaire Design

As presented in Section 1.3, two surveys, i.e., Survey-1 and Survey-2, were designed and developed for the validity and reliability of the implementation in this thesis, respectively. The aims of these surveys are noted here to remind, as stated in Chapter 1: *The aim of the Survey-1* is to determine the appropriateness of the ergonomics indicators proposed through a comprehensive literature review as fundamental components of a systematic approach integrating ergonomics and sustainability. Accordingly, *the aim of the Survey-2* is to measure the perception of the applicability of a systematic approach comprising a performance measurement system as the fundamental part of such an approach that integrates ergonomics and sustainability to monitor and evaluate processes of organizations holistically. In the following paragraphs, these two terms, i.e., validity and reliability, are explained by associating with the aims and structures of the surveys designed and developed for this thesis, and detailed explanations for these surveys are given immediately after.

The *validity* here refers to the determination of the appropriateness of the proposed ergonomics indicators by considering the opinions of experts, who are researchers and practitioners specialized in ergonomics and sustainability. In a general manner, Trochim & Donnelly (2006) indicate that validity is the “best available approximation to the truth of a given proposition, inference, or conclusion” (p. 20). More specifically, Hair, Black, Babin, & Anderson (2014) define validity as the “extent to which a measure or set of measures correctly represents the concept of study” (p. 3). By considering these definitions, it is aimed that the accuracy of the systematic approach comprising the performance measurement system and its proposed ergonomics indicators will be presented through this viewpoint.

On the other hand, the *reliability* here refers to the perception measurement on the applicability of a systematic approach, comprising these proposed ergonomics indicators, that integrates ergonomics and sustainability in companies by considering the opinions of practitioners, who are specialized in ergonomics and sustainability and are potential users of such an approach. Similarly, Hair et al. (2014) define reliability

as the “extent to which a variable or set of variables is consistent in what it is intended to measure” (p. 2). Trochim & Donnelly (2006) support this definition by indicating that the term reliability corresponds to the consistency or repeatability of measures, meaning that similar results can be obtained from a reliable measure. By considering these definitions, it is aimed that the consistency of the systematic approach comprising the performance measurement system and its proposed ergonomics indicators will be presented through this viewpoint.

In short, validity and reliability form a continuum rather than being distinct (Trochim & Donnelly, 2006). Accordingly, Hair et al. (2014) summarize these two terms by highlighting that validity is related to *what* is being measured (i.e. how well the measures define the concept), while reliability deals with *how* it is measured (i.e. consistency of the measures). As stated before, the *what* part (i.e. validity) of this thesis will be met by asking the appropriateness of the twenty-five ergonomics indicators proposed in this thesis to the experts specialized in ergonomics and sustainability. Subsequently, the *how* part (i.e. reliability) of this thesis will be met by asking the evaluation of these indicators through five evaluation criteria consolidated for this thesis to the practitioners, who are specialized in ergonomics and sustainability and are potential users of such an approach. Hence, measuring the perception of the applicability of a systematic approach, comprising these proposed ergonomics indicators in a performance measurement system, can be achieved.

By considering all, the two surveys, i.e., Survey-1 and Survey-2, comprising the questionnaires designed for this thesis, are presented in detail in the following subsections, respectively. It should be underlined that, besides collecting data for statistical analysis, these surveys assist in collecting data for the hybrid multi-criteria analysis, which enables presenting the prioritization of the proposed ergonomics indicators to be used for the systematic approach as examples.

5.2.1 The Designed Questionnaire for Survey-1

This survey represents the third phase, *Implementation for Validity*, of the research methodology of this thesis in Figure 1.1. As highlighted before, the target group of this survey is the experts on ergonomics and sustainability, who are researchers and practitioners in these areas. To invite the most experienced potential respondents relevant to ergonomics and sustainability, an attentive work was carried out in this thesis: A detailed and careful investigation was made for inviting the researchers from universities in different countries, while comprehensive meetings were made with executives in companies in Turkey for inviting the practitioners.

Through a more detailed look, it can be stated that the invitation of the experts to the survey was divided into two parts: The first part comprises the invitation of the researchers from universities in different countries and continents. These experts have many papers in ergonomics and sustainability research areas, and these papers are the prominent ones by considering their citation and download counts. The second part comprises the invitation of the practitioners in Turkey. These experts are white-collar employees, who are specialized in ergonomics and sustainability and have various projects in these areas.

Since the aim of this survey is to determine the appropriateness of the ergonomics indicators proposed in this thesis, all respondents were informed about the meaning of *appropriateness* and were kindly expected to consider that meaning during their evaluations. It was highlighted that the appropriateness in this survey comprises adequacy, comprehensiveness, representativeness, and comprehensibility. The questionnaire was accessible for four weeks, and a reminder was sent out after two weeks to increase the number of respondents.

In the following part of this subsection, detailed explanations on the designed questionnaire for Survey-1 are presented by considering its three parts, namely *Respondents' Information*, *Ergonomics Indicators*, and *General Evaluation*, constituted for this thesis.

- *First part of the questionnaire (Respondents' Information):* Since potential respondents may have some concerns about the confidentiality of their personal information (e.g. age, gender, education level, and country), which may lead to a decrease in the response rate of the survey, only the *expertise level* was asked in this part of the designed questionnaire. The expertise level here refers to the experience in ergonomics and sustainability areas (years).
- *Second part of the questionnaire (Ergonomics Indicators):* All twenty-five ergonomics indicators, which were proposed through a comprehensive literature review as fundamental components of a systematic approach integrating ergonomics and sustainability, were put in a questionnaire through designed close-ended questions. Respondents were asked to evaluate these ergonomics indicators through a 7-points Likert-type scale. The questions in this designed questionnaire, comprising the proposed ergonomics indicators, were ordered arbitrarily to achieve randomness between their classifications in terms of main dimensions and proposed sub-dimensions in the three-dimensional structure (Figure 3.4) and indicator type (Table 3.2). This design enabled a respondent to present a more objective evaluation on indicators by having no idea on neither which indicators are classified together nor which indicators are classified under which main dimensions and proposed sub-dimensions.
- *Final part of the questionnaire (General Evaluation):* This part consists of one optional question that allows respondents to write their comments and suggestions related to the survey.

5.2.2 The Designed Questionnaire for Survey-2

This survey represents the fourth phase, *Implementation for Reliability*, of the research methodology of this thesis in Figure 1.1. As highlighted before, the target group of this survey is the practitioners in companies in Turkey, who are specialized in ergonomics and sustainability and are potential users of the systematic approach, comprising the proposed ergonomics indicators, that integrates ergonomics and sustainability in companies. Additionally, these potential respondents are the white-

collar employees (i.e. senior managers, department managers, or employees working in various departments) in companies. To invite the potential respondents most relevant to ergonomics and sustainability, an attentive work was carried out in this thesis, similar to Survey-1's: At first, companies having employees with the qualifications specified for the survey were investigated. Then, comprehensive meetings were made with executives in these companies for inviting the practitioners.

Since the aim of this survey is to measure the perception of the applicability of the systematic approach comprising the ergonomics indicators proposed in this thesis, the questionnaire was designed for enabling the evaluation of the proposed ergonomics indicators through a multi-criteria perspective. This perspective includes the criteria consolidated for the evaluation of an indicator after a comprehensive literature review in this thesis. The details of these evaluation criteria, which are *Measurability*, *Reliability*, *Resilience*, *Proactiveness*, and *Policy Relevance* are given in the following part of this subsection. Accordingly, all respondents were informed about the meanings of these criteria and were kindly expected to consider those meanings during their evaluations. The questionnaire was accessible for twelve weeks, and several reminders were sent out during this period to increase the number of respondents.

Similar to Section 5.2.1, in the following part of this subsection, detailed explanations on the designed questionnaire for Survey-2 are presented by considering its four parts, namely *Respondents' Information*, *Evaluation Criteria*, *Ergonomics Indicators*, and *General Evaluation*, constituted for this thesis.

- *First part of the questionnaire (Respondents' Information):* Age, gender, education level, department, expertise level, and knowledge level, as personal information, were asked in this part of the designed questionnaire. This information provides independent variables for the survey, and the ones related to the research were used for the statistical analysis by gathering the primary data from the questionnaire. Since confidentiality protocols were made at the request of the companies, the data gathered from this part will be presented in Chapter 6 in aggregated forms to protect their confidentiality.

- *Second part of the questionnaire (Evaluation Criteria):* As highlighted before, this part comprises the five evaluation criteria, namely *Measurability*, *Reliability*, *Resilience*, *Proactiveness*, and *Policy Relevance*. These criteria were consolidated by reviewing many prominent studies in sustainability and indicator development. The details of these criteria are summarized in Table 5.1 below. It should be noted that the meanings of the five evaluation criteria defined through the consolidation of the subcriteria listed in Table 5.1 were indicated in this part of the designed questionnaire to inform respondents. Subsequently, respondents were asked the designed close-ended questions to evaluate these criteria through a scale from 1 (i.e. equally important) to 9 (i.e. extremely more important) for weighting. This part enables respondents to determine the weights of the criteria for use in the multi-criteria analysis.

Table 5.1 The evaluation criteria consolidated for this thesis with the subcriteria they comprise

Criterion	Reference	Subcriterion	Reference
Measurability	Bonisoli, Galdeano-Gómez, & Piedra-Muñoz (2018), Dhakal & Imura (2003), Erol et al. (2009), Joung et al. (2012), Lockie, Lawrence, Dale, & Taylor (2002), Pires, Morato, Peixoto, Bradley, & Muller (2020), Roy & Chan (2012)	Timeliness	Guy & Kibert (1998), Joung et al. (2012), Pires et al. (2020)
		Data Accessibility	Joung et al. (2012)
		Data Availability	Bonisoli et al. (2018), Booyesen (2002), Erol et al. (2009), Guy & Kibert (1998), Pires et al. (2020), Roy & Chan (2012), Singh, Murty, Gupta, & Dikshit (2012)
		Cost-Effectiveness	Erol et al. (2009), Pires et al. (2020), Qiu, Zhu, Wang, & Cheng (2007), Roy & Chan (2012), Tanzil & Beloff (2006)
		Clarity	Booyesen (2002), La Rovere et al. (2010), Singh et al. (2012)
		Simplicity	Aveline, Rousseau, Guichard, Laurent, & Bockstaller (2009), Booyesen (2002), Dhakal & Imura (2003), Kurka & Blackwood (2013), La Rovere et al. (2010), Lockie et al. (2002), Pires et al. (2020), Qiu et al. (2007), Singh et al. (2012), Tanzil & Beloff (2006)
		Usefulness	Aveline et al. (2009), Pires et al. (2020), Tanzil & Beloff (2006)
Reliability	Bringhenti, Zandonade, & Günther (2011), Erol et al. (2009), Guy & Kibert (1998), Joung et al. (2012), Kurka & Blackwood (2013), La Rovere et al. (2010), López-Ridaura, Masera, & Astier (2002), Pires et al. (2020)	Validity	Bonisoli et al. (2018), Bringhenti et al. (2011), Erol et al. (2009), Guy & Kibert (1998), La Rovere et al. (2010)
		Accuracy	Fraser, Dougill, Mabee, Reed, & McAlpine (2006), Pires et al. (2020)
		Relevance	Bonisoli et al. (2018), Joung et al. (2012), Kurka & Blackwood (2013), La Rovere et al. (2010), Lockie et al. (2002), Pires et al. (2020), Tan, Yeo, Ng, Tjandra, & Song (2015)
Resilience	López-Ridaura et al. (2002), López-Ridaura, Van Keulen, Van Ittersum, & Leffelaar (2005)	Flexibility	Aveline et al. (2009), Bonisoli et al. (2018), Booyesen (2002), Dhakal & Imura (2003), Guy & Kibert (1998), Pires et al. (2020), Singh et al. (2012)
		Sensitivity	Aveline et al. (2009), La Rovere et al. (2010), Meul et al. (2008), Pires et al. (2020)
		Adaptability	Bossel (2000), López-Ridaura et al. (2002)
		Responsiveness	Guy & Kibert (1998)
		Applicability	Tan et al. (2015), Zhen et al. (2005)
Proactiveness	Erol et al. (2009), Guy & Kibert (1998)	Timeliness	Lockie et al. (2002)
		Predictability	Pires et al. (2020), Qiu et al. (2007)
Policy Relevance	Bonisoli et al. (2018), Erol et al. (2009), Guy & Kibert (1998)	Complementarity	Tanzil & Beloff (2006)
		Connectedness	Pupphachai & Zuidema (2017)

- *Third part of the questionnaire (Ergonomics Indicators):* This part comprises the twenty-three ergonomics indicators proposed in this thesis and the evaluations on these indicators through the five evaluation criteria presented in the second part. The appropriateness of these indicators was validated by the experts on ergonomics and sustainability through Survey-1. The evaluations in this part provide dependent variables for the survey, and they can be used for both statistical analysis and multi-criteria analysis by gathering the primary and secondary data from the questionnaire, respectively. Respondents were asked to evaluate these ergonomics indicators in terms of the evaluation criteria through a 7-points Likert-type scale for prioritization. Similar to Survey-1, these indicators were put in a questionnaire through designed close-ended questions that were ordered arbitrarily to achieve randomness between the classifications of these indicators and enable a respondent to present a more objective evaluation on indicators.
- *Final part of the questionnaire (General Evaluation):* This part consists of two questions querying the evaluation of the indicators proposed in this thesis as a whole; respondents were asked to evaluate the survey through a 7-points Likert-type scale. Additionally, in this part, there are two optional questions that allow respondents to write their comments and suggestions for improving the developed systematic approach.

5.3 Research Instruments

Fundamentally, the research instruments of this thesis are divided into two parts by considering the data type gathered from two questionnaires designed for this thesis: The first part is the statistical analysis, and the second part is the multi-criteria analysis. The analysis was conducted using the primary and secondary data, respectively. To introduce the close-ended questions designed for this thesis and the methods used for the hybrid multi-criteria analysis, the explanations are given in the following parts of this subsection.

5.3.1 Primary Data for Statistical Analysis

Various statistical tests, whose results will be presented in the next chapter, were performed through the primary data to interpret the characteristics of these data. In this subsection, the types of closed-ended questions designed for Survey-1 and Survey-2 are presented as one of the research instruments of this thesis. Accordingly, the primary data gathered from these questions enables performing the statistical tests.

As stated before, Survey-1 is for determining the appropriateness of the ergonomics indicators proposed in this thesis. From this viewpoint, the questions comprising these indicators in Survey-1 were designed using a 7-points Likert-type scale by considering the response anchors called *Level of Appropriateness* (i.e. 1–Absolutely inappropriate, 2–Inappropriate, 3–Slightly inappropriate, 4–Neutral, 5–Slightly appropriate, 6–Appropriate, 7–Absolutely appropriate) (Vagias, 2006). Similarly, Survey-2 is for measuring the perception of the applicability of the systematic approach comprising the ergonomics indicators proposed in this thesis. In this regard, the preferred 7-points Likert-type scale in Survey-2 comprises the response anchors called *Level of Agreement* (i.e. 1–Strongly disagree, 2–Disagree, 3–Somewhat disagree, 4–Neither agree or disagree, 5–Somewhat agree, 6–Agree, 7–Strongly agree) (Vagias, 2006). It should be underlined that a 7-points scale provides optimal reliability, and the preference to use a scale that more than 7-points does not provide a sufficient increase in reliability to be worth these efforts (Croasmun & Ostrom, 2011; Symonds, 1924).

The reason for the preference of Likert-type scales for the surveys designed and developed for this thesis can be clarified through the definition of Likert-type scales: Likert-type scales comprises single questions that have original Likert response options (Boone & Boone, 2012; Clason & Dormody, 1994). Contrary to Likert scales, the researcher does not attempt to combine the series of individual questions, designed as Likert-type scales in the research instrument, into a composite scale (Boone & Boone, 2012). Similarly, if the researcher's primary interest is not to synthesize respondents' attitudes but to capture their actions and feelings on the study, this requires the individual analysis of questions through using the Likert-type scale to find

out the respondents' collective degree of agreement (Boone & Boone, 2012; Joshi, Kale, Chandel, & Pal, 2015). On the other hand, a latent (i.e. underlying) variable representing the respondents' opinions and attitudes exists in Likert scales (Clason & Dormody, 1994; Joshi et al., 2015). Since these two surveys comprise individual questions related to the proposed ergonomics indicators and there is no latent variable defined to be measured through the gathered data, the Likert-type scale was preferred for use in these surveys. It should be noted here that the combined results are planned to be achieved through multi-criteria analysis (Phase 5 in Figure 1.1).

5.3.2 Secondary Data for Multi-Criteria Analysis

Two methods, whose results will be presented in the next chapter, were performed through the secondary data to perform a hybrid multi-criteria analysis. In this subsection, the theoretical backgrounds of these methods are presented as another research instrument of this thesis. Accordingly, the secondary data obtained from aggregation enables presenting a base study as an example for prioritizing the proposed ergonomics indicators to be used for the systematic approach.

5.3.2.1 Best-Worst Method (BWM)

BWM (Rezaei, 2015, 2016) was used in this thesis to determine the weights of the consolidated evaluation criteria to be used for multi-criteria analysis. BWM is a multi-criteria decision making (MCDM) method deriving the weights by using the pairwise comparisons of the best and worst criteria with others (Rezaei, 2015). This enables using fewer pairwise comparisons comparatively to the other MCDM methods such as Analytic Hierarchy Process (AHP); therefore, BWM not only needs less data, but also achieves more consistent solutions (Rezaei, 2015, 2016). Other reasons for using this method are the ability to be combined with other MCDM methods and the ease of its use by scoring with only integers (Rezaei, 2015).

As presented in the assumptions of this thesis listed in Section 5.1, Rezaei's (2016) linear model providing a unique solution for criteria weights was used in this thesis.

The reason for this preference is that Rezaei's (2015) original model provides multiple optimal solutions due to its non-linearity, but a unique solution is required in this thesis. Through these weights gathered uniquely, the prioritization of the proposed ergonomics indicators to be used for the systematic approach as examples can be achieved.

Despite being a new method, many researchers prefer using BWM for their studies, and these studies have various application areas such as *technology* (Ren, Liang, & Chan, 2017; Van De Kaa, Janssen, & Rezaei, 2018), *manufacturing* (Malek & Desai, 2019; Moktadir, Ali, Kusi-Sarpong, & Shaikh, 2018), *energy* (Van De Kaa, Fens, & Rezaei, 2019; Van De Kaa, Kamp, & Rezaei, 2017; You, Guo, Zhao, & Zhao, 2017), *supply chain* (Ahmadi, Kusi-Sarpong, & Rezaei, 2017; Kusi-Sarpong, Gupta, & Sarkis, 2019; Rezaei & Lajimi, 2019; Rezaei, Wang, & Tavasszy, 2015; Wan Ahmad, Rezaei, Sadaghiani, & Tavasszy, 2017), *transportation* (Groenendijk, Rezaei, & Correia, 2018; Rezaei, Van Wulfften Palthe, Tavasszy, Wiegmans, & Van Der Laan, 2019), *performance* (Dwivedi et al., 2021; Salimi & Rezaei, 2018), and *service* (Gupta, 2018; Rezaei, Kothadiya, Tavasszy, & Kroesen, 2018).

Finally, in this subsection, the steps of BWM are presented as follows (Rezaei, 2015, 2016). Before this, it should be considered here that BWM is based on pairwise comparisons between criteria, and the relative preference of criterion i to criterion j is represented by a_{ij} in this regard (Rezaei, 2015).

- *Step 1:* Determination of a set of decision criteria $\{c_1, c_2, \dots, c_n\}$, where n is the number of criteria that the decision-maker uses to make a decision.
- *Step 2:* Determination of the best (i.e. most desirable, most important) and the worst (i.e. least desirable, least important) criterion among the criteria determined in Step 1.
- *Step 3:* Determination of the preference of the best criterion determined in Step 2 over all the other criteria determined in Step 1 through a 9-points scale of 1

to 9, where 1 means equally important and 9 means extremely more important. The Best-to-Others (BO) vector, which is the result of these pairwise comparisons, is as follows: $A_B = (a_{B1}, a_{B2}, \dots, a_{Bn})$, where a_{Bj} represents the preference of the best criterion B over criterion j , and $a_{BB} = 1$.

- *Step 4:* Determination of the preference of all the other criteria determined in Step 1 over the worst criterion determined in Step 2 through a 9-points scale of 1 to 9, where 1 means equally important and 9 means extremely more important. The Others-to-Worst (OW) vector, which is the result of these pairwise comparisons, is as follows: $A_W = (a_{1W}, a_{2W}, \dots, a_{nW})^T$, where a_{jW} represents the preference of criterion j over the worst criterion W , and $a_{WW} = 1$.
- *Step 5:* Calculation of the optimal weights of the criteria $(w_1^*, w_2^*, \dots, w_n^*)$ by minimizing the maximum absolute differences $\{|w_B - a_{Bj}w_j|, |w_j - a_{jW}w_W|\}$ for all j , or equivalently:

$$\begin{aligned}
 & \min \max_j \{|w_B - a_{Bj}w_j|, |w_j - a_{jW}w_W|\} \\
 & \text{s.t.} \\
 & \sum_j w_j = 1 \\
 & w_j \geq 0, \text{ for all } j
 \end{aligned} \tag{5.1}$$

By transferring Model (5.1) to the following linear programming model, it can be solved enabling having a unique solution:

$$\begin{aligned}
 & \min \zeta^L \\
 & \text{s.t.} \\
 & |w_B - a_{Bj}w_j| \leq \zeta^L, \text{ for all } j \\
 & |w_j - a_{jW}w_W| \leq \zeta^L, \text{ for all } j \\
 & \sum_j w_j = 1 \\
 & w_j \geq 0, \text{ for all } j
 \end{aligned} \tag{5.2}$$

Solving Model (5.2) results in optimal weights of the criteria ($w_1^*, w_2^*, \dots, w_n^*$) and the optimal objective function value ζ^L . Rezaei (2016) defines ζ^L as “an indicator of the consistency of the comparisons” (p. 130) of the linear model (5.2), and it represents a high level of consistency when its value closes to zero. Later, for evaluating the consistency, Liang, Brunelli, & Rezaei (2020) define the input-based consistency ratio (CR^I), which is formulated as follows:

$$CR^I = \max_j CR_j^I, \text{ where } CR_j^I = \begin{cases} \frac{|a_{Bj} \times a_{jW} - a_{BW}|}{a_{BW} \times a_{BW} - a_{BW}} & a_{BW} > 1 \\ 0 & a_{BW} = 1 \end{cases} \quad (5.3)$$

In Formula (5.3), CR^I represents the global input-based consistency ratio for all criteria, while CR_j^I is the local consistency level associated with criterion C_j . Liang et al. (2020) also present consistency thresholds to check CR^I values, indicating that the CR^I value is acceptable when its value is lower than the threshold determined by considering the number of the criteria of the problem and the extent of the evaluation grades that the decision-maker identifies.

5.3.2.2. Preference Ranking Organization METHod for Enrichment Evaluations (PROMETHEE)

PROMETHEE (Brans, 1982; Brans & Vincke, 1985; Brans, Vincke, & Mareschal, 1986) was used in this thesis to prioritize the proposed ergonomics indicators to be used for the systematic approach. PROMETHEE is an outranking method, which is basically one of the categories of the MCDM methods (Brans & De Smet, 2016), to rank and select a finite set of alternatives among criteria that are generally conflicting (Behzadian, Kazemzadeh, Albadvi, & Aghdasi, 2010). It should be highlighted that, as Al-Rashdan, Al-Kloub, Dean, & Al-Shemmeri (1999) observes, there is a tendency about outranking methods being the most successful category of the MCDM methods due to being adaptable to real-world problems and being more easily comprehended by decision-makers.

The prominent features of PROMETHEE are clearness, simplicity, and stability (Brans et al., 1986). Comparatively to the other MCDM methods in application and conception, PROMETHEE is a quite simple ranking method (Brans et al., 1986; Behzadian et al., 2010). Additionally, PROMETHEE, which is defined as an interactive MCDM approach, has the ability to handle both qualitative and quantitative criteria (Maity & Chakraborty, 2015).

Other reasons for using this method in this thesis can be clarified as follows: The friendliness of use and its mathematical properties bring PROMETHEE success that is a significant number of successful applications was achieved through this method (Brans & De Smet, 2016). Additionally, this method needs quite clear additional information (e.g. weights, thresholds, and preferences), which are understood and defined easily (Brans & De Smet, 2016). Brans et al. (1986) present that some small deviations in determining these parameters generally do not cause important modifications of the rankings obtained from the method. As another superiority of the method, decision-makers can determine preference function for each criterion separately in PROMETHEE; hence, this enables each criterion to evaluate on a different basis and making better decisions (Balali, Zahraie, & Roozbahani, 2014).

PROMETHEE has been widely used to solve MCDM problems for decades, whose application areas are very diversified such as *water resources* (Mutikanga, Sharma, & Vairavamoorthy, 2011; Simon, Brüggemann, & Pudenz, 2004), *energy* (Andreopoulou, Koliouka, Galariotis, & Zopounidis, 2018; Cavallaro, 2009; Doukas, Patlitzianas, & Psarras, 2006; Topcu & Ulengin, 2004), *supply chain* (Abdullah, Chan, & Afshari, 2019; Dulmin & Mininno, 2003; Safari, Fagheyi, Ahangari, & Fathi, 2012; Wang & Yang, 2007), *health care* (Amaral & Costa, 2014), *finance* (Albadvi, Chaharsooghi, & Esfahanipour, 2007; Bouri, Martel, & Chabchoub, 2002; Hababou & Martel, 1998), *construction* (Balali et al., 2014; Morkunaite, Podvezko, Zavadskas, & Bausys, 2019; Polat, 2016), *manufacturing* (Anand & Kodali, 2008; Govindan, Kannan, & Shankar, 2015; Maity & Chakraborty, 2015; Vinodh & Girubha, 2012), *mining* (Abedi, Torabi, Norouzi, Hamzeh, & Elyasi, 2012; Balusa & Singam, 2018; Bogdanovic, Nikolic, & Ilic, 2012), *environment* (Al-Rashdan et al., 1999; Kapepula,

Colson, Sabri, & Thonart, 2007; Vego, Kučar-Dragičević, & Koprivanac, 2008), and *tourism* (Lopes, Muñoz, & Alarcón-Urbistondo, 2018).

Finally, in this subsection, the steps of PROMETHEE are presented as follows, comprising PROMETHEE I (partial ranking) and PROMETHEE II (complete ranking) (Brans & De Smet, 2016). Before this, it should be noted here that, as Brans & De Smet (2016) state, PROMETHEE considers a multi-criteria problem such as $\max \{g_1(a), g_2(a), \dots, g_i(a), \dots, g_k(a) \mid a \in A\}$, where A is a finite set of possible alternatives $\{a_1, a_2, \dots, a_i, \dots, a_n\}$ and $\{g_1(\cdot), g_2(\cdot), \dots, g_j(\cdot), \dots, g_k(\cdot)\}$ a set of evaluation criteria, and the problem has a basic data comprising an evaluation table in Table 5.2 below:

Table 5.2 The evaluation table of PROMETHEE (Brans & De Smet, 2016)

a	$g_1(\cdot)$	$g_2(\cdot)$	...	$g_j(\cdot)$	...	$g_k(\cdot)$
a_1	$g_1(a_1)$	$g_2(a_1)$	...	$g_j(a_1)$	...	$g_k(a_1)$
a_2	$g_1(a_2)$	$g_2(a_2)$	...	$g_j(a_2)$	...	$g_k(a_2)$
...	...	...	...	...	...	...
a_i	$g_1(a_i)$	$g_2(a_i)$	...	$g_j(a_i)$	...	$g_k(a_i)$
...	...	...	...	...	...	...
a_n	$g_1(a_n)$	$g_2(a_n)$	...	$g_j(a_n)$	...	$g_k(a_n)$

- *Step 1:* Calculation of the deviations between pairs of alternatives within each criterion using Formula (5.4) below, where $d_j(a,b)$ represents the deviation between alternative a and alternative b for all j :

$$d_j(a,b) = g_j(a) - g_j(b) \quad (5.4)$$

- *Step 2:* Calculation of the preference functions between pairs of alternatives within each criterion using Formula (5.5) below, where $P_j(a,b)$ represents the preference of alternative a over alternative b for the deviations between their evaluations on criterion $g_j(\cdot)$ in case of criteria to be maximized:

$$P_j(a,b) = F_j[d_j(a,b)] \quad \forall a,b \in A \quad , \quad \text{for which} \quad 0 \leq P_j(a,b) \leq 1 \quad (5.5)$$

Here, $F_j[.]$ represents the type of preference functions for criterion $g_j(.)$. In PROMETHEE, there are six types of preference functions that the decision-maker can use by defining the relevant parameters that are q (i.e. indifference threshold), p (i.e. strict preference threshold), and s (i.e. an intermediate value between q and p). Brans & De Smet (2016) define these thresholds as “The q indifference threshold is the largest deviation which is considered as negligible by the decision maker, while the p preference threshold is the smallest deviation which is considered as sufficient to generate a full preference.” (p. 194). It should be noted that Formula (5.5) can be given by $P_j(a,b) = F_j[-d_j(a,b)]$ in case of criteria to be minimized.

- *Step 3:* Calculation of the aggregated preference indices between pairs of alternatives within all criteria using Formula (5.6) below, where w_j represents the weights of relative importance of the different criteria, satisfying that $\sum_{j=1}^k w_j = 1$:

$$\begin{cases} \pi(a,b) = \sum_{j=1}^k P_j(a,b)w_j \\ \pi(b,a) = \sum_{j=1}^k P_j(b,a)w_j \end{cases} \quad \forall a,b \in A \quad (5.6)$$

Here, $\pi(a,b)$ represents the degree that alternative a is preferred to alternative b over all the criteria, and $\pi(b,a)$ similarly represents the degree that alternative b is preferred to alternative a . Since a is better than b for some criteria and contrarily b is better than a , $\pi(a,b)$ and $\pi(b,a)$ are generally positive, holding the following properties for all $(a, b) \in A$:

$$\begin{cases} \pi(a,a) = 0 \\ 0 \leq \pi(a,b) \leq 1 \\ 0 \leq \pi(b,a) \leq 1 \\ 0 \leq \pi(a,b) + \pi(b,a) \leq 1 \end{cases} \quad (5.7)$$

It can be stated that:

$$\begin{cases} \pi(a,b) \sim 0 \text{ implies a weak global preference of } a \text{ over } b \\ \pi(a,b) \sim 1 \text{ implies a strong global preference of } a \text{ over } b \end{cases} \quad (5.8)$$

- *Step 4:* Calculation of the positive and negative outranking flows for each alternative a using Formula (5.9) and Formula (5.10) below:

$$\Phi^+(a) = \frac{1}{n-1} \sum_{x \in A} \pi(a,x) \quad (5.9)$$

$$\Phi^-(a) = \frac{1}{n-1} \sum_{x \in A} \pi(x,a) \quad (5.10)$$

Here, the positive outranking flow given in Formula (5.9) represents how alternative a outranks all the other alternatives, representing its power. The higher $\Phi^+(a)$, the better the alternative. Similarly, the negative outranking flow given in Formula (5.10) represents how alternative a is outranked by all the other alternatives, representing its weakness. The lower $\Phi^-(a)$, the better the alternative. It should be highlighted that the PROMETHEE I (partial ranking) is the result of these positive and negative outranking flows, given as follows:

$$\begin{cases} aP^I b & \text{iff} & \begin{cases} \Phi^+(a) > \Phi^+(b) \text{ and } \Phi^-(a) < \Phi^-(b), \text{ or} \\ \Phi^+(a) = \Phi^+(b) \text{ and } \Phi^-(a) < \Phi^-(b), \text{ or} \\ \Phi^+(a) > \Phi^+(b) \text{ and } \Phi^-(a) = \Phi^-(b); \end{cases} \\ aI^I b & \text{iff} & \Phi^+(a) = \Phi^+(b) \text{ and } \Phi^-(a) = \Phi^-(b); \\ aR^I b & \text{iff} & \begin{cases} \Phi^+(a) > \Phi^+(b) \text{ and } \Phi^-(a) > \Phi^-(b), \text{ or} \\ \Phi^+(a) < \Phi^+(b) \text{ and } \Phi^-(a) < \Phi^-(b); \end{cases} \end{cases} \quad (5.11)$$

Where P^I , I^I , and R^I represent preference, indifference, and incomparability, respectively. Formula (5.11) indicates that $aP^I b$ means alternative a outranks alternative b , $aI^I b$ means alternative a is indifferent to alternative b , and $aR^I b$ means alternative a and alternative b are incomparable.

- *Step 5*: Calculation of the net outranking flows for each alternative a using Formula (5.12) below:

$$\Phi(a) = \Phi^+(a) - \Phi^-(a) \quad (5.12)$$

It is clear that the net outranking flow given in Formula (5.12) is the balance between the positive and negative outranking flows given in Formula (5.9) and Formula (5.10). The higher $\Phi(a)$, the better the alternative, so that:

$$\begin{cases} aP^II b & \text{iff } \Phi(a) > \Phi(b), \\ aI^II b & \text{iff } \Phi(a) = \Phi(b). \end{cases} \quad (5.13)$$

Where P^II represents preference, and I^II represents indifference. Formula (5.13) indicates that $aP^II b$ means alternative a outranks alternative b , and $aI^II b$ means alternative a is indifferent to alternative b , holding the following properties:

$$\begin{cases} -1 \leq \Phi(a) \leq 1, \\ \sum_{x \in A} \Phi(a) = 0. \end{cases} \quad (5.14)$$

As it can be stated by considering both Formula (5.11) and Formula (5.13), PROMETHEE I allows incomparability between alternatives, while all the alternatives are comparable in PROMETHEE II. Through this viewpoint, all alternatives can be ranked through their net outranking flows given in Formula (5.12).

In the following chapter, the efforts made for data analysis are presented, comprising all analysis (i.e. statistical analysis and multi-criteria analysis) made for Survey-1 and Survey-2 using the primary and secondary data collected for the validity and reliability of the implementation in this thesis.

CHAPTER SIX

DATA ANALYSIS

This chapter comprises the analysis for Survey-1 and Survey-2, using Mann-Whitney U test, Kruskal-Wallis test, and Chi-Square Test of Independence (i.e. statistical analysis) as well as BWM and PROMETHEE (i.e. hybrid multi-criteria analysis).

6.1 Analysis for Survey-1

As stated before, Survey-1, whose target group is the experts on ergonomics and sustainability, was designed and developed for the validity of the implementation in this thesis. The main point here was to determine the appropriateness of the ergonomics indicators proposed in this thesis. The invitation process of the experts, both the researchers from universities in different countries and the practitioners working in companies in Turkey, was attentively carried out, as stated in the previous chapter. Accordingly, in this subsection, the aggregation of the primary data gathered from these experts through Survey-1 using two different scenarios (i.e. use of median and use of weighted arithmetic mean) and the selection of the proposed ergonomics indicators through these aggregated results are presented, after the respondents' information and the internal consistency reliability of the data of Survey-1 are given.

Importantly, there was no opportunity to fill out the designed questionnaire of Survey-1 face-to-face since the researchers were from different countries and continents. In parallel, the questionnaires were not filled out face-to-face for the practitioners in Turkey due to the COVID-19 pandemic. Consequently, 12 researchers and 6 practitioners specialized in ergonomics and sustainability were invited to Survey-1. All potential respondents were informed by a cover letter accompanying the questionnaire, comprising a detailed explanation about the survey and declaring that participation in the survey was voluntary. Accordingly, the experts who responded to the survey represent the ones that accepted to participate in the survey voluntarily. The response rate of the survey is 67% (12 out of 18), with responses of 6 researchers (50%;

6 out of 12) and 6 practitioners (100%; 6 out of 6). It should be underlined that the required number of experts to gather reliable data for MCDM analysis is ideally 4-10 (Kusi-Sarpong et al., 2019; Rezaei et al., 2018).

As presented in the part of the detailed explanations on the designed questionnaire for Survey-1 in Section 5.2.1, only the expertise level was asked to the respondents due to the potential respondents who may have some confidentiality concerns. In this regard, the *expertise level* of all experts who responded to Survey-1 varies between 3 and 25 years, with a mean of 11.0833 and a standard deviation of 6.3455; while this data varies between 8 and 25 years with a mean of 15.1667 and a standard deviation of 6.3692 for the researchers and between 3 and 10 years with a mean of 7.0000 and a standard deviation of 2.8284 for the practitioners who responded to Survey-1.

Croasmun & Ostrom (2011) specify that Cronbach's alpha coefficient (Cronbach, 1951) is calculated to report the internal consistency reliability of the data gathered from the questionnaire having the Likert-type scale. Based on the collected data (i.e. the responses of 12 experts), the Cronbach's alpha coefficient calculated using IBM SPSS Statistics (Version 26) is 0.9139. Additionally, Cronbach's alpha coefficients for each sub-dimension proposed in this thesis were calculated, obtaining 0.9076, 0.7150, 0.7236, 0.8066, 0.7212, and 0.8287 for *Loss*, *Investment*, *Conditions*, *Contribution*, *Self-Development*, and *Satisfaction*, respectively. These values present that the survey reaches acceptable reliability by obtaining Cronbach's alpha coefficient higher than 0.70 as suggested (Nunnally, 1978; Yuan, Zeng, Skibniewski, & Li, 2009).

6.1.1 Preparation of Data

Undoubtedly, the representative value of all responses is seen as the aggregated value (Beliakov, Pradera, & Calvo, 2007). Through this viewpoint, Forman & Peniwati (1998) suggest two fundamental aggregation approaches: Aggregation of individual judgments (AIJ) is appropriate in case of respondents acting together as a unit, while aggregation of individual priorities (AIP) is appropriate in case of respondents acting as separate individuals (Forman & Peniwati, 1998).

Since all respondents of the surveys in this thesis (i.e. both Survey-1 and Survey-2) have the same viewpoint through the cover letter comprising detailed explanations about the surveys and have similar specializations and competence in ergonomics and sustainability, the AIJ approach was utilized for the aggregation of the primary data of the proposed ergonomics indicators. Exceptionally, the AIP approach was utilized for the aggregation of the weights of the consolidated evaluation criteria due to the data collection principle of the method used (i.e. BWM), which will be presented in the following part of this chapter. Furthermore, the reasons for the preferences of use of median and use of weighted arithmetic mean in the aggregation part of this thesis for the primary data gathered from both Survey-1 and Survey-2 can be clarified as follows:

- The *Scenario-1* is the use of median due to the scale of the data. Beliakov et al. (2007) state that median has an attractive attribute, having applicability to data constructed on an ordinal scale (i.e. when only ordering is essential rather than numerical values). Accordingly, the scale assigned for the data gathered from the Likert-type scale, as for this thesis, is an example of ordinal scales (Joshi et al., 2015). Lindstädt, Proksch, & Slapin (2020) suggest that, comparatively to mean, median is better for recovering the truth. Beliakov et al. (2007) support this by stating that median represents all data typically more than mean.
- The *Scenario-2* is the use of weighted arithmetic mean preferred to enrich the implementation part of this thesis. In this scenario, the aggregated data is achieved by summing weighted averages (i.e. the multiplication of the Likert-type score with the number of respondents who give that score) and dividing this summation by the total number of respondents (Marandure, Mapiye, Makombe, & Dzama, 2017). This calculation was made separately for all questions comprising indicators in both two surveys designed and developed for this thesis. It should be noted that weighted arithmetic mean is the most commonly used aggregation method (Beliakov et al., 2007).

Consequently, the aggregated data of 12 experts who responded to Survey-1 is presented in Table 6.1, considering both Scenario-1 and Scenario-2 explained above.

Table 6.1 The results of the aggregation of the primary data gathered from Survey-1

Main Dimension	Proposed Sub-Dimension	No	Proposed Ergonomics Indicator	Scenario-1	Scenario-2
				Median	Weighted Arithmetic Mean
Economic	Loss	EI ₁	Number of accident-free days per year	5.0000	4.9167
		EI ₂	Number of injury-free days per year	5.0000	4.9167
		EI ₃	Percentage of total lost time due to accidents and injuries relative to the total hours worked per year	5.5000	5.0000
		EI ₄	Expenditure on medical treatments for accidents, injuries and occupational diseases per year	4.0000	4.3333
		EI ₅	Number of cases of occupational diseases per year	5.5000	5.0833
	Investment	EI ₆	Annual investment cost for ergonomics interventions and EHS issues	6.5000	5.9167
		EI ₇	Cost of EHS training of employees per year	5.0000	4.8333
		EI ₈	Expenditure on employee development per year	5.0000	4.9167
		EI ₉	Expenditure on research and development, technology, and innovation per year to enhance ergonomically and environmentally-friendly designed processes	5.5000	5.7500
Ecological	Conditions	EI ₁₀	Number of complaints due to physical conditions (noise, temperature, odour, dust, etc.) per year	5.0000	5.4167
		EI ₁₁	Number of complaints from community per year	4.5000	4.4167
		EI ₁₂	Number of days when there are unfavourable physical conditions (noise, temperature, odour, dust, etc.) per year	5.0000	5.0000
		EI ₁₃	Percentage of employees working in unfavourable conditions leading to physical and mental health problems per year	5.5000	5.4167
		EI ₁₄	Number of activities made for improving working conditions per year	6.0000	6.0000
	Contribution	EI ₁₅	Number of volunteers for making charitable contributions to EHS issues per year	5.5000	4.8333
		EI ₁₆	Percentage of recycled products/raw materials used in ergonomically designed processes per year	5.0000	5.0000
		EI ₁₇	Percentage of annual incentives and promotions made for stakeholders to contribute ergonomically and environmentally-friendly designed processes	5.0000	5.2500
Social	Self-Development	EI ₁₈	Percentage of employees receiving EHS training per year	6.0000	5.9167
		EI ₁₉	Percentage of total time spent due to EHS training relative to the total hours worked per year	6.0000	5.6667
		EI ₂₀	Number of suggested improvements made by employees per year	6.0000	5.6667
		EI ₂₁	Annual number of activities made for the proper implementation of the procedures related to ergonomics interventions and EHS issues	6.0000	5.5833
	Satisfaction	EI ₂₂	Annual turnover rate of employees	5.0000	4.6667
		EI ₂₃	Percentage of employees who are satisfied with their work	6.0000	5.6667
		EI ₂₄	Number of complaints due to working conditions not covered by decent work per year	6.0000	5.1667
		EI ₂₅	Percentage of employees participating in managerial decisions related to ergonomics interventions and EHS issues per year	6.5000	6.0000

6.1.2 Selection of the Proposed Ergonomics Indicators

Table 6.1 presents a remarkable result, having aggregated data being close to each other through two scenarios. Subsequently, a cut-off point was specified to select the most appropriate ergonomics indicators to be used in further analysis (i.e. Survey-2). This value enables evaluating the two results achieved in Scenario-1 and Scenario-2 by considering the aggregated data of each proposed ergonomics indicator scored by the experts. Similar to Danso's (2018) and Salamid, Kheybari, Ishizaka, & Farazmand's (2021) studies, 4.5000 was set as a cut-off point for this survey. This means that if the aggregated data of one ergonomics indicator was equal to 4.5000 or below this cut-off value, that indicator was determined as inappropriate by the experts and should not be selected for further analysis. The set cut-off value enables representing the respondents' choice on the appropriateness of the proposed ergonomics indicators ordered between 4–Neutral and 5–Slightly appropriate through moving from neutral to appropriateness part of the Likert-type scale used in the survey.

By considering the set cut-off point, two ergonomics indicators, EI₄ (median = 4.0000, weighted arithmetic mean = 4.3333) and EI₁₁ (median = 4.5000, weighted arithmetic mean = 4.4167), were excluded in both two scenarios from further analysis of this thesis (Table 6.1). As highlighted before, the respondents were informed about neither three-dimensional structure nor indicator types presented for classifying the proposed ergonomics indicators to receive a more objective evaluation.

In this regard, the following subsection of this chapter continues with the analysis made for the twenty-three ergonomics indicators, which were proposed in this thesis after a comprehensive literature review conducted systematically and attentively and later were determined as appropriate for being fundamental components of such a systematic approach by the experts (Survey-1).

6.2 Analysis for Survey-2

As stated before, Survey-2, whose target group is the practitioners in companies in Turkey, was designed and developed for the reliability of the implementation in this thesis. The main point here was to measure the perception of the applicability of the systematic approach comprising the ergonomics indicators proposed in this thesis. The invitation process of the practitioners, who are the white-collar employees specialized in ergonomics and sustainability and are potential users of this systematic approach, was attentively carried out, as comprehensively explained in the previous chapter. Accordingly, in this subsection, statistical analysis and multi-criteria analysis using the primary and secondary data gathered from these practitioners through Survey-2, including the aggregation of the primary data using two different scenarios introduced in the previous subsection (i.e. use of median and use of weighted arithmetic mean) are presented, after the respondents' information and the internal consistency reliability of the data of Survey-2 are given.

Due to the COVID-19 pandemic, very few companies could be contacted to invite to Survey-2. This invitation phase, comprising various meetings made with executives in these companies to explain the aim and scope of the survey as well as the thesis, also took several weeks due to the same reason. The scope of this thesis, including the search on human, work design, and workplace design (Chapter 1, Chapter 2, and Chapter 3), was another challenging issue for this invitation phase; companies were not willing to participate in the survey due to some confidentiality concerns related to their employees and organization. By considering all these issues, the data collection phase of this survey was completed through the invitation of 186 practitioners in 11 different companies in Turkey. Similar to Survey-1, all potential respondents were informed by a cover letter accompanying the questionnaire, comprising a detailed explanation about the survey and declaring that participation in the survey was voluntary. Accordingly, the practitioners who responded to the survey represent the ones that accepted to participate in the survey voluntarily. Through the participation of 59 practitioners, the response rate of the survey is 32% (59 out of 186).

Since there was no opportunity to fill out the questionnaire face-to-face due to the COVID-19 pandemic, the executives also helped to distribute the questionnaire to the potential respondents in companies who were identified together by considering the theoretical background of this thesis. Although this distribution may lead to a relatively low response rate due to not having the opportunity to fill out the questionnaire face-to-face, fortunately, the data collection phase was completed most effectively with the voluntary efforts of these executives on distributing and frequently reminding the questionnaire to the potential respondents. Another reason for the relatively low response rate of the survey is the designed questionnaire comprising nested and comprehensive questions related to various confidential issues of organizations as well as its long and time-consuming responses. This feedback was taken many times from the executives contacted; unfortunately, there was no opportunity to shorten the designed questionnaire due to the theoretical background of this thesis.

As presented in the part of the detailed explanations on the designed questionnaire for Survey-2 in Section 5.2.2, several personal information (i.e. age, gender, education level, department, expertise level, and knowledge level) was collected through the questionnaire to present the information about the respondents and use some of this information as independent variables for the statistical analysis. The data relating to this personal information is presented in this thesis in aggregated forms to protect their confidentiality, such as *age* (minimum = 25, maximum = 53, mean = 37.0847, standard deviation = 6.9339), *expertise level* (minimum = 1, maximum = 25, mean = 6.7542, standard deviation = 6.1710), and *knowledge level* (minimum = 1, maximum = 6, mean = 3.8136, standard deviation = 1.4911 for *Ergonomics*, minimum = 1, maximum = 7, mean = 4.7458, standard deviation = 1.3594 for *Sustainability*, minimum = 1, maximum = 7, mean = 3.9322, standard deviation = 1.4126 for *Ergonomics and Sustainability*). Additionally, 61% of all respondents are *Female* (36 out of 59), while 39% of all are *Male* (23 out of 59).

For the *education levels* of the respondents, it is stated that there are 2 respondents (3%) having *Associate's Degree*, 31 respondents (53%) having *Bachelor's Degree*, 25 respondents (42%) having *Master's Degree*, and 1 respondent (2%) having *Doctorate*

Degree. The gathered data related to the respondents' *departments* is summarized by dividing them into three groups, namely *Coordination* (e.g. Occupational Health & Safety, Business Development), *Administration* (e.g. Human Resources, Finance, Senior Management), and *Operations* (e.g. Manufacturing, Supply Chain Management), including 21 respondents (36%), 17 respondents (28%), and 21 respondents (36%), respectively.

It should be noted here that the *expertise levels* and *knowledge levels* were gathered from the survey by kindly asking the respondents to consider these two definitions of Ergonomics and Sustainability, respectively: "Ergonomics (or human factors) is the scientific discipline concerned with the understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and methods to design in order to optimize human well-being and overall system performance." (International Ergonomics Association [IEA], 2000). "Sustainability demands ways of living, working and being that enable all people of the world to lead healthy, fulfilling, and economically secure lives without destroying the environment and without endangering the future welfare of people and the planet." (Johnston et al., 2007, p. 62). Similar to Survey-1, the *expertise level* here refers to the experience in ergonomics and sustainability areas (years). Also, the three questions for asking *knowledge levels* were designed using a scale from 1 (i.e. little knowledge) to 7 (i.e. much knowledge), representing the knowledge levels of the respondents related to *Ergonomics*, *Sustainability*, and *Ergonomics and Sustainability*. In short, due to the confidentiality protocols made at the requests of the companies, no information, except for the aggregated forms summarized above, was shared in this thesis about the companies, their employees (i.e. practitioners) to whom the questionnaire was distributed, and the individual responses (i.e. primary data) of these employees.

The research instruments of this thesis (Section 5.3) introduced that Survey-2 has individual questions related to the proposed ergonomics indicators. These questions include five questions for each indicator, enabling respondents to score each indicator by considering five evaluation criteria consolidated for this thesis (i.e. *Measurability*, *Reliability*, *Resilience*, *Proactiveness*, and *Policy Relevance*). As presented in Survey-

1 to report the internal consistency reliability of the data, Cronbach's alpha coefficients were calculated for each ergonomics indicator ($n = 23$) in this survey using IBM SPSS Statistics (Version 26). Accordingly, the calculated Cronbach's alpha coefficients represent the reliability of the data of these five questions for each ergonomics indicator ($n = 23$). Consequently, based on the collected data (i.e. the responses of 59 practitioners), the calculated Cronbach's alpha coefficients were 0.7433, 0.7052, 0.8525, 0.8557, 0.8957, 0.7835, 0.9354, 0.8412, 0.8147, 0.9076, 0.8965, 0.8793, 0.9094, 0.9040, 0.8509, 0.7002, 0.8345, 0.8966, 0.8424, 0.7083, 0.8054, 0.8999, and 0.9249 for EI₁, EI₂, EI₃, EI₅, EI₆, EI₇, EI₈, EI₉, EI₁₀, EI₁₂, EI₁₃, EI₁₄, EI₁₅, EI₁₆, EI₁₇, EI₁₈, EI₁₉, EI₂₀, EI₂₁, EI₂₂, EI₂₃, EI₂₄, and EI₂₅, respectively. Again, these values present that the survey reaches acceptable reliability by obtaining Cronbach's alpha coefficients higher than 0.70 as suggested (Nunnally, 1978; Yuan et al., 2009).

6.2.1 Statistical Analysis for Primary Data

As presented in the previous chapter, multiple statistical analysis, including the Mann-Whitney U test, the Kruskal-Wallis test, and the Chi-Square Test of Independence, were conducted to present the characteristics of the primary data. Similar to the calculation of Cronbach's alpha coefficients, all statistical analysis in this thesis was performed using IBM SPSS Statistics (Version 26).

Firstly, in this part of the thesis, the *Mann-Whitney U test* was performed for each primary data gathered from the five questions of each ergonomics indicator. This means that 115 results (i.e. 23 indicators, comprising 5 questions for each) for the Mann-Whitney U test were reported for this thesis. In this regard, the data was divided into two groups by considering the respondents' education levels, such as Bachelor's Degree ($n = 31$) and Master's Degree ($n = 25$). The data belongs to 3 remaining respondents was excluded from this analysis due to their education levels (i.e. 2 respondents having Associate's Degree and 1 respondent having Doctorate Degree). The null hypotheses for testing statistically significant differences between these two groups are presented in Appendix-4. Accordingly, the results of the Mann-Whitney U tests are as follows:

Table 6.2 The results of the Mann-Whitney U tests for all proposed ergonomics indicators ($n = 23$)

Proposed Ergonomics Indicator	Consolidated Evaluation Criteria									
	Measurability		Reliability		Resilience		Proactiveness		Policy Relevance	
	U	p	U	p	U	p	U	p	U	p
EI ₁	377.0000	0.8369	377.5000	0.8540	306.0000	0.1653	347.0000	0.4948	386.5000	0.9860
EI ₂	343.0000	0.3835	311.5000	0.1742	311.5000	0.2029	320.5000	0.2588	387.0000	0.9931
EI ₃	367.0000	0.7122	369.0000	0.7492	327.0000	0.3033	365.0000	0.7020	339.5000	0.4098
EI ₅	352.0000	0.5357	335.0000	0.3716	275.5000	0.0560	302.5000	0.1494	329.0000	0.3110
EI ₆	362.5000	0.6607	369.0000	0.7508	269.0000	0.0424	314.0000	0.2042	356.5000	0.5913
EI ₇	373.5000	0.7945	374.5000	0.8216	305.5000	0.1663	318.5000	0.2386	355.5000	0.5765
EI ₈	320.0000	0.2376	349.5000	0.5170	344.5000	0.4654	382.0000	0.9253	376.0000	0.8434
EI ₉	368.0000	0.7275	338.5000	0.3876	299.5000	0.1324	311.5000	0.1875	344.5000	0.4486
EI ₁₀	324.0000	0.2762	371.5000	0.7858	295.5000	0.1116	375.5000	0.8370	335.5000	0.3764
EI ₁₂	359.5000	0.6387	367.0000	0.7310	338.0000	0.4017	349.5000	0.5212	369.5000	0.7608
EI ₁₃	383.0000	0.9396	362.5000	0.6750	365.0000	0.7031	312.0000	0.2027	304.5000	0.1611
EI ₁₄	331.0000	0.3278	384.0000	0.9521	273.5000	0.0503	345.5000	0.4753	377.0000	0.8560
EI ₁₅	354.5000	0.5672	370.0000	0.7650	282.5000	0.0714	322.0000	0.2633	357.0000	0.6055
EI ₁₆	365.0000	0.6991	338.0000	0.4008	273.5000	0.0494	309.0000	0.1759	377.0000	0.8583
EI ₁₇	379.0000	0.8842	362.0000	0.6650	331.0000	0.3304	339.5000	0.4096	370.0000	0.7651
EI ₁₈	344.5000	0.3727	387.5000	1.0000	352.5000	0.5496	285.0000	0.0740	308.5000	0.1602
EI ₁₉	352.0000	0.5213	363.5000	0.6756	257.5000	0.0279	318.0000	0.2355	387.0000	0.9931
EI ₂₀	372.0000	0.7838	382.5000	0.9301	330.5000	0.3248	330.0000	0.3234	329.0000	0.3117
EI ₂₁	382.5000	0.9318	356.5000	0.5987	285.5000	0.0806	333.0000	0.3483	374.5000	0.8226
EI ₂₂	325.0000	0.2449	376.5000	0.8450	289.0000	0.0925	319.0000	0.2442	349.5000	0.5129
EI ₂₃	374.5000	0.8239	372.5000	0.8001	314.5000	0.2098	324.5000	0.2800	344.5000	0.4633
EI ₂₄	371.5000	0.7869	368.5000	0.7478	312.5000	0.2023	344.5000	0.4679	361.0000	0.6539
EI ₂₅	325.0000	0.2928	378.5000	0.8791	318.5000	0.2379	325.0000	0.2878	317.0000	0.2329

Note: Some of the p -values were remarked to indicate the statistically significant results ($n = 3$).

As the results in Table 6.2 show, nearly all hypotheses ($n = 112$) were failed to reject, representing no statistically significant difference between education levels on the evaluation criteria of EIs. Exceptionally, as remarked in Table 6.2, only three hypotheses were rejected, which were listed below, since their p -values were lower than 0.05:

- $H23_0$ was rejected representing that there is statistically significant difference between education levels on the resilience of EI₆ ($U = 269.0000$, $p = 0.0424$).
- $H68_0$ was rejected representing that there is statistically significant difference between education levels on the resilience of EI₁₆ ($U = 273.5000$, $p = 0.0494$).
- $H83_0$ was rejected representing that there is statistically significant difference between education levels on the resilience of EI₁₉ ($U = 257.5000$, $p = 0.0279$).

Later, the *Kruskal-Wallis test* was performed for each primary data gathered from the five questions of each ergonomics indicator. This means that 115 results (i.e. 23 indicators, comprising 5 questions for each) for the Kruskal-Wallis test were reported for this thesis. In this regard, the data was divided into three groups by considering the respondents' departments, such as Coordination ($n = 21$), Administration ($n = 17$), and Operations ($n = 21$). The null hypotheses for testing statistically significant differences between these three groups are presented in Appendix-5. Accordingly, the results of the Kruskal-Wallis tests are as follows:

Table 6.3 The results of the Kruskal-Wallis tests for all proposed ergonomics indicators ($n = 23$)

Proposed Ergonomics Indicator	Consolidated Evaluation Criteria									
	Measurability		Reliability		Resilience		Proactiveness		Policy Relevance	
	<i>H</i>	<i>p</i>	<i>H</i>	<i>p</i>	<i>H</i>	<i>p</i>	<i>H</i>	<i>p</i>	<i>H</i>	<i>p</i>
El ₁	7.1011	0.0287	7.1503	0.0280	0.2113	0.8998	2.9866	0.2246	3.6448	0.1616
El ₂	0.7569	0.6849	0.7224	0.6968	0.1747	0.9163	0.4419	0.8018	2.8997	0.2346
El ₃	7.1981	0.0273	6.2142	0.0447	2.4156	0.2989	3.1339	0.2087	6.9089	0.0316
El ₅	3.0268	0.2202	0.0562	0.9723	0.1705	0.9183	3.9921	0.1359	0.8434	0.6559
El ₆	1.4789	0.4774	1.5533	0.4599	0.6349	0.7280	0.5649	0.7539	0.2401	0.8869
El ₇	2.1739	0.3372	3.3857	0.1840	0.4702	0.7905	2.1841	0.3355	5.9666	0.0506
El ₈	0.0777	0.9619	0.5418	0.7627	0.9163	0.6324	0.8230	0.6627	1.6873	0.4301
El ₉	0.4609	0.7942	2.5049	0.2858	3.6712	0.1595	1.3559	0.5077	1.0027	0.6057
El ₁₀	0.3440	0.8420	1.6160	0.4458	2.4854	0.2886	4.8484	0.0886	2.3916	0.3025
El ₁₂	1.5088	0.4703	0.4475	0.7995	0.0459	0.9773	1.7808	0.4105	0.4323	0.8056
El ₁₃	1.2000	0.5488	0.1340	0.9352	0.7616	0.6833	1.7429	0.4183	1.1142	0.5729
El ₁₄	0.1734	0.9170	1.1915	0.5512	0.5042	0.7772	4.0755	0.1303	1.5265	0.4661
El ₁₅	2.5852	0.2746	1.8875	0.3892	0.6905	0.7080	0.0776	0.9619	3.8192	0.1481
El ₁₆	0.5885	0.7451	2.6485	0.2660	0.3725	0.8301	0.2652	0.8758	0.4020	0.8179
El ₁₇	3.2426	0.1976	1.4780	0.4776	3.5093	0.1730	0.5398	0.7634	0.4261	0.8081
El ₁₈	5.5352	0.0628	3.7676	0.1520	0.5889	0.7450	1.8314	0.4002	2.1729	0.3374
El ₁₉	1.6684	0.4342	1.1960	0.5499	0.7840	0.6757	1.4492	0.4845	3.2967	0.1924
El ₂₀	2.8229	0.2438	3.0750	0.2149	0.9593	0.6190	0.6133	0.7359	0.6208	0.7331
El ₂₁	3.8194	0.1481	1.0160	0.6017	1.1162	0.5723	2.7747	0.2497	1.1828	0.5535
El ₂₂	4.0333	0.1331	2.4886	0.2881	2.7445	0.2535	0.5036	0.7774	0.9499	0.6219
El ₂₃	0.9144	0.6330	1.5279	0.4658	3.4029	0.1824	2.8182	0.2444	1.8156	0.4034
El ₂₄	0.6239	0.7320	0.9483	0.6224	4.4768	0.1066	0.0217	0.9892	0.9581	0.6194
El ₂₅	0.5169	0.7723	1.0231	0.5996	4.5109	0.1048	0.6340	0.7283	0.5391	0.7637

Note: Some of the *p*-values were remarked to indicate the statistically significant results ($n = 5$).

As the results in Table 6.3 show, nearly all hypotheses ($n = 110$) were failed to reject, representing no statistically significant difference departments on the evaluation criteria of EIs. Exceptionally, as remarked in Table 6.3, only five hypotheses were rejected, which were listed below, since their *p*-values were lower than 0.05:

- H_{116_0} was rejected representing that there is statistically significant difference between departments on the measurability of EI_1 ($H = 7.1011$, $p = 0.0287$).
- H_{117_0} was rejected representing that there is statistically significant difference between departments on the reliability of EI_1 ($H = 7.1503$, $p = 0.0280$).
- H_{126_0} was rejected representing that there is statistically significant difference between departments on the measurability of EI_3 ($H = 7.1981$, $p = 0.0273$).
- H_{127_0} was rejected representing that there is statistically significant difference between departments on the reliability of EI_3 ($H = 6.2142$, $p = 0.0447$).
- H_{130_0} was rejected representing that there is statistically significant difference between departments on the policy relevance of EI_3 ($H = 6.9089$, $p = 0.0316$).

Furthermore, the *Chi-Square Test of Independence* was performed for the primary data gathered from the respondents' selections on the most and least important evaluation criterion. This analysis was made in two parts by considering respondents' education levels and departments, respectively. This means that 4 results (i.e. 2 results, comprising respondents' education levels, and 2 results, comprising respondents' departments) for the Chi-Square Test of Independence were reported for this thesis.

For the first part of the Chi-Square Test of Independence, the data belongs to the same two groups presented in the Mann-Whitney U test (i.e. 31 respondents having Bachelor's Degree, and 25 respondents having Master's Degree) was used. Again, the data belongs to 3 remaining respondents was excluded from this analysis due to their education levels (i.e. 2 respondents having Associate's Degree, and 1 respondent having Doctorate Degree). The null hypotheses for testing statistically significant relationships between these two groups are presented as follows:

H_{231_0} : *There is no statistically significant relationship between education levels on the most important evaluation criterion selected.*

H_{232_0} : *There is no statistically significant relationship between education levels on the least important evaluation criterion selected.*

Accordingly, the results of the first part of the Chi-Square Test of Independence tests (i.e. education levels) are as follows:

- H_{231_0} was failed to reject representing that there is no statistically significant relationship between education levels on the most important evaluation criterion selected ($\chi^2 = 4.698, p = 0.195$).
- H_{232_0} was failed to reject representing that there is no statistically significant relationship between education levels on the least important evaluation criterion selected ($\chi^2 = 3.340, p = 0.503$).

Finally, for the second part of the Chi-Square Test of Independence, the data belongs to the same three groups presented in the Kruskal-Wallis test (i.e. 21 respondents working in departments related to Coordination, 17 respondents working in departments related to Administration, and 21 respondents working in departments related to Operations) was used. The null hypotheses for testing statistically significant relationships between these three groups are presented as follows:

H_{233_0} : There is no statistically significant relationship between departments on the most important evaluation criterion selected.

H_{234_0} : There is no statistically significant relationship between departments on the least important evaluation criterion selected.

Accordingly, the results of the second part of the Chi-Square Test of Independence tests (i.e. departments) are as follows:

- H_{233_0} was failed to reject representing that there is no statistically significant relationship between departments on the most important evaluation criterion selected ($\chi^2 = 8.277, p = 0.218$).
- H_{234_0} was failed to reject representing that there is no statistically significant relationship between departments on the least important evaluation criterion selected ($\chi^2 = 3.745, p = 0.879$).

6.2.2 Multi-Criteria Analysis for Secondary Data

As presented in the previous chapter, the hybrid multi-criteria analysis, including the Best-Worst Method (BWM) and the Preference Ranking Organization METHod for Enrichment Evaluations (PROMETHEE), was applied in this thesis by using the secondary data for weighting the consolidated evaluation criteria and for prioritizing the proposed ergonomics indicators. Both methods enable presenting a base study as an example for developing the systematic approach, indicating the prioritization and determination of the proposed ergonomics indicators to be used for such an approach.

6.2.2.1 Weighting of the Consolidated Evaluation Criteria

The linear BWM presented in Chapter 5 was performed using the Excel Solver. The data, belonging to respondents ($n = 59$) and having a scale from 1 (i.e. equally important) to 9 (i.e. extremely more important) for pairwise comparisons of criteria, was gathered from the questionnaire designed for Survey-2 (please see the *second part of the questionnaire* in Section 5.2.2 for details). Accordingly, the BWM was run for each respondent's data separately to weight the five evaluation criteria consolidated for this thesis. This means that the AIP approach was utilized for the aggregation of these weights, as highlighted in Section 6.1.1. The reason for this preference is related to the data collection principle of BWM: Since the best (i.e. most important) and the worst (i.e. least important) criterion selected by different respondents might be different, it is not appropriate to aggregate data through the AIJ approach in BWM (Salamirad et al., 2021).

The results (i.e. weights) obtained using each respondent's data ($n = 59$) separately are presented in Table 6.4 below. The consistent ones of these results should be used for aggregation. In this regard, the CR^I values, i.e., the input-based consistency ratios proposed by Liang et al. (2020) (i.e. Formula 5.3 in Chapter 5), were calculated (Table 6.4). Subsequently, the CR^I values were checked through the input-based thresholds determined by Liang et al. (2020).

Comparatively to the original (i.e. output-based) consistency ratio, the input-based consistency ratio has several desirable properties that the reason for this preference is related to: Providing immediate feedback due to being based on input (i.e. judgments), ease of its interpretation, providing a clear guideline to revise the inconsistent judgments, and being model-independent (Liang et al., 2020). Unfortunately, the revision of the inconsistent judgments could not be possible due to not having the opportunity to fill out the questionnaire face-to-face under the COVID-19 pandemic; therefore, 42 consistent results in Table 6.4 were used for aggregation.

Table 6.4 The results of BWM for each respondent's data ($n = 59$), including input-based consistency ratios

Respondent of Survey-2	Weights of the Consolidated Evaluation Criteria					CR^I	Consistent?
	Measurability	Reliability	Resilience	Proactiveness	Policy Relevance		
R_01	0.5928	0.1046	0.0436	0.1395	0.1196	1.0000	No
R_02	0.0428	0.6208	0.1223	0.1070	0.1070	0.7639	No
R_03	0.3953	0.3488	0.1163	0.0930	0.0465	0.2143	Yes
R_04	0.3525	0.2049	0.0328	0.2049	0.2049	0.0972	Yes
R_05	0.1054	0.6114	0.1205	0.1205	0.0422	0.7639	No
R_06	0.1842	0.1842	0.1842	0.3421	0.1053	0.1667	Yes
R_07	0.0325	0.2240	0.1494	0.3701	0.2240	0.1667	Yes
R_08	0.2512	0.4186	0.1674	0.0372	0.1256	0.1250	Yes
R_09	0.5455	0.1364	0.1364	0.1364	0.0455	0.2917	Yes
R_10	0.6530	0.0837	0.1076	0.0942	0.0614	0.2500	Yes
R_11	0.1121	0.1963	0.1308	0.3645	0.1963	0.1667	Yes
R_12	0.6339	0.1126	0.1001	0.0408	0.1126	1.0000	No
R_13	0.1381	0.0987	0.1381	0.5742	0.0509	0.2639	Yes
R_14	0.3711	0.2165	0.2165	0.1443	0.0515	0.2000	Yes
R_15	0.4000	0.2276	0.0690	0.1517	0.1517	0.2000	Yes
R_16	0.2632	0.2632	0.1579	0.2895	0.0263	0.0972	Yes
R_17	0.1033	0.5994	0.1181	0.1378	0.0413	0.7639	No
R_18	0.2310	0.2310	0.4402	0.0679	0.0299	0.8750	No
R_19	0.1100	0.1100	0.6381	0.0978	0.0440	0.7639	No
R_20	0.4162	0.1214	0.1618	0.2428	0.0578	0.2000	Yes
R_21	0.1931	0.1448	0.1448	0.4759	0.0414	0.2083	Yes
R_22	0.5823	0.0886	0.1772	0.1013	0.0506	0.2083	Yes
R_23	0.2781	0.3576	0.1788	0.1192	0.0662	0.2000	Yes
R_24	0.3636	0.1515	0.2273	0.0303	0.2273	0.2083	Yes
R_25	0.3934	0.2295	0.1639	0.0492	0.1639	0.0694	Yes
R_26	0.6017	0.0950	0.0387	0.1221	0.1425	1.0000	No
R_27	0.1266	0.3418	0.3038	0.1899	0.0380	0.0714	Yes
R_28	0.0401	0.0985	0.1108	0.6239	0.1267	1.0000	No
R_29	0.1496	0.2244	0.2244	0.3622	0.0394	0.2619	Yes
R_30	0.1770	0.4513	0.1327	0.1858	0.0531	0.2143	Yes
R_31	0.1197	0.6128	0.0431	0.1047	0.1197	0.6528	No

Table 6.4 Continues

Respondent of Survey-2	Weights of the Consolidated Evaluation Criteria					CR ¹	Consistent?
	Measurability	Reliability	Resilience	Proactiveness	Policy Relevance		
R_32	0.4615	0.2706	0.0424	0.1353	0.0902	0.2083	Yes
R_33	0.0445	0.5701	0.1306	0.0980	0.1568	0.8571	No
R_34	0.5275	0.1319	0.1648	0.1319	0.0440	0.2917	Yes
R_35	0.1993	0.4649	0.0369	0.1494	0.1494	0.2500	Yes
R_36	0.5429	0.0467	0.1109	0.1331	0.1664	0.2917	Yes
R_37	0.0413	0.1014	0.1014	0.6420	0.1140	1.0000	No
R_38	0.1270	0.2117	0.0907	0.5246	0.0460	0.2222	Yes
R_39	0.1107	0.1107	0.0410	0.6270	0.1107	0.8750	No
R_40	0.0996	0.1744	0.0527	0.5861	0.0872	0.2639	Yes
R_41	0.1047	0.6492	0.0628	0.0916	0.0916	0.1667	Yes
R_42	0.6421	0.0955	0.0578	0.1091	0.0955	0.2639	Yes
R_43	0.0435	0.6304	0.1087	0.1087	0.1087	0.7639	No
R_44	0.0547	0.0903	0.1445	0.6073	0.1032	0.2639	Yes
R_45	0.0617	0.6476	0.1057	0.0925	0.0925	0.2083	Yes
R_46	0.0858	0.6690	0.0965	0.0858	0.0629	0.2500	Yes
R_47	0.5347	0.1607	0.1286	0.0474	0.1286	0.2222	Yes
R_48	0.4922	0.2953	0.0844	0.0844	0.0438	0.2639	Yes
R_49	0.4228	0.1812	0.1812	0.0336	0.1812	0.2500	Yes
R_50	0.6502	0.1027	0.0418	0.1027	0.1027	1.0000	No
R_51	0.1662	0.3877	0.0308	0.2492	0.1662	0.2500	Yes
R_52	0.1082	0.0947	0.0531	0.6178	0.1262	0.2917	Yes
R_53	0.1089	0.1089	0.0403	0.6173	0.1245	0.8750	No
R_54	0.2857	0.3214	0.1786	0.1786	0.0357	0.1667	Yes
R_55	0.4158	0.2366	0.1183	0.1577	0.0717	0.2000	Yes
R_56	0.0979	0.0457	0.1370	0.5481	0.1713	0.2917	Yes
R_57	0.4312	0.2082	0.1636	0.1227	0.0743	0.2000	Yes
R_58	0.1218	0.1066	0.6091	0.0406	0.1218	0.7639	No
R_59	0.2979	0.2553	0.1702	0.1064	0.1702	0.1667	Yes

Note: Some of the Respondent IDs are remarked to indicate the consistent results ($n = 42$).

The geometric mean was used for the aggregation of the consistent results ($n = 42$) presented in Table 6.4. The reason for this preference can be clarified as follows: The linear BWM (Rezaei, 2016), i.e., Model 5.2 in Chapter 5, produces weights as ratios by considering one of the constraints of the model (i.e. the sum of all weights, defined as decision variables, must be equal to 1) and the definition of decision variables (i.e. all weights must be equal to 0 or above). This means that the model presents the results normalized into the range $[0, 1]$. Accordingly, Fleming & Wallace (1986) suggest using the geometric mean method if the data is normalized (i.e. presented as ratios).

The overall weights of the consolidated evaluation criteria, which were aggregated through the geometric mean of 42 consistent results obtained from BWM, were calculated as 0.2370, 0.2037, 0.1161, 0.1633, and 0.0847 for *Measurability*, *Reliability*, *Resilience*, *Proactiveness*, and *Policy Relevance*, respectively. Since the geometric mean of the data, which is suitably normalized, is used to estimate the ratio scale corresponding to this data (Crawford & Williams, 1985), these aggregated weights should be normalized. Consequently, the normalized values of the overall weights are 0.2944, 0.2532, 0.1442, 0.2029, and 0.1053, respectively. It should be noted that all responses were equally weighted (i.e. no weights were assigned to the respondents) during their aggregation.

6.2.2.2 Prioritization of the Proposed Ergonomics Indicators

The PROMETHEE presented in Chapter 5 was performed using the Visual PROMETHEE (VP) software. The data belonging to the same respondents ($n = 59$) with BWM and having a 7-points Likert-type scale that comprises the response anchors called *Level of Agreement* was gathered from the same questionnaire designed for Survey-2. To provide the evaluation table of PROMETHEE as presented in Table 5.2, the twenty-three ergonomics indicators were designed by consisting of five questions for each, enabling respondents to score each indicator by considering five consolidated evaluation criteria (please see the third part of the questionnaire in Section 5.2.2 for details). Again, all responses were equally weighted (i.e. no weights were assigned to the respondents) during their aggregation.

Accordingly, PROMETHEE was run for the respondents' aggregated data to prioritize the proposed ergonomics indicators. This means that the AIJ approach was utilized for the aggregation of these primary data, as highlighted in Section 6.1.1. The efforts made for implementing the two scenarios developed for this aggregation to provide the evaluation table of PROMETHEE are given in the following part, while the other inputs for PROMETHEE, i.e., determination of preference functions, indifference thresholds, and preference thresholds, are presented immediately after this.

In Scenario-1, the respondents' data ($n = 59$) was aggregated using their median. This aggregated data, presented in Table 6.5 below, was used for providing the evaluation table of PROMETHEE in Scenario-1. Since the aggregated data in Table 6.5 has an ordinal scale due to the use of a 7-points Likert-type scale, the scales of all criteria were defined as *qualitative* in VP software.

Table 6.5 The respondents' aggregated data obtained using the median of the data (Scenario-1)

Proposed Ergonomics Indicator	Consolidated Evaluation Criteria				
	Measurability	Reliability	Resilience	Proactiveness	Policy Relevance
El ₁	6	6	5	5	6
El ₂	6	6	4	5	6
El ₃	6	5	5	5	5
El ₅	6	5	5	5	5
El ₆	6	5	5	5	5
El ₇	6	5	4	5	6
El ₈	6	5	5	5	5
El ₉	6	5	5	5	5
El ₁₀	5	5	4	5	5
El ₁₂	5	4	4	4	4
El ₁₃	5	4	4	4	4
El ₁₄	6	5	5	5	5
El ₁₅	5	5	5	5	5
El ₁₆	5	5	4	4	5
El ₁₇	5	4	5	4	5
El ₁₈	6	6	5	5	6
El ₁₉	6	5	5	5	5
El ₂₀	6	5	5	5	5
El ₂₁	5	5	5	5	5
El ₂₂	6	6	5	5	5
El ₂₃	5	4	4	4	5
El ₂₄	5	5	4	4	5
El ₂₅	5	4	4	4	4

Accordingly, for Scenario-1, the preference functions, which are another input for PROMETHEE, were selected for all five criteria as *Level*, indicating the *Type IV-Level criterion* (Brans et al., 1986; Brans & De Smet, 2016). The reason for the preference of *Type IV* can be clarified as follows: The most used preference function with qualitative criteria is *Type IV* (Anand & Kodali, 2008; Routroy & Kodali, 2007). Additionally, Deshmukh (2013) suggests *Type IV* if smaller deviations are preferred to be differentiated from larger ones.

Later, in Scenario-2, the respondents' data ($n = 59$) was aggregated using their weighted arithmetic mean. This aggregated data, presented in Table 6.6 below, was used for providing the evaluation table of PROMETHEE in Scenario-2. The aggregated data in Table 6.6 has a quantitative scale; hence, the scales of all criteria were defined as *numerical* in VP software.

Table 6.6 The respondents' aggregated data obtained using the weighted arithmetic mean of the data (Scenario-2)

Proposed Ergonomics Indicator	Consolidated Evaluation Criteria				
	Measurability	Reliability	Resilience	Proactiveness	Policy Relevance
El ₁	5.8475	5.5593	4.2881	4.4746	5.2542
El ₂	5.7119	5.3729	3.9322	4.1864	5.1017
El ₃	5.4407	5.1356	4.4915	4.6102	5.0000
El ₅	5.2034	4.5593	4.4068	4.3729	4.8814
El ₆	5.3559	4.9153	4.5254	4.6949	4.8475
El ₇	5.6441	5.2712	4.2881	4.5593	5.3051
El ₈	5.2712	4.8644	4.6949	4.8305	5.0508
El ₉	5.2881	5.0169	4.6949	5.0169	5.2373
El ₁₀	5.1525	4.4407	4.1864	4.6102	4.7119
El ₁₂	4.3390	4.1356	3.8644	4.0169	4.3390
El ₁₃	4.4068	4.0000	4.0339	4.0847	4.2373
El ₁₄	5.1017	4.6610	4.4068	4.5932	4.9492
El ₁₅	5.0000	4.6780	4.4915	4.5085	4.6271
El ₁₆	4.8983	4.5932	4.3051	4.5424	4.6949
El ₁₇	4.9153	4.4237	4.5085	4.5254	4.6780
El ₁₈	5.8305	5.6102	4.6102	5.0508	5.5085
El ₁₉	5.4746	5.1864	4.3898	4.6949	5.2034
El ₂₀	5.4068	5.1864	4.8644	4.9661	5.0000
El ₂₁	5.0678	4.7797	4.5085	4.9153	4.9831
El ₂₂	5.8136	5.4915	4.4915	4.5424	4.7966
El ₂₃	4.8983	4.1864	4.2034	4.2712	4.4407
El ₂₄	4.6441	4.1695	4.0169	4.1864	4.2881
El ₂₅	4.5254	4.3559	4.2881	4.4746	4.4746

Accordingly, for Scenario-2, the preference functions, which are another input for PROMETHEE, were selected for all five criteria as *Linear*, indicating the *Type V-V-shape with indifference criterion* (Brans et al., 1986; Brans & De Smet, 2016). The reason for the preference of *Type V* can be clarified as follows: The most used preference function with quantitative criteria is *Type V* (Anand & Kodali, 2008; Routroy & Kodali, 2007). Deshmukh (2013) suggests *Type V*, similar to his suggestion

on *Type IV*, through the use of indifference threshold; this enables smaller deviations to be differentiated from larger ones.

It should be highlighted that the preference functions preferred for both scenarios use q (i.e. indifference threshold) and p (i.e. preference threshold) for the analysis. These thresholds are another input for PROMETHEE, and their values should be assigned. Similar to Safari et al.'s (2012) study, these assignments were made through VP software (i.e. Preference Function Assistant) for this thesis. In this assignment, the value of q was set to the standard deviation of the differences between evaluations of alternatives for the criterion considered. Subsequently, the value of p was set to the sum of this standard deviation with the average difference of evaluations of alternatives for the criterion considered. In short, the threshold values assigned to each criterion are presented in Table 6.7 below by considering both scenarios (i.e. Scenario-1 coded as *qualitative* and Scenario-2 coded as *numerical* in VP software).

Table 6.7 The assigned threshold values for both scenarios

Consolidated Evaluation Criteria	Scenario-1		Scenario-2	
	q (indifference threshold)	p (preference threshold)	q (indifference threshold)	p (preference threshold)
Measurability	0.4998	1.0136	0.3568	0.8726
Reliability	0.6195	1.2756	0.3812	0.9529
Resilience	0.5000	0.9980	0.2089	0.4971
Proactiveness	0.4967	0.9394	0.2354	0.5634
Policy Relevance	0.5860	1.1236	0.2771	0.6813

In the following chapter, a comprehensive discussion of the findings of this thesis is presented, comprising indicator selection, data characteristics interpretation, criteria weighting, indicator prioritization, and indicator classification by considering all analysis made using the primary and secondary data gathered from Survey-1 and Survey-2. Additionally, the results of PROMETHEE by separately considering these two scenarios presented above are also given in this chapter, with a detailed discussion presented for each.

CHAPTER SEVEN

DISCUSSION OF FINDINGS

This chapter comprises the discussion of findings of this thesis, including indicator selection, data characteristics interpretation, criteria weighting, indicator prioritization, and indicator classification, besides the general evaluation of the implementation part.

7.1 Overview

As presented in the last part of Chapter 5, different research instruments, i.e., the two surveys designed and developed for this thesis to provide the primary data for statistical analysis and provide the secondary data for BWM and PROMETHEE for multi-criteria analysis, were used in this thesis. Accordingly, the discussion of findings of this thesis is quite diverse, presented respectively in the following subsections by considering Survey-1, Survey-2, and their implementation steps given in Chapter 6.

7.1.1 Indicator Selection

The results of *Survey-1* show that two indicators, which belong to the *Loss* sub-dimension of the *Economic* dimension and the *Conditions* sub-dimension of the *Ecological* dimension (i.e. EI₄–*Expenditure on medical treatments for accidents, injuries and occupational diseases per year* and EI₁₁–*Number of complaints from community per year*, respectively), were found inappropriate by the experts (Table 6.1). Essentially, it should be highlighted that the two scenarios used for aggregation present the same results for the determination of the appropriateness of the proposed ergonomics indicators by excluding the two same indicators.

7.1.2 Data Characteristics Interpretation

The majority of the results of the *statistical analysis* using the primary data gathered from *Survey-2* were found statistically not significant (Section 6.2.1). The relatively low sample sizes in this thesis may be the underlying reason. Unfortunately, it is

highlighted that the relatively low response rate of Survey-2 (i.e. 32%) is an outcome of the difficulty in contacting companies due to the COVID-19 pandemic and some confidentiality concerns of companies related to their employees and organization due to the scope of this thesis (i.e. search on human, work design, and workplace design). Additionally, the detailed discussion on the statistical analysis in this thesis is presented as follows, including the statistical tests performed in this thesis by considering the education levels and departments of the respondents of Survey-2:

- For the *Mann-Whitney U test*, the reason for obtaining no statistically significant difference between education levels on nearly all consolidated evaluation criteria of EIs (97%; 112 out of 115) can be the research field of the respondents having Master's Degree (Table 6.2). Essentially, this information was not taken through Survey-2 from the respondents due to potential confidentiality concerns, and it is not certainly known whether the respondents have a Master's Degree in ergonomics and sustainability or not.
- For the *Kruskal-Wallis test*, the reason for obtaining no statistically significant difference between departments on nearly all consolidated evaluation criteria of EIs (96%; 110 out of 115) can be the project teams built holistically and composed of the practitioners specialized in ergonomics and sustainability (Table 6.3). It can be stated that the members of the project teams, i.e., the respondents invited to Survey-2, have the same viewpoint within scope, objectives, and targets for achievement.
- For the *Chi-Square Test of Independence*, the reason for obtaining no statistically significant relationship between education levels on the most important evaluation criterion selected and on the least important evaluation criterion selected can be the personal preferences of the respondents. The same reason can also be considered for the departments. Originally, this part of the statistical analysis (i.e. the null hypotheses H_{231_0} , H_{232_0} , H_{233_0} , and H_{234_0} in Section 6.2.1) belongs to the design phase of the systematic approach by weighting the consolidated evaluation criteria for prioritizing the proposed ergonomics indicators, and it is thought that deciding on such a task by a smaller working group in a project team may produce a more consistent result.

7.1.3 Criteria Weighting

The results of *BWM* in Section 6.2.2.1 show that 42 practitioners, whose data were consistent, decided *Measurability* as the most important criterion through the aggregated normalized value of 0.2944, while *Policy Relevance* was decided as the least important criterion through the aggregated normalized value of 0.1053. It should be highlighted that the variability of the consistent data for each criterion, especially for *Measurability*, *Reliability*, and *Proactiveness*, is high: *Measurability* (minimum = 0.0325, maximum = 0.6530, mean = 0.2985, standard deviation = 0.1792), *Reliability* (minimum = 0.0457, maximum = 0.6690, mean = 0.2465, standard deviation = 0.1559), *Resilience* (minimum = 0.0308, maximum = 0.3038, mean = 0.1317, standard deviation = 0.0595), *Proactiveness* (minimum = 0.0303, maximum = 0.6178, mean = 0.2226, standard deviation = 0.1777), and *Policy Relevance* (minimum = 0.0263, maximum = 0.2273, mean = 0.1006, standard deviation = 0.0587).

7.1.4 Indicator Prioritization

The results of *PROMETHEE* obtained through VP software using the aggregated data for two scenarios (Table 6.5 for Scenario-1 and Table 6.6 for Scenario-2) with the weights calculated through *BWM* (0.2944, 0.2532, 0.1442, 0.2029, and 0.1053 for *Measurability*, *Reliability*, *Resilience*, *Proactiveness*, and *Policy Relevance*) and the assigned threshold values (Table 6.7) are presented below in three parts as *PROMETHEE Flow Tables*, *PROMETHEE Networks*, and *GAIA Planes*. The discussion is also presented within these parts.

The *PROMETHEE Flow Tables* in Table 7.1 and Table 7.2 represent the rankings to be used for the prioritization of the proposed ergonomics indicators by considering Scenario-1 and Scenario-2, respectively. The rankings, which are indicated as *Rank* in the tables, were obtained using the net outranking flows (Φ) of the alternatives (i.e. indicators) calculated using Formula (5.12) in Chapter 5. It is reminded that net outranking flow is the balance between positive and negative outranking flows (Φ^+ and Φ^- , respectively), and all the alternatives are comparable in *PROMETHEE II*.

Table 7.1 presents that EI₁ and EI₁₈ are the best alternatives; on the contrary, EI₁₂, EI₁₃, and EI₂₅ are the worsts. It is remarkable that some of the indicators (e.g. EI₃, EI₅, EI₆, EI₈, EI₉, EI₁₄, EI₁₉, EI₂₀) have the same ranks due to the same outranking flow values. The reason for this remarkable result is defining all criteria as qualitative in VP software due to the primary data aggregated using mean in Scenario-1 (Table 6.5).

Table 7.1 The PROMETHEE Flow Table for Scenario-1 (retabulated from VP software)

Rank	Proposed Ergonomics Indicator	Net Outranking Flow (Φ)	Positive Outranking Flow (Φ^+)	Negative Outranking Flow (Φ^-)
1	EI ₁	0.3812	0.3812	0.0000
1	EI ₁₈	0.3812	0.3812	0.0000
3	EI ₂₂	0.3262	0.3357	0.0096
4	EI ₂	0.2304	0.3222	0.0918
5	EI ₃	0.1938	0.2264	0.0326
5	EI ₅	0.1938	0.2264	0.0326
5	EI ₆	0.1938	0.2264	0.0326
5	EI ₈	0.1938	0.2264	0.0326
5	EI ₉	0.1938	0.2264	0.0326
5	EI ₁₄	0.1938	0.2264	0.0326
5	EI ₁₉	0.1938	0.2264	0.0326
5	EI ₂₀	0.1938	0.2264	0.0326
13	EI ₇	0.0981	0.2129	0.1148
14	EI ₁₅	0.0399	0.1595	0.1196
14	EI ₂₁	0.0399	0.1595	0.1196
16	EI ₁₀	-0.1108	0.1005	0.2113
17	EI ₁₇	-0.3046	0.0662	0.3707
18	EI ₁₆	-0.3230	0.0359	0.3589
18	EI ₂₄	-0.3230	0.0359	0.3589
20	EI ₂₃	-0.4553	0.0072	0.4625
21	EI ₁₂	-0.5104	0.0000	0.5104
21	EI ₁₃	-0.5104	0.0000	0.5104
21	EI ₂₅	-0.5104	0.0000	0.5104

On the other hand, Table 7.2 presents twenty-three rankings with different net outranking flows (Φ) of the alternatives, indicating that EI₁₈ is the best and EI₁₂ is the worst alternative. The variety of the results, i.e., obtaining different Φ values, corresponds to the scales of the criteria defined as numerical in VP software due to the primary data aggregated using weighted arithmetic mean in Scenario-2 (Table 6.6).

Table 7.2 The PROMETHEE Flow Table for Scenario-2 (retabulated from VP software)

Rank	Proposed Ergonomics Indicator	Net Outranking Flow (Φ)	Positive Outranking Flow (Φ^+)	Negative Outranking Flow (Φ^-)
1	EI ₁₈	0.5686	0.5697	0.0010
2	EI ₂₀	0.3766	0.3858	0.0091
3	EI ₁	0.3237	0.3773	0.0535
4	EI ₉	0.3088	0.3344	0.0256
5	EI ₂₂	0.3085	0.3507	0.0422
6	EI ₇	0.2494	0.2914	0.0420
7	EI ₁₉	0.2395	0.2586	0.0191
8	EI ₃	0.1999	0.2280	0.0280
9	EI ₈	0.1924	0.2346	0.0422
10	EI ₆	0.1380	0.1845	0.0465
11	EI ₂₁	0.1079	0.1924	0.0845
12	EI ₂	0.0765	0.2734	0.1969
13	EI ₁₄	-0.0137	0.1088	0.1225
14	EI ₅	-0.0742	0.0831	0.1573
15	EI ₁₅	-0.0902	0.0795	0.1697
16	EI ₁₀	-0.1174	0.0738	0.1912
17	EI ₁₆	-0.1486	0.0554	0.2040
18	EI ₁₇	-0.1495	0.0663	0.2158
19	EI ₂₅	-0.3411	0.0242	0.3654
20	EI ₂₃	-0.3438	0.0141	0.3579
21	EI ₂₄	-0.5091	0.0000	0.5091
22	EI ₁₃	-0.6339	0.0000	0.6339
23	EI ₁₂	-0.6685	0.0000	0.6685

The *PROMETHEE Networks* in Figure 7.1 and Figure 7.2 presents the rankings in Table 7.1 and Table 7.2 in visualized forms through a clearer look at the incomparabilities between alternatives (i.e. indicators). As highlighted in Chapter 5, PROMETHEE I allows incomparability between alternatives. This incomparability comes from considering two values, positive and negative outranking flows (Φ^+ and Φ^- , respectively), to rank the alternatives. The higher Φ^+ and the lower Φ^- are required for indicating that an alternative is better than others.

In this regard, for Scenario-1, it can be stated that EI₂ and EI₃ are incomparable since EI₂ has higher Φ^+ and Φ^- values than EI₃'s (Figure 7.1). The comparison between EI₁₆ and EI₁₇ is another example for representing this incomparability for Scenario-1. It should be noted here that the alternatives having the same Φ^+ and Φ^- values are presented together in Figure 7.1.

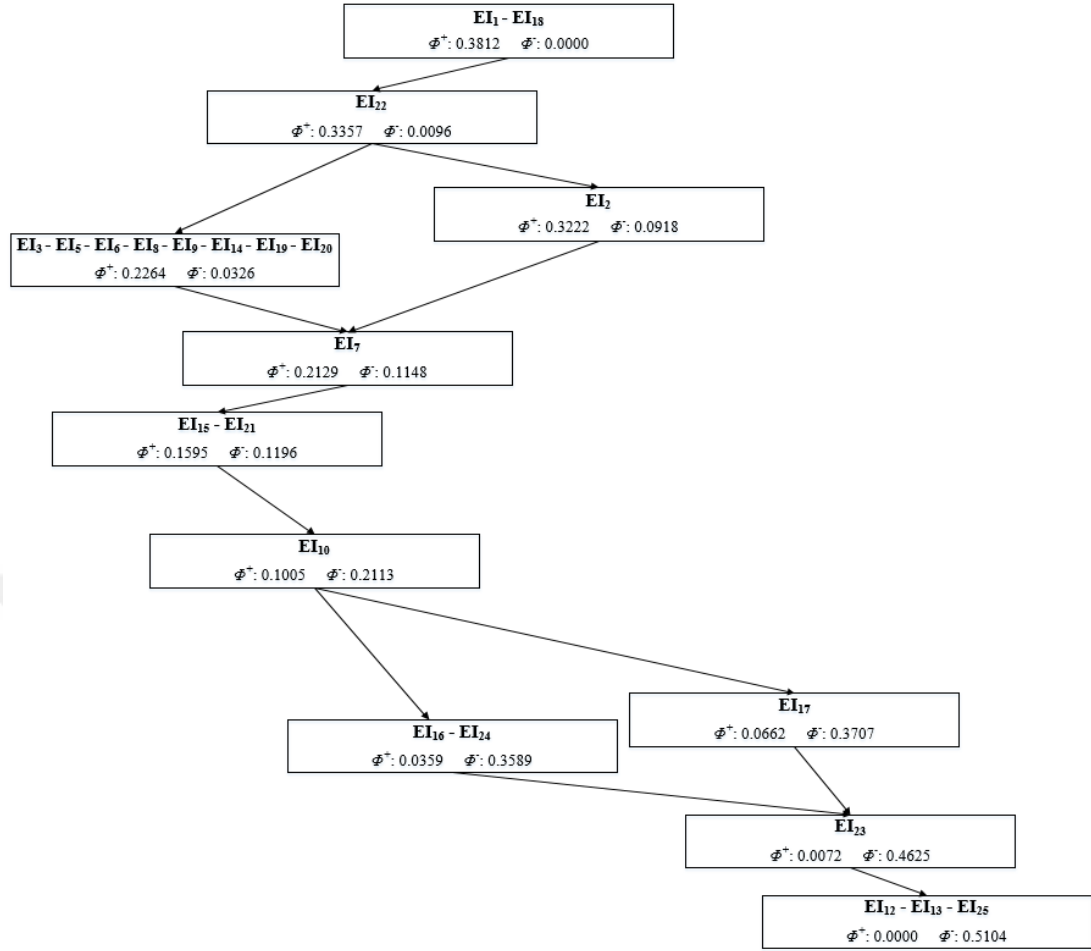


Figure 7.1 The PROMETHEE Network for Scenario-1 (redrawn from VP software)

Obviously, Figure 7.2 shows that many incomparabilities occur in Scenario-2: For example, EI₁, EI₉, EI₁₉, and EI₂₂ are incomparable due to not providing higher Φ^+ and lower Φ^- values for an alternative over others when comparing pairwise. The same inference can be made for EI₂₃ and EI₂₅ since EI₂₃ has lower Φ^+ and Φ^- values than EI₂₅'s. The incomparabilities between EI₆ and EI₂₁ as well as EI₁₆ and EI₁₇ can also be given as examples. Similar to the reason for obtaining different Φ values, the reason for gathering results including several incomparabilities between alternatives can be associated with defining all criteria as numerical in VP software due to the primary data aggregated using weighted arithmetic mean in Scenario-2 (Table 6.6).

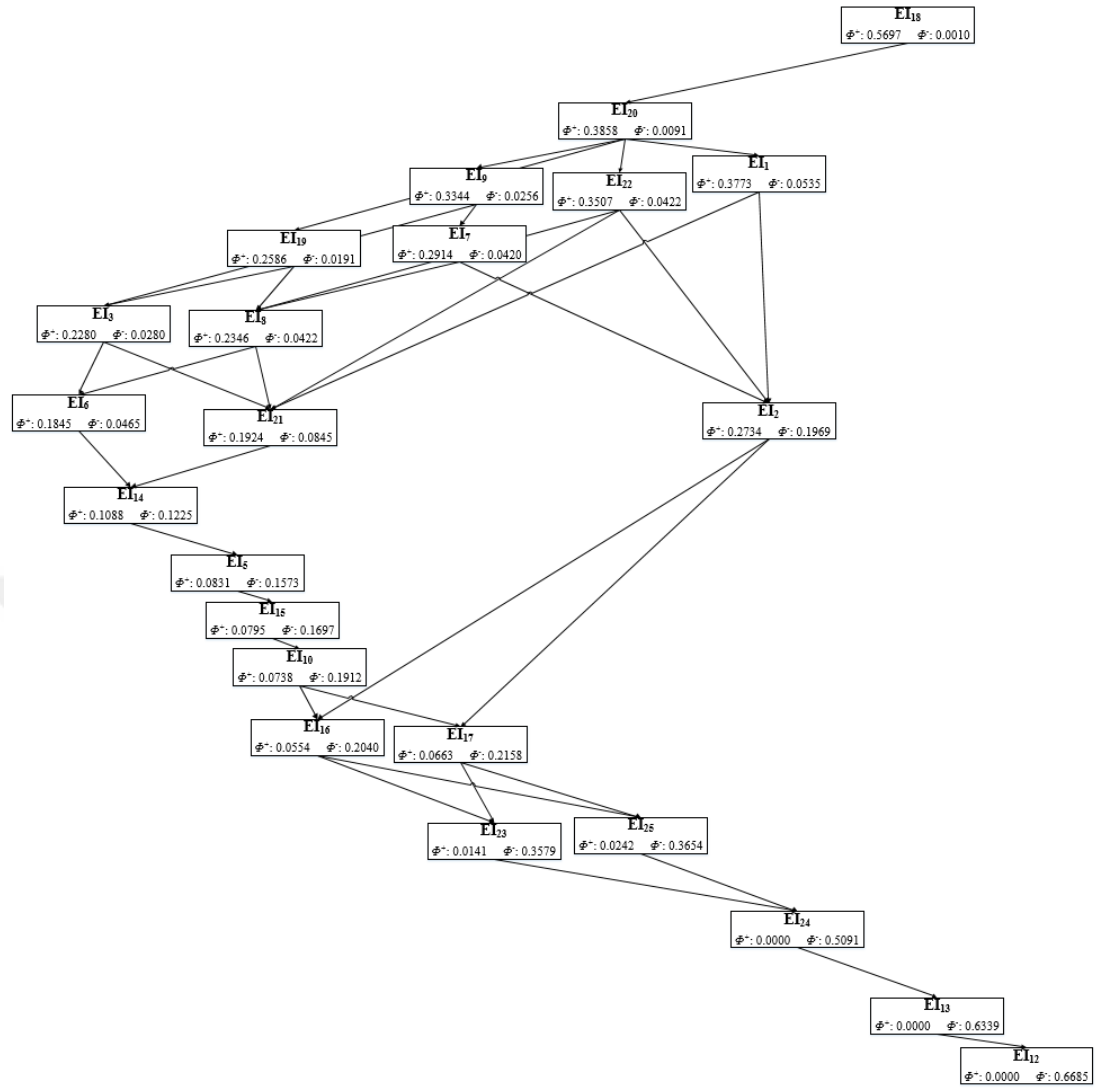


Figure 7.2 The PROMETHEE Network for Scenario-2 (redrawn from VP software)

The *GAIA* (Geometrical Analysis for Interactive Assistance) *Planes* (Brans & Mareschal, 1994; Mareschal & Brans, 1988) in Figure 7.3 and Figure 7.4 present the decision problems of Scenario-1 and Scenario-2 in a visualized way. This method uses a matrix, which comprises the net outranking flows (Φ) of all alternatives provided by PROMETHEE, including all the information that reflects the decision maker's preferences (Brans & Mareschal, 1994). The aim here is to provide a two-dimensional representation of the alternatives through the Principal Component Analysis by defining a plane while losing the information as few as possible by projection (Brans & Mareschal, 1994). The quality of the analysis is measured by this lost information;

Brans & Mareschal (1994) present this issue by defining δ , which is “a measure of the quantity of information being preserved” (p. 304). Provided that δ is sufficiently high, the properties presented below hold (Brans & De Smet, 2016, p. 203-204):

P 1: The longer a criterion axis in the GAIA plane, the more discriminating this criterion.

P 2: Criteria expressing similar preferences are represented by axes oriented in approximatively the same direction.

P 3: Criteria expressing conflicting preferences are oriented in opposite directions.

P 4: Criteria that are not related to each others in terms of preferences are represented by orthogonal axes.

P 5: Similar alternatives are represented by points located close to each other.

P 6: Alternatives being good on a particular criterion are represented by points located in the direction of the corresponding criterion axis.

In the GAIA analysis, the decision axis (π) represents the projection of the weights of the criteria on the plane (Brans & De Smet, 2016; Brans & Mareschal, 1994); its direction provides information to the decision maker on which criteria agree with the rankings obtained from PROMETHEE II (Mareschal & Brans, 1988). Additionally, the alternatives, which are positioned in the direction of π , are the ones that are recommended by PROMETHEE II (Brans & Mareschal, 1994). Ultimately, it is stated that the longer π , the stronger decision power, and it enables the decision maker to select alternatives as far as possible in the direction of π (Brans & De Smet, 2016).

By considering all these issues, several interpretations can be made in Figure 7.3. Firstly, it is stated that no criteria are conflicting with each other in Scenario-1 since there are not any criteria that are oriented in the opposite directions. Accordingly, four of five evaluation criteria consolidated for this thesis, namely *Measurability*, *Reliability*, *Proactiveness*, and *Policy Relevance*, express similar preferences. Also, it can be stated that the fifth criterion, i.e., *Resilience*, is rather independent with *Measurability* and *Proactiveness* due to the orthogonality of their axes. Furthermore, *Resilience* is the most discriminating criterion with the longest criterion axis, while

Reliability, *Proactiveness*, and *Policy Relevance* can also be indicated as discriminating on results.

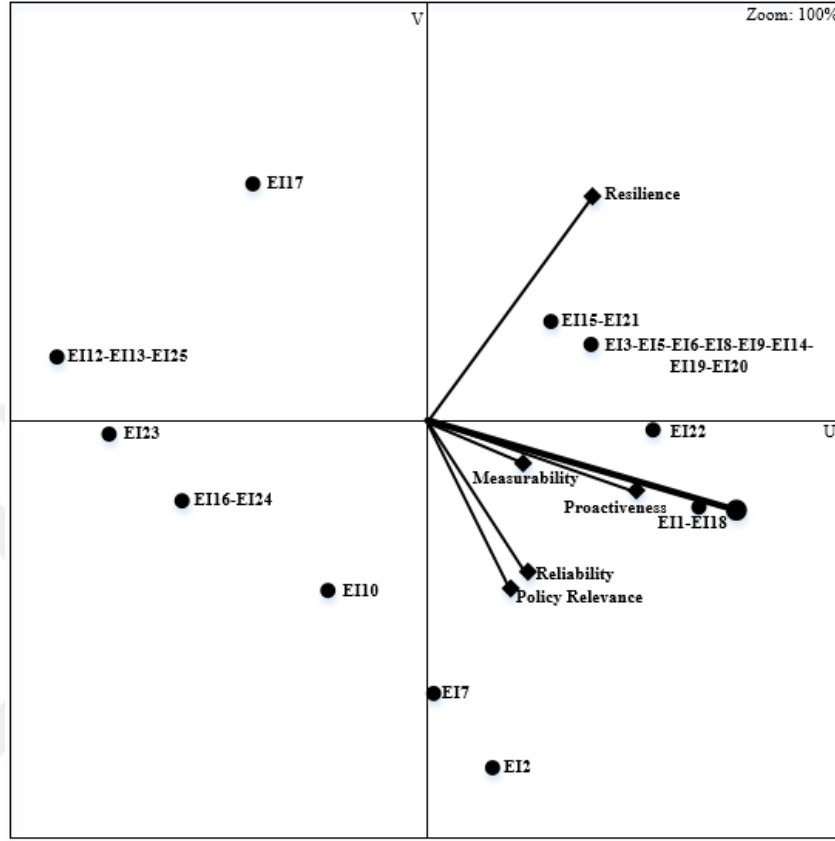


Figure 7.3 The GAIA Plane for Scenario-1 (redrawn from VP software)

Moreover, in Figure 7.3, the alternatives (i.e. the proposed ergonomics indicators) EI_1 and EI_{18} are rather good on the criteria *Measurability* and *Proactiveness*, also good on the criteria *Reliability* and *Policy Relevance*, and not so bad on the criterion *Resilience*. Similarly, EI_{22} is good on all five criteria, while EI_2 and EI_7 are good on *Reliability* and *Policy Relevance* and not so bad on *Measurability*, *Proactiveness*, and *Resilience*. Additionally, the eight alternatives EI_3 , EI_5 , EI_6 , EI_8 , EI_9 , EI_{14} , EI_{19} , EI_{20} with the same Φ value and the two alternatives EI_{15} and EI_{21} with the same Φ value are rather good on *Resilience* and not so bad on the other four criteria. On the contrarily, the alternatives that are positioned on the left side of the V-axis (i.e. EI_{10} , EI_{17} , EI_{16} , EI_{24} , EI_{23} , EI_{12} , EI_{13} , EI_{25}) are the ones that have negative Φ values, representing their weaknesses in the decision problem.

Figure 7.3 also shows that the direction of the decision axis is towards EI₁ and EI₁₈, which are the alternatives in the first rank, i.e., the best compromise, for Scenario-1. This inference supports the results presented in Table 7.1. It can also be stated that this decision axis has a strong decision power due to its length. Finally, the parameter δ representing the quality of the analysis is 88%, indicating a satisfying level. This means that the lost information by projection is 12% of the total, while 88% of all information is preserved.

Similar to Figure 7.3, several interpretations can be made in Figure 7.4. Firstly, it is stated that no criteria are conflicting with each other in Scenario-2 since there are not any criteria that are oriented in the opposite directions. Accordingly, three of five evaluation criteria consolidated for this thesis, namely *Measurability*, *Reliability*, and *Policy Relevance*, express similar preferences. Also, it can be stated that the other two criteria, i.e., *Resilience* and *Proactiveness*, is rather independent with *Policy Relevance* due to the orthogonality of their axes. Furthermore, *Resilience* is the most discriminating criterion with the longest criterion axis, and *Proactiveness* follows it, while *Measurability*, *Reliability*, and *Policy Relevance* can also be indicated as discriminating on results.

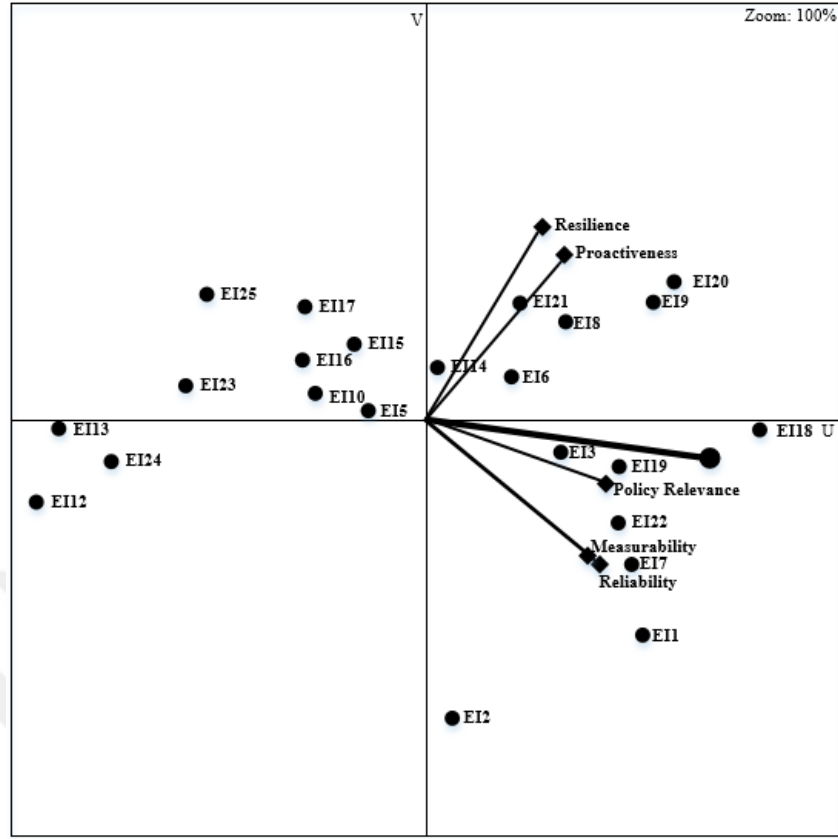


Figure 7.4 The GAIA Plane for Scenario-2 (redrawn from VP software)

Moreover, in Figure 7.4, the alternative (i.e. the proposed ergonomics indicator) EI_{18} is good on all five criteria, while EI_{19} and EI_3 are rather good on the criterion *Policy Relevance*, also good on the criteria *Measurability* and *Reliability*, and not so bad on the criteria *Resilience* and *Proactiveness*. Similarly, EI_{20} , EI_9 , EI_8 , EI_6 , and EI_{21} are good on *Resilience* and *Proactiveness* and not so bad on *Measurability*, *Reliability*, and *Policy Relevance*. Additionally, EI_1 , EI_{22} , and EI_7 are rather good on *Measurability*, *Reliability*, and *Policy Relevance* and not so bad on *Resilience* and *Proactiveness*, while EI_2 is good on *Measurability*, *Reliability*, and *Policy Relevance* and not so bad on *Resilience* and *Proactiveness*. On the contrarily, the alternatives that are positioned on the left side of the V-axis (i.e. EI_{14} , EI_5 , EI_{15} , EI_{10} , EI_{16} , EI_{17} , EI_{25} , EI_{23} , EI_{24} , EI_{13} , EI_{12}) are the ones that have negative Φ values, representing their weaknesses in the decision problem.

Figure 7.4 also shows that the direction of the decision axis is towards EI₁₈, which is the alternative in the first rank, i.e., the best compromise, for Scenario-2. This inference supports the results presented in Table 7.2. It can also be stated that this decision axis has a strong decision power due to its length. Finally, the parameter δ representing the quality of the analysis is 94%, indicating a satisfying level. This means that the lost information by projection is only 6% of the total, while 94% of all information is preserved.

7.1.5 Indicator Classification

The proposed ergonomics indicators, which were prioritized through hybrid multi-criteria analysis as examples to be used for the systematic approach, are discussed here by considering both Scenario-1 and Scenario-2. As presented in Chapter 5, positive outranking flow (Φ^+) can be defined as the measure of power and negative outranking flow (Φ^-) as the measure of weakness; therefore, the higher the net outranking flow (Φ), the better the alternative. Accordingly, the proposed ergonomics indicators having positive Φ values (Table 7.1 and Table 7.2) can be determined as examples to be used for such an approach. Importantly, despite using different aggregation methods, the rankings of indicators obtained from two scenarios are very similar (Table 7.1 and Table 7.2). This remarkable result means that despite defining the scales of criteria differently (i.e. *qualitative* for Scenario-1 and *numerical* for Scenario-2) and obtaining different Φ values, only three alternatives, i.e., EI₅, EI₁₄, and EI₁₅, have positive Φ values as a difference of rankings between the ones having positive Φ values in two scenarios. Consequently, the rankings in Table 7.2 (i.e. Scenario-2) were regarded for determining the indicators as examples to be used for such an approach, while these three indicators were also considered due to having positive Φ values in Scenario-1. Then, the twenty-three ergonomics indicators with their two different classifications proposed in this thesis (Figure 3.4 and Table 3.2) are summarized below.

Table 7.3 The proposed ergonomics indicators with their rankings and Φ values obtained from the hybrid multi-criteria analysis and their classifications proposed in this thesis

Rank	Φ	No	Proposed Ergonomics Indicator	First Classification		Second Classification
				Main Dimension	Proposed Sub-Dimension	Indicator Type
1	0.5686	EI ₁₈	Percentage of employees receiving EHS training per year	Social	Self-Development	Leading
2	0.3766	EI ₂₀	Number of suggested improvements made by employees per year	Social	Self-Development	Leading
3	0.3237	EI ₁	Number of accident-free days per year	Economic	Loss	Lagging
4	0.3088	EI ₉	Expenditure on research and development, technology, and innovation per year to enhance ergonomically and environmentally-friendly designed processes	Economic	Investment	Leading
5	0.3085	EI ₂₂	Annual turnover rate of employees	Social	Satisfaction	Lagging
6	0.2494	EI ₇	Cost of EHS training of employees per year	Economic	Investment	Leading
7	0.2395	EI ₁₉	Percentage of total time spent due to EHS training relative to the total hours worked per year	Social	Self-Development	Leading
8	0.1999	EI ₃	Percentage of total lost time due to accidents and injuries relative to the total hours worked per year	Economic	Loss	Lagging
9	0.1924	EI ₈	Expenditure on employee development per year	Economic	Investment	Leading
10	0.1380	EI ₆	Annual investment cost for ergonomics interventions and EHS issues	Economic	Investment	Leading
11	0.1079	EI ₂₁	Annual number of activities made for the proper implementation of the procedures related to ergonomics interventions and EHS issues	Social	Self-Development	Leading
12	0.0765	EI ₂	Number of injury-free days per year	Economic	Loss	Lagging
13	-0.0137	EI ₁₄	Number of activities made for improving working conditions per year	Ecological	Conditions	Leading
14	-0.0742	EI ₅	Number of cases of occupational diseases per year	Economic	Loss	Lagging
15	-0.0902	EI ₁₅	Number of volunteers for making charitable contributions to EHS issues per year	Ecological	Contribution	Leading
16	-0.1174	EI ₁₀	Number of complaints due to physical conditions (noise, temperature, odour, dust, etc.) per year	Ecological	Conditions	Lagging
17	-0.1486	EI ₁₆	Percentage of recycled products/raw materials used in ergonomically designed processes per year	Ecological	Contribution	Leading
18	-0.1495	EI ₁₇	Percentage of annual incentives and promotions made for stakeholders to contribute ergonomically and environmentally-friendly designed processes	Ecological	Contribution	Leading
19	-0.3411	EI ₂₅	Percentage of employees participating in managerial decisions related to ergonomics interventions and EHS issues per year	Social	Satisfaction	Leading
20	-0.3438	EI ₂₃	Percentage of employees who are satisfied with their work	Social	Satisfaction	Leading
21	-0.5091	EI ₂₄	Number of complaints due to working conditions not covered by decent work per year	Social	Satisfaction	Lagging
22	-0.6339	EI ₁₃	Percentage of employees working in unfavourable conditions leading to physical and mental health problems per year	Ecological	Conditions	Lagging
23	-0.6685	EI ₁₂	Number of days when there are unfavourable physical conditions (noise, temperature, odour, dust, etc.) per year	Ecological	Conditions	Lagging

Note: Some of the ergonomics indicators are remarked to indicate the ones determined as examples to be used for the systematic approach ($n = 15$).

As presented in Table 7.3, the ergonomics indicators, which have positive Φ values in both Scenario-1 and Scenario-2 (12 out of 23), and the first three ergonomics indicators, which have negative Φ values in Scenario-2 but have positive Φ values in Scenario-1 (3 out of 23), were proposed to be used for the systematic approach. It is reminded that the data used for calculating these Φ values as representing the rankings obtained from PROMETHEE II were collected through Survey-2 from the practitioners in companies in Turkey, who are specialized in ergonomics and sustainability and are potential users of such an approach. Importantly, these practitioners were not informed about the two classifications presented in Table 7.3 to receive a more objective evaluation.

Accordingly, the results presented in Table 7.3, i.e., the proposed ergonomics indicators that were prioritized and determined as examples to be used for the systematic approach ($n = 15$), are remarkable by considering their main dimensions, proposed sub-dimensions, and indicator types, which are summarized below:

- *For the first classification comprising the main dimensions and the proposed sub-dimensions,*
 - All ergonomics indicators that belong to the *Economic* dimension (i.e. EI₁, EI₂, EI₃, EI₅, EI₆, EI₇, EI₈, and EI₉) are ranked high as the ones proposed for the systematic approach. It can be stated that this result shows the dominance of the business models focusing on *Loss* and *Investment* in Turkey since the practitioners mostly pay attention to the ergonomics indicators belonging to these sub-dimensions.
 - All ergonomics indicators that belong to the *Self-Development* sub-dimension of the *Social* dimension (i.e. EI₁₈, EI₁₉, EI₂₀, and EI₂₁) are also ranked high. These indicators are related to training, suggested improvements, and proper implementation of the procedures, which can be indicated as the efforts made by companies in Turkey for ergonomics and sustainability in general. Moreover, it is thought-provoking that the majority of the ergonomics indicators (3 out of 4) that belong to the *Satisfaction* sub-dimension of the *Social* dimension (i.e. EI₂₃, EI₂₄, and

EI₂₅) are in the lower ranks, even though these indicators are related to the critical issues in organizations such as employees' participation in managerial decisions, work satisfaction, and decent work. The only indicator that belongs to the *Satisfaction* sub-dimension of the *Social* dimension and is ranked high comprises the turnover rate (i.e. EI₂₂).

- Only two ergonomics indicators that belong to the *Ecological* dimension (i.e. EI₁₄ and EI₁₅) are ranked high by taking place after the other ergonomics indicators proposed for the systematic approach. These indicators belong to the *Conditions* and *Contribution* sub-dimensions, having negative Φ values in Scenario-2 but having positive Φ values in Scenario-1. It can be stated that much more efforts should be made for spreading the idea of preserving the ecology as well as improving the working conditions by considering the remaining ergonomics indicators belonging to this dimension (i.e. EI₁₀, EI₁₂, EI₁₃, EI₁₆, and EI₁₇).
- For the second classification comprising the indicator types, it is stated that the majority of the ergonomics indicators proposed for the systematic approach (67%; 10 out of 15) is *leading* indicators. This result, i.e., using these leading indicators that are proactive, can be indicated as encouraging for organizations in Turkey to take precautions and minimize risk levels.

7.2 General Evaluation

By considering all these issues, the main point here can be summarized as follows: All ergonomics indicators proposed in this thesis ($n = 25$) (Figure 3.4) are valuable and eligible, and although they can be improved, undoubtedly, they were proposed as the candidates to be used for a systematic approach that integrates ergonomics and sustainability to monitor and evaluate processes of organizations holistically. It is reminded that nearly all of these indicators (23 out of 25) were determined as appropriate by the experts (i.e. Survey-1), who are researchers and practitioners specialized in ergonomics and sustainability and working in these areas for years.

Nevertheless, some experts commented on these proposed ergonomics indicators, whose appropriateness were asked through *Survey-1*, to improve the developed systematic approach comprising these indicators as fundamental components (please see the *final part of the questionnaire* in Section 5.2.1 for details). One suggestion, which belongs to a researcher from a university having many years of experience in ergonomics and sustainability, points out social sustainability by highlighting that the indicators presented in *Survey-1* seem to relate to social sustainability. Indeed, this is an expected result, aiming to present the coherence between ergonomics and sustainability, and this coherence was presented in this thesis through the proposed ergonomics indicators consolidated from the selected sustainability indicators as a result of the integration of ergonomics and sustainability.

Another suggestion in *Survey-1*, which belongs to another researcher from a university having many years of experience in ergonomics and sustainability, remarks on a missing way of the indicators by indicating that the ecological aspects are almost not considered. As presented, the proposed ergonomics indicators enable considering the ecological aspects mostly through measuring working conditions (i.e. the proposed ergonomics indicators classified under *Conditions* sub-dimension) within the scope of this thesis (i.e. search on human, work design, and workplace design), although there are also some ergonomics indicators proposed for measuring ecological aspects within a broader perspective (i.e. the proposed ergonomics indicators classified under *Contribution* sub-dimension). Moreover, it can be indicated that obtaining relatively low rankings through the hybrid multi-criteria analysis using the secondary data gathered from *Survey-2* for the ergonomics indicators classified under the *Ecological* dimension reflects these missing ecological aspects (Table 7.3); these indicators were not also preferred by the practitioners in Turkey, who are specialized in ergonomics and sustainability and are potential users of such a systematic approach.

Additionally, the general evaluation of *Survey-2*, whose aim is to measure the perception of the applicability of such a systematic approach and whose respondents are the practitioners in companies in Turkey specialized in ergonomics and sustainability and potential users of the systematic approach, was made through two

questions having a 7-points Likert-type scale to query the evaluation of the indicators proposed in this thesis as a whole (please see the *final part of the questionnaire* in Section 5.2.2 and Section 5.3.1 for details). It is presented that the responses to these two questions, which are discussed below in detail, represent the usefulness and competence of the systematic approach comprising the ergonomics indicators proposed in this thesis:

- The *first question* is related to query the appropriateness of the proposed ergonomics indicators to be used for such an approach while measuring the performance of various processes in an organization and monitoring their results. The points given by the respondents for this question varies between 2 and 7, representing *Disagree* and *Strongly agree* by considering the used response anchors called *Level of Agreement*, with a mean of 5.1356 and a standard deviation of 1.2520. Essentially, obtaining a mean of over 5 points (i.e. *Somewhat agree*), which is higher than the midpoint (i.e. 4 representing *Neither agree or disagree*) of the Likert-type scale, can be indicated as a satisfying result with a relatively low standard deviation. Although 2 points (i.e. *Disagree*) were given to this question at a minimum in the survey, the number of respondents who gave this point is only 3 (5%; 3 out of 59), while the number of respondents who gave 3 points (i.e. *Somewhat disagree*) is only 5 (8%; 5 out of 59), and the number of respondents who gave 4 points (i.e. *Neither agree or disagree*) is only 4 (7%; 4 out of 59) with a total of 20% of all respondents (12 out of 59). Furthermore, the remaining respondents (80%; 47 out of 59) gave 5 points (36%; 21 out of 59), 6 points (36%; 21 out of 59), and 7 points (8%; 5 out of 59), which correspond to *Somewhat agree*, *Agree*, and *Strongly agree*, respectively.
- The *second question* is related to query the appropriateness of the proposed ergonomics indicators in terms of ergonomics and sustainability for measuring the performance of any processes in organizations and monitoring their results by minor modifications when necessary. The points given by the respondents for this question varies between 3 and 7, representing *Somewhat disagree* and *Strongly agree* by considering the used response anchors called *Level of*

Agreement, with a mean of 5.4915 and a standard deviation of 0.9354. Essentially, obtaining a mean of over 5 points (i.e. *Somewhat agree*), which is higher than the midpoint (i.e. 4 representing *Neither agree or disagree*) of the Likert-type scale, can be indicated as a satisfying result with a relatively low standard deviation. Although 3 points (i.e. *Somewhat disagree*) were given to this question at a minimum in the survey, the number of respondents who gave this point is only 2 (3%; 2 out of 59), while the number of respondents who gave 4 points (i.e. *Neither agree or disagree*) is only 4 (7%; 4 out of 59) with a total of 10% of all respondents (6 out of 59). Furthermore, the remaining respondents (90%; 53 out of 59) gave 5 points (41%; 24 out of 59), 6 points (36%; 21 out of 59), and 7 points (13%; 8 out of 59), which correspond to *Somewhat agree*, *Agree*, and *Strongly agree*, respectively.

Consequently, as stated previously in many subsections of this thesis, the ultimate goal of this thesis is to develop such a systematic approach integrating ergonomics and sustainability through the proposed ergonomics indicators for sustainable process performance measurement in ergonomics. During the efforts made for achieving this, it was planned that such an approach should comprise a performance measurement system and those ergonomics indicators as the fundamental part of it. The main point here was to build a structure that enables measuring the performance of various processes in organizations and monitoring their results systematically.

In this regard, the development of the systematic approach integrating ergonomics and sustainability as the result of this thesis is presented in the following chapter into three steps, comprising the fundamental components, the main structure, and the roadmap proposal. It should be noted that these steps represent the development phases of the systematic approach, which were constituted by considering the frameworks presented in Chapter 4.

CHAPTER EIGHT

SYSTEMATIC APPROACH DEVELOPMENT INTEGRATING ERGONOMICS AND SUSTAINABILITY

This chapter comprises the development phases of the systematic approach, including fundamental components, main structure, and the roadmap proposal representing the systematic approach.

8.1 Fundamental Components of the Systematic Approach

As presented in Chapter 4 in detail, there are various frameworks in literature comprising the main structures, components, and steps of performance measurement systems. Since such a system was defined in this thesis as a fundamental part of the systematic approach, these frameworks can be indicated as the guidelines to develop this approach. By considering all, the fundamental components of the systematic approach to be developed as the result of this thesis is presented below in Figure 8.1.

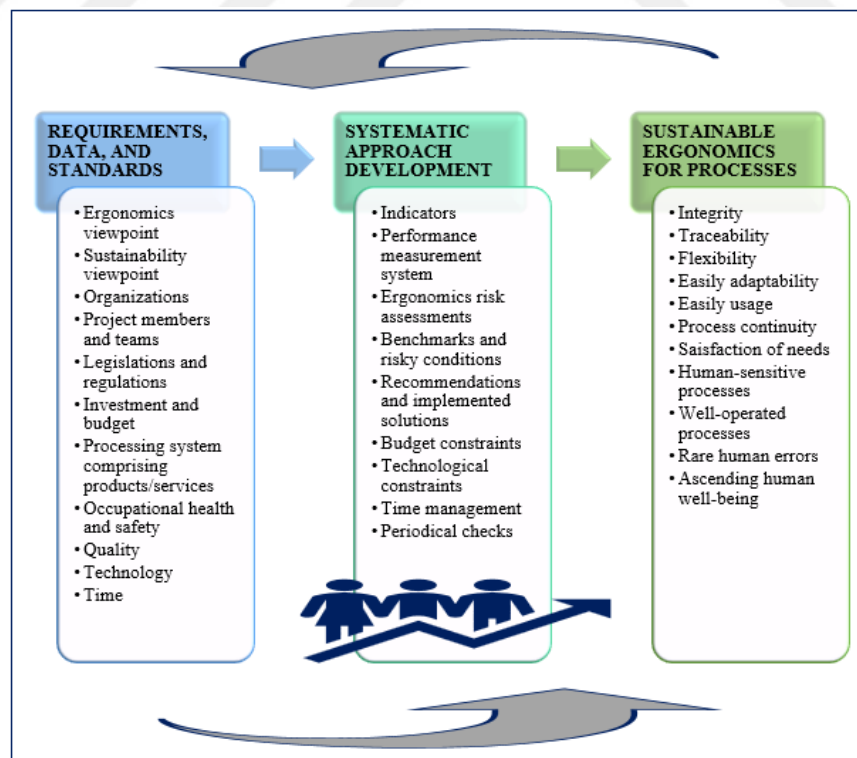


Figure 8.1 The fundamental components of the systematic approach

The structure in Figure 8.1 was depicted as a process model, including the three phases, namely input, transformation, and output. Additionally, it was constituted as a recurring process; a bidirectional flow was depicted with two opposite-way arrows, representing the continuous review and feedback for the three-phased structure. The phases in Figure 8.1 were defined as *Requirements, Data, and Standards, Systematic Approach Development, and Sustainable Ergonomics for Processes*, respectively:

- *The first phase* consists of the issues related to human, work design, and workplace design under the sustainable ergonomics domain, which is the scope of this thesis. These issues can be defined as *inputs*, and the lack of one of them or their mismanagement may lead to an ineffectively developed systematic approach and unfavourable and inefficient processes in organizations.
- *The second phase* is the systematic approach to be developed for sustainable process performance measurement in ergonomics. This phase can be defined as *transformation*; it contains a set of events, tasks, evaluations, and key elements rather than issues that should be regarded. The success of the entire process is affected by the proper implementation of this phase.
- *The third phase* comprises the qualifications of the approach as well as aims and targets. These main focus points can be defined as *outputs*, and this phase describes the desired result to be achieved when all is fulfilled.

8.2 Main Structure of the Systematic Approach

The main structure of the systematic approach to be developed as the result of this thesis is presented below in Figure 8.2. It was depicted as a representative of this approach by presenting all the efforts made in this thesis, comprising deeply searches both in ergonomics and sustainability as well as designs, proposals, justifications, presentations, discussions, and the publishing of two papers whose details were given in Chapter 1. This structure can be stated as a summary of the thesis, including all the efforts (i.e. systematic literature review, classifications, and detailed descriptions for the proposal of ergonomics indicators, hybrid multi-criteria analysis, and a roadmap proposal) made for achieving the development of the systematic approach.

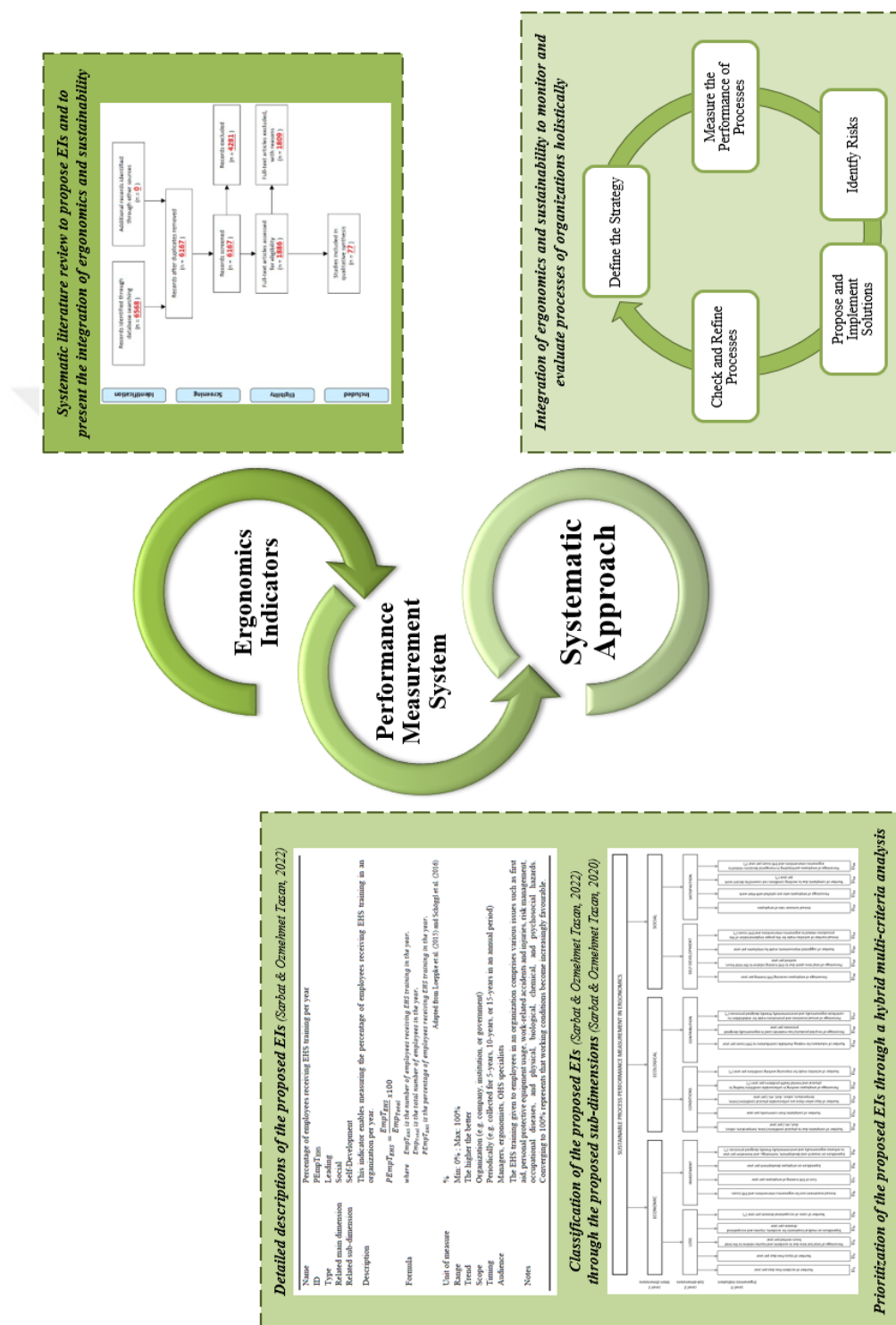


Figure 8.2 The main structure of the systematic approach comprising the proposed ergonomics indicators and performance measurement system

8.3 A Roadmap Proposal Representing the Systematic Approach

Ultimately, the systematic approach developed in this thesis is presented below in Figure 8.3. This systematic approach is indicated as a roadmap proposal for the organizations whose processes are needed to be monitored and evaluated holistically under the sustainable ergonomics domain. In this regard, five phases, namely *Define the Strategy*, *Measure the Performance of Processes*, *Identify Risks*, *Propose and Implement Solutions*, and *Check and Refine Processes*, were defined for this approach.

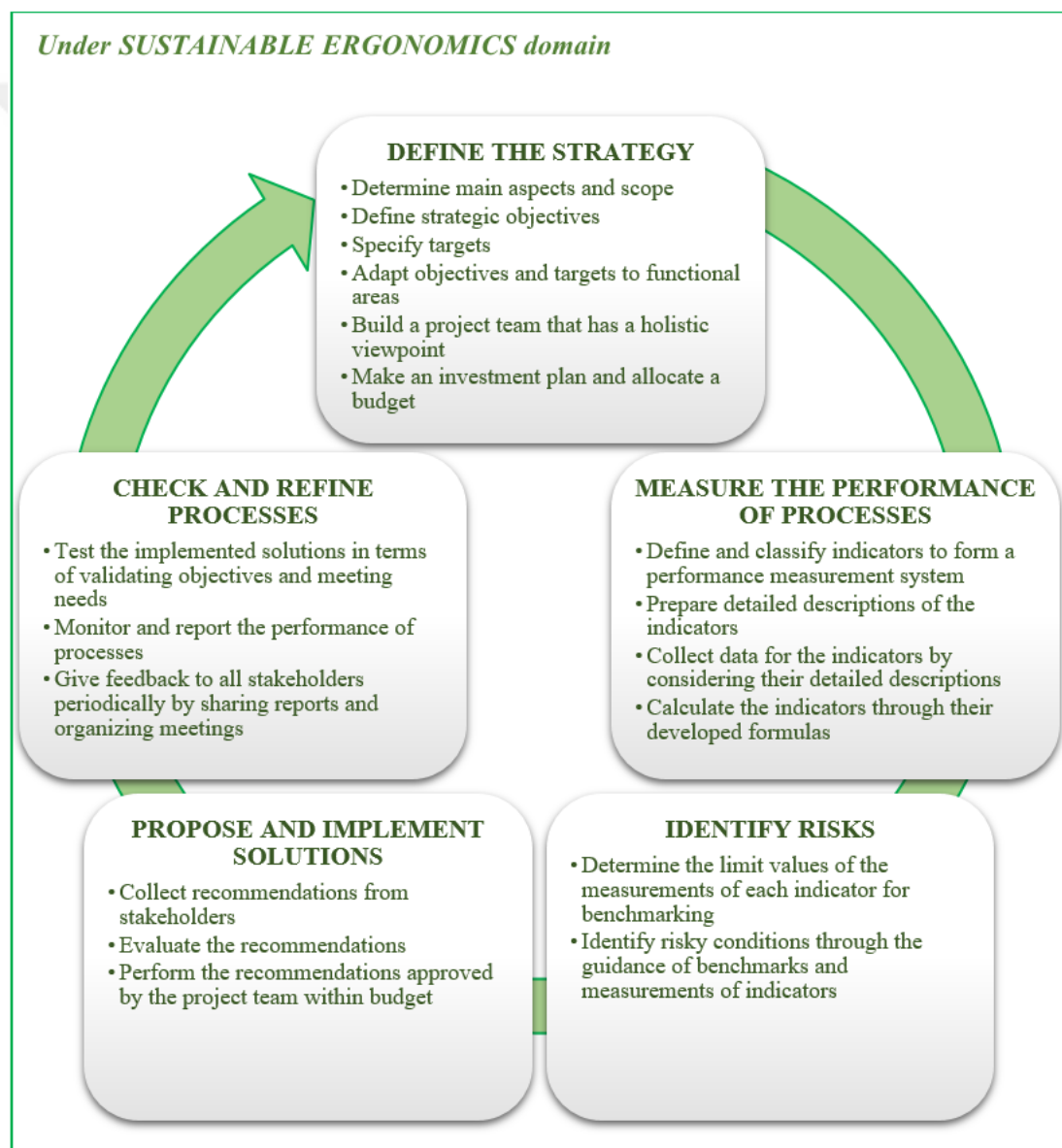


Figure 8.3 The systematic approach developed in this thesis

- *The first phase (i.e. Define the Strategy)* is the general framework of the systematic approach, comprising main aspects, scope, strategic objectives, targets, investment plan, and budget. These issues are begun to be defined from the top of the organizational hierarchy and are adapted to the lowest functional areas. Building a project team, which conducts and manages the systematic approach within a holistic point-of-view, is also one of the steps of this phase.
- *The second phase (i.e. Measure the Performance of Processes)* basically represents the performance measurement system. The first two steps of this phase (i.e. defining and classifying ergonomics indicators with preparing their detailed descriptions) are related to the development of such a system, and the remaining two (i.e. collecting data and calculating ergonomics indicators) are for putting the system into practice. All efforts made in this thesis to develop such a system (i.e. the first two steps of this phase) were presented in Chapter 2 and Chapter 3. Additionally, the implementation parts of this thesis, i.e., Chapter 5, Chapter 6, and Chapter 7, also present the proposed ergonomics indicators as examples to be used for the systematic approach by prioritizing them through hybrid multi-criteria analysis.
- *The third phase (i.e. Identify Risks)* comprises the reflections, i.e., outputs, of the performance measurement system presented in the previous phase and the evaluations on these outputs to identify risky conditions in various processes of organizations. This phase is based on the limit values (i.e. benchmarks) of the ergonomics indicators determined for comparison with the measurements of the indicators calculated in the previous phase. The benchmarking here can be both internally or externally; the first one is to compare the measurements with the values calculated in the previous period for the same process of an organization, while the second one is to compare the measurements with the values of competitor organizations.
- *The fourth phase (i.e. Propose and Implement Solutions)* is the solution phase, which consists of stakeholders' recommendations for the processes identified in the previous phase as having risky conditions. Here, the evaluation and implementation of these recommendations are made by the project team by

considering the budget. If the budget allocated in the first phase is insufficient for all suggested solutions, the project team may prioritize the solutions.

- *The fifth phase (i.e. Check and Refine Processes)* is the final phase, which comprises the testing, monitoring, and reporting of the performance of processes of organizations measured through the systematic approach. The important point here is validating objectives and meeting needs, which are defined in the first phase, through the systematic approach. Periodical feedback given to all stakeholders is another important step of this phase for generating the organizational culture for sustainable process performance measurement in ergonomics.

In the following chapter, a summarization of all efforts made in this thesis is presented by comprising summary and concluding remarks, implications for theory and practice, and future research directions of this thesis.

CHAPTER NINE

CONCLUSION

This chapter comprises the summary and concluding remarks, implications for theory and practice, and future research directions of this thesis.

9.1 Summary and Concluding Remarks

The rapidly changing global world, where it is now harder to provide and preserve human well-being, poses many challenges that may affect human well-being. Although ergonomics has tried to provide human well-being for decades with its multi-disciplinary structure, even if only daily needs are considered, the responsibilities of ergonomics in providing sufficient solutions to challenging conditions can be easily noticed. Subsequently, the reflections of these challenges can be more crucial for the organizations, which should provide ergonomically favourable working conditions to thousands of employees. To provide these conditions, well-operated processes should be achieved at first; hence, ergonomists or managers, as the stakeholders responsible for designing works, workplaces, and related business processes in organizations suitable for employees, work for measuring the performance of processes, identifying potential ergonomics risks, and proposing solutions. Basically, existing approaches have been developed for the well-being of all stakeholders as well as organizations. Unfortunately, it can be stated that these efforts are not sufficient anymore to have well-designed and effectively managed processes in ergonomics.

Indeed, as Thatcher et al. (2018) denote, it is difficult to expect the ergonomics discipline to ‘fight’ these challenges by itself. Nevertheless, there is an endeavour for many sustainable products and systems to achieve widespread adoption and use (Thatcher, 2012). Furthermore, by spreading throughout industrial, scientific, political, commercial, and other various channels, sustainability has become significant in recent years (Haslam & Waterson, 2013). By considering all these issues, it can be stated that the sustainability concept can assist ergonomics in this regard by holistically incorporating economic, ecological, and social issues. Essentially, sustainability is not

a new approach in ergonomics since the general principles of sustainability have been an integral part of the discipline for a long time (Zink & Fischer, 2013). Nevertheless, a more sustainable approach should be reflected by ergonomics on living and being (Lange-Morales et al., 2014). In this regard, sustainability should stimulate ergonomics researchers and practitioners to look at the world from a broader view rather than dealing with narrow conceptualizations of ergonomics problems (Thatcher & Yeow, 2016).

The latest practices show that organizations try to meet stakeholders' needs within a sustainability point-of-view by using various indicators. These indicators, depending on what type of processes or organizations they are used for, can be ecological, technological, economic, managerial, social, or belonging to any research area that works for measuring the performance of processes of organizations. It is highlighted that these indicators can facilitate to determine which process is needed to be improved by considering the measurements made systematically and periodically. According to Wells, Neumann, Nagdee, & Theberge's (2013) findings, indicators on ergonomics, which may enable ergonomics integration with the ordinary improvement works, are being developed by large companies. Rather than presenting more costly quantitative proof to stakeholders to convince them of the need for changing these improvement projects, this action (i.e. development of indicators) can serve this aim, and, the cost of the programs related to ergonomics can be reduced in this way (Wells et al., 2013). All these efforts can be more practical and useful if they are made systematically and periodically as part of an ongoing holistic sustainability measurement. Therefore, it is thought that better perpetual conditions are more likely to be provided with using sustainability in ergonomics.

As it can be easily noticed from the relevant literature, there are many organizations that consolidate these sustainability indicators for monitoring and evaluating their processes systematically. By starting from this easily adaptable structure of sustainability indicators, it is stated that sustainability indicators can also be consolidated for the proposal of ergonomics indicators. Additionally, these ergonomics indicators can be classified into some new dimensions or sub-dimensions in ergonomics under a

sustainability point-of-view to build a theoretical background for developing a systematic approach that integrates ergonomics and sustainability. The fundamental part of such an approach can be a performance measurement system comprising these proposed ergonomics indicators.

Under these circumstances, the sustainability concept was discussed in this thesis to support ergonomics by developing a systematic approach for sustainable process performance measurement in ergonomics. In other words, it can be stated that identifying relations between ergonomics and sustainability is not difficult due to the central position of humans in ergonomics and the implicit and explicit effects of humans over the three dimensions of sustainability (i.e. *Economic*, *Ecological*, and *Social*). Basically, it was frequently highlighted in this thesis that these potential relations can be presented with the help of sustainability indicators, their consolidated forms to ergonomics (i.e., ergonomics indicators), and classifications of these consolidated forms into new sub-dimensions through a structural framework used as a theoretical background for the systematic approach development integrating ergonomics and sustainability. To develop such an approach and present this coherence, various efforts were achieved in this thesis, and these efforts are visualized in Figure 9.1 within three phases and eleven steps.

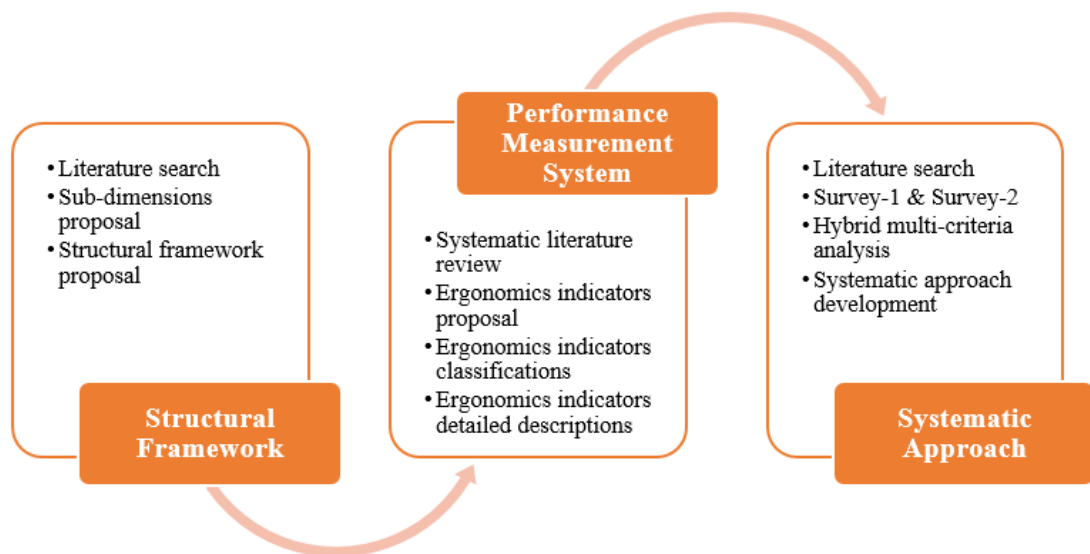


Figure 9.1 The summary of this thesis representing the efforts achieved in this thesis

The phases and their steps in Figure 9.1 are summarized as follows:

- The first phase, i.e., *Structural Framework*, corresponds to Chapter 2 of this thesis. As presented in Figure 1.2, this chapter consists of the first paper produced from this thesis (Sarbat & Ozmehmet Tasan, 2020).
 - The first step, i.e., *Literature search*, comprises the research on sustainability and its potential contributions to ergonomics through indicators to present the integration of ergonomics and sustainability (Section 2.1).
 - The second step, i.e., *Sub-dimensions proposal*, represents the six sustainability sub-dimensions proposed for ergonomics (Figure 2.4), namely *Loss*, *Investment*, *Conditions*, *Contribution*, *Self-Development*, and *Satisfaction*, by considering human, work design and workplace design together referring to the fundamental elements of ergonomics (i.e. job/task, workplace & equipment, work organization, and employee) in Scott et al. (2010).
 - The third step, i.e., *Structural framework proposal*, is stated as the theoretical background of this thesis, including the relations between fundamental elements of ergonomics and sustainability dimensions to present the integration of ergonomics and sustainability. In this base framework (Figure 2.8), two new sub-dimensions summarized in the second step were proposed for each three dimensions of sustainability. The proposed ergonomics indicators consolidated from the selected sustainability indicators, which were the frequently encountered indicators in the prominent studies in this area, were also classified in these sub-dimensions (Figure 2.5, Figure 2.6, and Figure 2.7).
- The second phase, i.e., *Performance Measurement System*, corresponds to Chapter 3 of this thesis. As presented in Figure 1.2, this chapter consists of the second paper produced from this thesis (Sarbat & Ozmehmet Tasan, 2022).
 - The fourth step, i.e., *Systematic literature review*, is a comprehensive literature search (Figure 3.1) conducted in this thesis to select the papers ($n = 77$ in Table 3.1) relevant to ergonomics and sustainability. These

papers helped to identify the sustainability indicators, which were used as references to propose ergonomics indicators through the consolidation of these indicators.

- The fifth step, i.e., *Ergonomics indicators proposal*, represents the ergonomics indicators ($n = 25$ in Figure 3.4) proposed in this thesis through the consolidation of the sustainability indicators selected from the papers summarized in the fourth step. These proposed ergonomics indicators can be used for a performance measurement system as the fundamental part of a systematic approach developed for sustainable process performance measurement in ergonomics.
- The sixth step, i.e., *Ergonomics indicators classifications*, presents two different classifications proposed in this thesis: The first classification is the presentation of the proposed ergonomics indicators within a three-dimensional structure (Figure 3.4), comprising the proposed sub-dimensions summarized in the second step, to monitor and evaluate processes of organizations holistically. The second classification is the presentation of these ergonomics indicators by considering their indicator types, i.e., being lagging or leading indicators (Table 3.2).
- The seventh step, i.e., *Ergonomics indicators detailed descriptions*, includes the identification of the detailed descriptions (Appendix-3) for the proposed ergonomics indicators to be used in a performance measurement system. These descriptions were proposed as a basis for systematic approach development for sustainable process performance measurement in ergonomics.
- The third phase, i.e., *Systematic Approach*, corresponds to Chapter 4, Chapter 5, Chapter 6, Chapter 7, and Chapter 8 of this thesis. As presented in Figure 1.2, these chapters consist of the third and fourth paper produced from this thesis, which were submitted to a journal.
- The eighth step, i.e., *Literature search*, comprises the research on the definitions and key issues for a performance measurement system with its suggested steps comprising its elements to present a theoretical look at

systematic approach development. Various frameworks in literature were presented in this part of the thesis (Section 4.2).

- The ninth step, i.e., *Survey-1 & Survey-2*, are the surveys designed and developed for this thesis (Section 5.2) for the validity and reliability of implementation, respectively. Specifically, Survey-1 is for determining the appropriateness of the proposed ergonomics indicators as fundamental components of a systematic approach integrating ergonomics and sustainability, while Survey-2 is for measuring the perception of the applicability of this systematic approach in companies. These surveys also provided data for the analysis made in this thesis (Chapter 6).
- The tenth step, i.e., *Hybrid multi criteria analysis*, includes BWM and PROMETHEE (Section 5.3.2) performed to present a base study as an example for prioritizing the proposed ergonomics indicators to be used for the systematic approach by using the secondary data of Survey-2 gathered from aggregation (Section 6.2.2).
- The eleventh step, i.e., *Systematic approach development*, represents the systematic approach (Figure 8.3) developed in this thesis for sustainable process performance measurement in ergonomics. This systematic approach was indicated as a roadmap proposal under the sustainable ergonomics domain for organizations to monitor and evaluate their processes holistically, while the fundamental components (Figure 8.1) and the main structure (Figure 8.2) of this developed systematic approach were also given, representing the development phases of this approach.

9.2 Implications for Theory and Practice

As Dul et al. (2012) summarize, there is a great potential of ergonomics to shape any designed artefact, which ranges from a product to an organizational environment, by considering the capacities and desires of humans, such that well-being and performance are optimized (Dul et al., 2012). It can be stated that this potential can be used in the development of a systematic approach integrating ergonomics and sustainability to monitor and evaluate any process holistically. Lange-Morales et al.

(2014) point out that the sustainability concept should be included in all ergonomics subdisciplines and working groups in the long term to integrate sustainability with ergonomics in practice. Therefore, if the developed systematic approach comprising both ergonomics and sustainability facilitates measuring the performance of processes of organizations under the sustainable ergonomics domain, the needs of the humans that benefit from business processes in the near future can be more easily met.

Undoubtedly, the endeavour here is structuring this thesis on this basis. Since the aim would be the consideration of all dimensions of sustainability rather than one or two of them (Lange-Morales et al., 2014), a structural framework for the integration of ergonomics and sustainability, comprising all three dimensions of sustainability as the main dimensions, the six sustainability sub-dimensions proposed for ergonomics in this thesis, and the twenty-five ergonomics indicators proposed in this thesis, was proposed in this thesis as *the first original contribution* for both theory and practice. It is stated in this thesis that this practical and easily adaptable framework can be used by the ergonomists or managers, who are responsible for having more traceable, manageable, and ergonomically well-designed processes in organizations, to facilitate having processes satisfying the needs of stakeholders and putting cost-effective as well as environmentally friendly interventions into practice.

Subsequently, it is considered that the integration of ergonomics and sustainability can constitute a coherent structure. To present this coherence, a systematic approach, comprising a performance measurement system and its proposed ergonomics indicators as the fundamental part of such an approach by integrating ergonomics and sustainability through these indicators for sustainable process performance measurement in ergonomics, was developed in this thesis as *the second original contribution* for both theory and practice. This approach facilitates monitoring, evaluating, and finally, overcoming the risks caused by unfavourable working conditions to provide and preserve human well-being by measuring the performance of processes of organizations through indicators.

As a consequence, it can be stated that the structural framework, proposed as a basis for representing the theoretical background in this thesis, can be used for monitoring and evaluating processes of organizations ergonomically under a sustainability point-of-view. Later, the proposal of the ergonomics indicators, which are related to various issues such as working conditions, decent work, innovations, employee empowerment and development, recycling, occupational health and safety, charities, and technology classified under six sustainability sub-dimensions proposed for ergonomics and then three dimensions of sustainability as a comprehensive solution proposal, enables developing the systematic approach integrating ergonomics and sustainability using these indicators as the fundamental part of it. It is stated that this systematic approach can help ergonomists or managers to ensure ergonomically favourable conditions by measuring the performance of processes of organizations in a sustainable way and monitoring their results systematically and periodically. Therefore, providing and preserving the continuity of processes while implementing timely and efficient ergonomics interventions for sustainable process performance measurement in ergonomics may be possible through this systematic approach.

9.3 Future Research Directions

As ordinarily indicated in all researches, this thesis also has some future research directions, which are presented below:

- Despite the endeavour of proposing a framework as a basis for sustainable process performance measurement in ergonomics by considering all dimensions of sustainability and various proposed sub-dimensions in this thesis, the delimitation of the comprehensive research made on ergonomics and sustainability presented in two chapters, i.e., in Chapter 2 for sub-dimensions and framework proposal (Section 2.2) and in Chapter 3 for ergonomics indicators proposal (Section 3.2), can ordinarily be indicated as subjective. Hence, various other new sustainability sub-dimensions for ergonomics and new consolidated ergonomics indicators can be proposed in further studies to detail the structural framework (Figure 2.8) and ergonomics indicators (Figure

3.4) proposed in this thesis by conducting different comprehensive systematic literature reviews with different inclusion and exclusion criteria.

- The target groups of the two surveys designed and developed for this thesis, i.e., Survey-1 (Section 5.2.1) and Survey-2 (Section 5.2.2), can be expanded by inviting more potential respondents, including the researchers from universities in different countries and the practitioners working in companies in Turkey. Accordingly, the primary data gathered from some of these respondents can be weighted for aggregation by collecting more personal information (e.g. the research field of their education levels, the number of projects they have, and the project durations that they are part of) related to their specializations and competence in ergonomics and sustainability.
- Different multi-criteria decision making methods through different parameters, by including either crisp data or fuzzy data, can be used in the hybrid multi-criteria analysis part of this thesis (Section 5.3.2).
- The relations between ergonomics and sustainability (Figure 2.8) can be identified and examined using Structural Equation Modelling, Principal Component Analysis, or other multivariate statistical analysis methods.
- The framework proposed in this thesis (Figure 2.8) is not for examining the systems in terms of the micro or macro level. In other words, the proposed ergonomics indicators (Figure 3.4) and the sustainability sub-dimensions proposed for ergonomics (Figure 2.4) were explicitly classified at neither micro level nor macro level due to its base structure. Importantly, depending on the type or scale of data to be collected and the process or organization to be implemented, it is thought that these indicators can be transformed easily to the micro or macro level indicators during the implementation of the systematic approach in organizations for sustainable process performance measurement in ergonomics. Nevertheless, all of these components proposed in this thesis for developing a systematic approach (i.e. the proposed framework, the proposed ergonomics indicators, and the sustainability sub-dimensions proposed for ergonomics) can be improved by considering the integration of the different system levels such as workplace, organization, inter-organization, and community levels in micro and macro-ergonomics.

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APPENDICES

APPENDIX-1: The First Part of the Consolidation of the Selected Sustainability Indicators and the Proposal of Ergonomics Indicators ($n = 17$) (modified from Sarbat & Ozmehmet Tasan, 2022)

Figure A.1 The lists belonging to the first part of the proposed ergonomics indicators

<i>Percentage of total time spent due to EHS training relative to the total hours worked per year</i>	<i>Percentage of total lost time due to accidents and injuries relative to the total hours worked per year</i>
• Social education & training (2) • Education and training (7) • Training (11) • Training on skills for employability (13) • Training of necessary skills for career advancement (13) • Education and training in security (15) • Average hours of employee training per year (17) • Average hours of sustainability training (hours) (17) • Number of training hours per employee (18) • Professional training and continuing education (20) • Training and education (21) • Training per employee per year (22) • Health Programmes and safety employees (28) • Hours of training (28) • The no. of OHS programs carried out in a defined period (29) • The no. of training courses on accident investigation (29) • The no. of emergency response procedures training course completed (29) • Average hours of training in health and safety topics (34) • Training (36) • Employee training (44) • Average hours of OHS training per year per gender, and by employee category (45) • Education and training (49) • Training (51) • Total number of hours of capacity and skill development training per employee (53) • Health and safety training per employee by employee category (53) • Average hours of health and safety training per year per employee by gender (53) • Participation in farmer training (54) • Training and career development (55) • Training of the employees (in hours) (58) • Average of training hours per employee per year (66) • Number of training or education courses that have been organized for employees (67) • Training and qualification of workers (69) • Training and education (75) • Training and education (77)	• Workers health and safety (1) • Health and safety management (2) • Impact of health conditions (7) • Number of sickness absence days (9) • Workers time off (injury/sick days) (11) • The rate of absence (12) • Number of days lost (15) • Absenteeism due to accident or illness (15) • Lost workday injury and illness case rate (17) • Lost workdays (days) (17) • Absence due to injuries or work-related illness (18) • Time of employee illness (18) • Sick leave (20) • Injuries, occupational diseases, lost days, absenteeism and fatalities (22) • Absenteeism (28) • Absenteeism rate by accidents at work (31) • Type of injury and rates of injury, occupational diseases, lost days, absenteeism, and total number of work-related fatalities, by region and by gender (34) • Time lost (36) • Time lost (44) • Rates of injury, occupational diseases, lost days, and absenteeism, and the number of work-related fatalities by region and gender (45) • Ratio of average annual scheduled work hours not lost due to injury or illness per employee to average annual scheduled work hours per employee (50) • Absenteeism (51) • Off days from work (number of days/year) (54) • Lost workdays (55) • Analysis of lost work days due to injuries and illness (65) • Decreasing the type and rate of injuries, occupational diseases, the total number of work-related fatalities, breakdown and lost days (66) • Percentage of days of sick leave in the total number of working days (67) • Worker health (75)

Figure A.1 Continues

Number of accident-free days per year	Percentage of recycled products/raw materials used in ergonomically designed processes per year
• Health and safety management (2) • Serious and fatal accidents (frequency and number) (4) • Accident fatalities (6) • Accident/incidence rates for employees, contractors, and fleets (7) • Number of occupational accidents (9) • Incidence rate of occupational accidents (9) • Severity rate of occupational accidents (9) • Number of working accidents in a certain time period (10) • The overall accident rate (12) • Accident rate-fatal accidents (12) • Frequency rate (15) • Number of fatal work accidents (15) • Total number of work accidents (15) • Severity rate (15) • Number of work accidents with missed work (15) • Number of accidents or incidents (18) • Occupational accidents (20) • Commuting accidents (20) • Workplace transport accidents (20) • Occupational safety (21) • Occupational accidents (25) • Mining fatalities (27) • Accident rate (28) • The no. of accidents, reported near misses (29) • The no. of accident reports sent to units (29) • The no. of near-miss reports by workers (29) • The no. of near misses (29) • The no. of accidents due to a lack of personal protective equipment (29) • Incidence rate of accidents at work (31) • Incidence rate of fatal accidents at work (31) • Frequency rate of accidents at work (31) • Severity rate of accidents at work (31) • Workplace accidents and illnesses (33) • Rate of fatal work injuries (33) • Type of injury and rates of injury, occupational diseases, lost days, absenteeism, and total number of work-related fatalities, by region and by gender (34) • Accidents (36) • Number of reported accidents in the park (38) • Number of road accidents (41) • Number of road fatalities (41) • Incidence rate of accidents at work (42) • Severity rate of accidents at work (42) • Rates of injury, occupational diseases, lost days, and absenteeism, and the number of work-related fatalities by region and gender (45) • Industrial safety (47) • Workplace accidents and illnesses (49) • Occupational Health and Safety (OHS) (51) • Work accidents (53) • Number of accidents and fatalities at work (57) • Accidents/injuries (58) • Workplace accidents (62) • Accident assessment and quantification (65) • Decreasing the type and rate of injuries, occupational diseases, the total number of work-related fatalities, breakdown and lost days (66) • Number of accidents/injuries at work per year (67) • Number of employee accidents (reverse) (74) • Severity of employee accidents (reverse) (74) • Worker safety (75) • Reduce accidents at the workstation (76)	• Renewable raw materials (3) • Recycled/reused materials (3) • Recycling of products (4) • Reuse of products (4) • Consumption of renewable materials (4) • Recycling (11) • Consumption of recycled materials and raw materials (12) • Use of clean material in production process (13) • Ratio of recycled content (13) • Utility of nonrenewable resources (13) • Percentage of products designed for disassembly, reuse, recycling (17) • Reused/recycled materials used in products (kg/unit) (17) • Share of reused or recycled material (18) • Mass fraction of reusable packaging (18) • Mass fraction of products from recyclable materials (18) • Mass fraction of products designed for disassembly reuse or recycling (18) • Use of renewable materials (22) • Use of recycled materials (22) • Recyclability of the product (22) • Consumption of recycled materials and raw materials (24) • 3 R's (Reduce, Reuse, Recycle) culture (28) • Recycled materials use (30) • Raw-material consumption (33) • Resource consumption rates (35) • Material recycling (37) • Usage of renewable material (47) • Product and packaging recyclability (53) • Mass fraction of reusable packaging (53) • Packaging recyclability per product (53) • Mass fraction of recycled packaging (53) • Reused packaging materials per product (53) • Amount of reused materials (53) • Total recyclable material in manufacturing (53) • Fraction of renewable raw materials (53) • Fraction of reused components (53) • Volume of recycling (58) • Volume of reuse (58) • Consumption of recycling materials (58) • Waste reduction and supports and stimulations of material reuse and recycling (60) • Reusable material (62) • Recyclable material (62) • Re-manufacturability of material (62) • Renewable sources rate (63) • Percentage of reusable / recycled material (63) • Waste recycling rate (64) • Ratio of recyclable material used to total material used (66) • Attempts to mitigate the environmental impact of product and services, packaging and transportation (66) • Percentage of product sold with recycle packaging material (66) • Percentage of recycled or renewable materials (67) • Material consumption (70) • Recycled content materials (71) • Product recycling (74) • Recycling (77) • Renewable materials (77) • Packaging (77)

Figure A.1 Continues

Number of days when there are unfavourable physical conditions (noise, temperature, odour, dust, etc.) per year - Noise pollution (3) - Workers and personnel's health and safety (3) - Noise level (18) - Noise pollution (20) - Noise impact (26) - Noise pollution (27) - Noise level (28) - Noise emission reduction (37) - Days of noise level exceeding standard (38) - Thermal comfort (39) - Environmental protection (44) - Operational discipline (44) - Protection from high temperatures & sunlight (48) - Light and noise pollution (48) - Ventilation potential (48) - Thermal comfort strategies (48) - Temperature level (53) - Vibration (53) - Noise level (53) - Mist/dust level (53) - Noise in factory (55) - Noise level (58) - Working conditions (62) - Average noise levels (64) - Reduce vibrations (68) - Dust emission (70) - Thermal comfort (71) - Internal noise levels (71) - Worker health (75) - Achieve the thermal comfort zone in the workplace (76) - Reduce noise level in the workplace (76) - Achieve adequate illumination levels at workstations (76)	Annual turnover rate of employees - Employee turnover (2) - Employee turnover rate (4) - Turnover rate (7) - Employee turnover rate (12) - Staff turnover (16) - Employee attrition (turnover) rate (17) - Turnover rate or average length of service of employees (years) (17) - Employee turnover (18) - Employment stability (21) - Turn over (28) - The rate of staff turnover (30) - Employee turnover rates and costs (35) - Employee turnover (36) - Talent attraction and retention (40) - Employee turnover (47) - Annual employee retention rate (breakdown by age group, gender, socio-economic class, etc.) (50) - Turnover (51) - Employee turnover (53) - Turnover index (58) - Employee turnover by age, gender and religion (66) - Percentage of employee turnover (67) - Reduce employee turnover rate (76)
Annual investment cost for ergonomics interventions and EHS issues - Investment costs for environmental protection (1) - Employee health evaluation (4) - Social support (8) - Investment in safety (15) - Expenditure on environmental protection (16) - Expenditure on health and safety (16) - Cost of health protection of employee (18) - Support for employee physical activity, health care, and medicine (18) - Health and safety (21) - Financial resources allocated for OHS/y (3) (29) - Acquired investments for environmental protection (30) - Safety at workplace (32) - Total expense in social services (52) - Cost of health protection of employee (53) - Investment (55) - Analysis of available funds for of workplace safety improvement (65) - Expenditure (77)	Number of complaints from community per year - Number of complaints received from the community (12) - Number of complaints received from stakeholders (12) - Customer complaints (number) (17) - Rate of customer complaints and returns (Number per product sold) (17) - Customer complaints (18) - Complaints (20) - Number of complaints received from stakeholders (24) - Complaints (27) - Number of complaints per customer/region (28) - The rate of complaints and how they were addressed (35) - Public perception (44) - Customer complaints (51) - Community complaints (51) - Complaints or feedback (55) - Number of complaining consumers (58) - Minimizing the number of customer complaints (quality, warranty and repair) (66) - The number of consumer complaints related to consumer health and safety (73)

Figure A.1 Continues

Percentage of employees receiving EHS training per year - Employee training and development (4) - Percentage of farmers who got training in occupational health (5) - Education and training (7) - Number or percentage of employees provided with the OSH training courses (9) - Number of OSH training courses for the company executives (9) - Training programs for workers and managers (10) - Percentage of managers and supervisors trained in occupational safety, health and injury management responsibilities (15) - Number of employees trained/to be trained (17) - Employees trained in sustainability (36) (17) - Rate of participation in promotional and training courses (19) - Employees receiving OHS training (22) - Annual percentage of employees receiving company-sponsored training for professional development (e.g. education reimbursement, cross-training opportunities, professional development seminars) (50) - Training and development (51) - Number of employed persons who have participated in occupation-related non-formal training/further training in the last 12 months (57) - Annual training plan for employees (65) - Percentage of all employees involved in training and education courses (67) - Staff training (74) - Provide training to the employees on sustainability (76) - Training and education (77)	Percentage of employees who are satisfied with their work - Employee satisfaction (4) - Satisfaction (8) - Happy workers (11) - Work satisfaction (16) - Satisfaction of social needs (16) - Employee satisfaction rate (18) - Satisfaction of social needs (18) - Satisfaction of farming job (19) - Job satisfaction (20) - Working condition (satisfaction) (26) - Level of employee satisfaction (28) - Work satisfaction (36) - Improved job satisfaction (37) - Talent attraction and retention (40) - Percentage of job satisfaction (46) - Annual employee retention rate (breakdown by age group, gender, socio-economic class, etc.) (50) - Percentage of employees that would recommend the company to a friend or relative as a place to work (50) - Percentage of employees that believe they belong or feel a sense of connectedness within the company (50) - Percentage of employees that envision themselves at the company for the remainder of their career (50) - Percentage of employees that believe the company values their quality of life (50) - Workers' satisfaction (55) - Satisfaction level (58) - Employee satisfaction (62) - Stakeholders' satisfaction rate (63) - Employee satisfaction rate (63) - Subjective feeling of satisfaction at work (65) - The job satisfaction (74) - Achieve operators' wellbeing and job satisfaction (76)
Expenditure on employee development per year - Training, interventions, information, tools and resources for OHS (14) - Investment in staff development (16) - Investments in employee development (18) - Promotion rate (36) - Human capital development (40) - Training and career development (55) - Analysis of investment in improvement of human activity (65) - Percentage of employee receiving regular performance and career development reviews (66) - Training and human resources development costs (74)	Number of complaints due to physical conditions (noise, temperature, odour, dust, etc.) per year - Noise complaints (4) - Odor complaints (4) - Complaints of dust (4) - The rate of complaints and how they were addressed (35) - Employee complaints (36) - Level of satisfaction with the outdoor illumination in the park (38) - Complaints or feedback (55) - Worker health (75) - Complaint (77)
Number of volunteers for making charitable contributions to EHS issues per year - Philanthropy – value of gifts, contributions to charity (12) - Fraction of charitable contributions (18) - Volunteers in no-profit organizations (per 100 residents aged 14+) (23) - Volunteers for HSE plans/projects (25) - Community (30) - Social investment (33) - Volunteers in non-profit institutions (per 100 residents aged 14+) (43) - Number of volunteers in associations, NGOs, etc. (64)	Number of suggested improvements made by employees per year - Number of improvement suggestions submitted by employees (17) - Rate of employees' suggested improvements in quality, social and EHS performance (17) - Number of suggested improvements by employee (18) - Rate of employees' suggested improvements in quality, social, and EHS performance (18) - The no. of recommendations for continual improvement (29) - Safety improvement (44) - Availability of options for employees to suggest improvements (53)

Figure A.1 Continues

<i>Number of injury-free days per year</i> • <i>Health and safety management (2)</i> • <i>Number of incidents (9)</i> • <i>Medical treatment injury (15)</i> • <i>Occupational safety (21)</i> • <i>Injuries, occupational diseases, lost days, absenteeism and fatalities (22)</i> • <i>Incidence rate of occupational injuries, fatal or leading to permanent disability (23)</i> • <i>Type of injury and rates of injury, occupational diseases, lost days, absenteeism, and total number of work-related fatalities, by region and by gender (34)</i> • <i>Reduction of injuries and fatalities (37)</i> • <i>Number of people injured in road accidents (41)</i> • <i>Incidence rate of occupational injuries, fatal or leading to permanent disability (43)</i> • <i>Rates of injury, occupational diseases, lost days, and absenteeism, and the number of work-related fatalities by region and gender (45)</i> • <i>Fatal work injuries (49)</i> • <i>Injuries (55)</i> • <i>Work related injuries (55)</i> • <i>Accidents/injuries (58)</i> • <i>Workplace accidents (62)</i> • <i>Statistical review of occupational injuries (63)</i> • <i>Decreasing the type and rate of injuries, occupational diseases, the total number of work-related fatalities, breakdown and lost days (66)</i> • <i>Number of accidents/injuries at work per year (67)</i> • <i>Disabling injury frequency rate (73)</i> • <i>Disabling injury severity rate (73)</i> • <i>Worker safety (75)</i> • <i>Reduce work-related injuries and illness (76)</i> • <i>Injury rate (77)</i>	<i>Expenditure on medical treatments for accidents, injuries and occupational diseases per year</i> • <i>Workplaces that are covered with occupational health services (5)</i> • <i>Minimal cost of absenteeism (7)</i> • <i>Maximum cost of absenteeism (7)</i> • <i>Cost of accidents at work (9)</i> • <i>Occupational health (21)</i> • <i>Compensated occupational problems (27)</i> • <i>Access to health-insurance programs (32)</i> • <i>Illnesses and accidents (33)</i> • <i>Healthcare security coverage (36)</i> • <i>Occupational health and safety (40)</i> • <i>Industrial safety (47)</i> • <i>Percentage of employee health care costs provided by the company (50)</i> • <i>Health insurance (51)</i> • <i>Availability, quality, quantity of critical services (healthcare, mental healthcare, education, training, law enforcement, first responders, etc.) (56)</i> • <i>Adequacy of funding and training for services (salary, staff, equipment, training, etc.) (56)</i> • <i>Analysis of costs of occupational injuries (65)</i> • <i>Workers health insurance (72)</i>
<i>Cost of EHS training of employees per year</i> • <i>Social education & training (2)</i> • <i>Expenditure on education and training (12)</i> • <i>The training investment (27)</i> • <i>Expenditure on education and training (30)</i> • <i>Cost for training workforce (37)</i> • <i>Cost for consulting professionals (37)</i> • <i>Cost involved in employee education and training (53)</i> • <i>Availability, quality, quantity of critical services (healthcare, mental healthcare, education, training, law enforcement, first responders, etc.) (56)</i> • <i>Adequacy of funding and training for services (salary, staff, equipment, training, etc.) (56)</i> • <i>Training and human resources development costs (74)</i>	

APPENDIX-2: The Second Part of the Consolidation of the Selected Sustainability Indicators and the Proposal of Ergonomics Indicators (n = 8) (modified from Sarbat & Ozmehmet Tasan, 2022)

Figure A.2 The lists belonging to the second part of the proposed ergonomics indicators

Number of cases of occupational diseases per year • Occupational illnesses (4) • Number of OSH-related issues reported by workers (9) • Number of working diseases produced in a certain time period (10) • Occupational diseases (12) • Occupational illnesses (15) • Occupational diseases (20) • Occupational safety (21) • Injuries, occupational diseases, lost days, absenteeism and fatalities (22) • Occupational diseases (24) • Occupational diseases (25) • The no. of OHS hazards reported by workers (29) • Incidence rate by occupational disease(s) reported (31) • Type of injury and rates of injury, occupational diseases, lost days, absenteeism, and total number of work-related fatalities, by region and by gender (34) • Rates of injury, occupational diseases, lost days, and absenteeism, and the number of work-related fatalities by region and gender (45) • Work related illness (53) • Number of diseases (58) • Decreasing the type and rate of injuries, occupational diseases, the total number of work-related fatalities, breakdown and lost days (66) • Reduce work-related injuries and illness (76)	Expenditure on research and development, technology, and innovation per year to enhance ergonomically and environmentally-friendly designed processes • Innovation capacity (2) • Innovation and technological advance (3) • Expenditure on research and development (12) • Capability of R&D (13) • Technological upgrades (13) • Use of environmentally friendly technology (13) • Innovation and R/D investments (17) • R&D budget share (18) • Rate of investment in agricultural activities (19) • Internal research and development capacity (20) • Research and development (R&D) (21) • R&D expenses related to sustainability (22) • Innovations (36) • Stimulating technological innovation (37) • Promoting the culture of innovation (37) • Improvement initiatives (44) • Research and development (51) • Research and development (53) • Investment in R&D activities (58) • Proportion of R&D cost in GDP (%) (59) • Total number of R&D (person) (59) • % of investments in environmental technology (63) • Application of eco-friendly technologies (74) • Innovation, R&D expenditure (77)
Annual number of activities made for the proper implementation of the procedures related to ergonomics interventions and EHS issues • Positive feedback and recognition for OHS (14) • The no. of workers who have a good understanding of OHS policy (29) • Percentage of employees informed about OHS policy (29) • The no. of OHS brochures distributed to workers (29) • The no. of OHS posters, bulletins, or newsletters published (29) • The no. of verified OHS procedures applied during purchase or use (29) • The no. of OHS policies that have been reviewed (29) • The no. of tasks that have OHS procedures (29) • The no. of units in which OHS report & record-keeping systems exist (29) • The no. of units that have an OHS reporting system (29) • The no. of units that have OHS reporting systems (29) • The no. of units where OHS performance has been evaluated (29) • The no. of OHS events for employees (29) • The no. of allocated for OHS training per person (29) • The no. of OHS violations, & no. of sanctions (29) • Percentage of OHS regulations & standards applicable to workstations (29) • Implementation of risk control (36) • Environmental policy/management system (40)	Percentage of annual incentives and promotions made for stakeholders to contribute ergonomically and environmentally-friendly designed processes • Percentage of products and services for which the impact on the health and safety of customers is evaluated during their life cycle (12) • Customer's perception towards green process (13) • Environmental certification (13) • Enlightening customers to return end-of-used products (13) • Incentive initiatives for recovery from discarded products (13) • Number of 'green' products (17) • Percentage of products and services for which the impact on the health and safety of customers is evaluated during their life cycle (24) • The no. of rewards given to workers for OHS hazard reports (29) • The no. of rewards for participating in OHS activities (29) • Incentives for innovation (37) • Reward and appreciation (51) • Environmental activity (52) • Promotion of environmentally friendly processes and products (60) • Attempts to mitigate the environmental impact of product and services, packaging and transportation (66)

Figure A.2 Continues

<i>Number of activities made for improving working conditions per year</i>	<i>Number of complaints due to working conditions not covered by decent work per year</i>
• Hazard prevention/closure rate (7) • Number of OSH inspections (9) • Number of occupational risk assessments (9) • Number of workplaces where protection measures were improved (9) • Number of OSH reports referred to the company's top management (9) • Health and safety measures at workplace (13) • Workplace OHS inspections and audits (14) • Risk management (14) • Occupational health and safety promotion programs (25) • The no. of OHS performance reports from units (29) • The no. of workstations for which a risk assessment exists & corrective action or changes have been made (29) • The no. of workstations that have an emergency response procedures procedure (29) • The no. of emergency response drills performed (29) • The no. of risk assessments carried out in units (29) • The no. of risk assessments updated (29) • The no. of audits performed in a given period (29) • The no. of audits that have been reviewed (29) • The no. of review meetings carried out (29) • The no. of meetings carried out to discuss corrective & preventive actions (29) • The no. of meetings held with workers on OHS issues (29) • The no. of managerial meetings to discuss OHS issues (29) • The no. of OHS meetings in which top managers participate (29) • The no. of managers of units attending review meetings (29) • Proportion of workers covered by workplace health promotion (31) • Health and safety topics assessed across the supply chain (34) • Significant actual and potential negative impacts on OHS practices in the supply chains and actions taken (45) • Efforts to reduce health, safety and environmental hazards (51) • Perceptions of management's overall commitment to health and safety issues (61) • Management efficiency in occupational health and safety system (65) • Safety assessment in the workplace (65) • Health and safety practices (72) • Health programs (industrial medicine, nutrition, etc.) (74) • Maintain operator/employee health (76) • Minimize the repetition of work (76) • Minimize/eliminate ergonomic hazards (76) • Minimize/eliminate physical and biological hazards (76) • Reduce/eliminate hazardous chemicals (76)	• Labor practices (2) • Work and workload (8) • Complaints relating to relationships in the workplace (12) • Cooperation, communication and interaction among farmers (19) • Occupational exposure by physical hazard (31) • Occupational exposure by hazard related to the activity (31) • Occupational exposure by psychosocial / organisational hazard (31) • Number of grievances about health and safety topics, addressed and resolved through formal grievance mechanisms (34) • The rate of complaints and how they were addressed (35) • Employee complaints (36) • Reduction of heavy works (37) • Levels of satisfaction of staff with staff relationships and participation (38) • Occupational health and safety (40) • Work environment (health & safety) (48) • Decent working hours (compliance with regulations) (51) • Decent workload (compliance with regulations) (51) • Employees involved in hazardous operations by the type (physical, biological, chemical) (53) • Physical load index (53) • Overtime work (53) • Workload distribution (54) • Workload (55) • Working hours (55) • Physical working conditions (55) • Complaints or feedback (55) • Physical workload (62) • Physiological workload (62) • Psychological workload (62) • Organizational workload (62) • Analysis of cases of mobbing at work (65) • Occupational health and safety (69) • Working hours (69) • Health and safety practices (72) • Management of overtime hours (73) • The proportion of staff with workload (74) • Worker health (75) • Reduce work-related psycho-social risks (76) • Maintain operator/employee health (76) • Appropriate/fair workload distribution for operators (76) • Minimize/eliminate ergonomic hazards (76) • Minimize/eliminate physical and biological hazards (76) • Reduce/eliminate hazardous chemicals (76) • Complaint (77)

Figure A.2 Continues

<i>Percentage of employees participating in managerial decisions related to ergonomics interventions and EHS issues per year</i>	<i>Percentage of employees working in unfavourable conditions leading to physical and mental health problems per year</i>
• Involving stakeholders in decision making (4) • Workers' engagement (11) • Empowerment and employee involvement in decision making about OHS (14) • Percentage of workers represented in health and safety committees (15) • Employment contribution (16) • Organization's openness to stakeholder review and participation in decision-making process (18) • Share of employees involved in systematic improvement activities (18) • Employment contribution (18) • Employment contribution (26) • The no. of accident investigations carried out with worker participation (29) • Percentage of total workforce represented in formal joint management-worker health and safety committees that help monitor and provide advice on occupational health and safety programs (34) • Empowerment and participation (39) • Percentage of the total workforce represented in formal joint management-worker health and safety committees that help monitor and advise on occupational health and safety programmes (45) • Percentage of employees that believe their contribution to the company is valued (50) • Total workforce represented in formal joint management-worker health and safety committees (53) • Involvement of stakeholders in strategy development and planning (57) • Participation in management decisions (58) • Workforce representation (77)	• Workers and personnel comfort (3) • Work and workload (8) • Health and stress (8) • Number of employees working in hazardous conditions (9) • Number of workers reporting stress at work (9) • Number of workers reporting work-related diseases (9) • Occupational exposure by physical hazard (31) • Occupational exposure by hazard related to the activity (31) • Occupational exposure by psychosocial / organizational hazard (31) • Reduction of heavy works (37) • Occupational health and safety (40) • Part of people who are stressed (46) • Work environment (health & safety) (48) • Employees involved in hazardous operations by the type (physical, biological, chemical) (53) • Physical load index (53) • Workload distribution (54) • Workload (55) • Physical working conditions (55) • Physical workload (62) • Physiological workload (62) • Psychological workload (62) • Organizational workload (62) • Research into causes and consequences of stressful situations (65) • Occupational health and safety (69) • Health and safety practices (72) • Management of overtime hours (73) • The percentage of employees who agree that their workplace is safe and comfortable (74) • The proportion of staff with workload (74) • Worker health (75) • Worker safety (75) • Reduce work-related psycho-social risks (76) • Maintain operator/employee health (76) • Appropriate/fair workload distribution for operators (76) • Minimize/eliminate ergonomic hazards (76) • Minimize/eliminate physical and biological hazards (76) • Reduce/eliminate hazardous chemicals (76)

APPENDIX-3: The Detailed Descriptions of the Ergonomics Indicators Proposed in this Thesis ($n = 25$) (modified from Sarbat & Ozmehmet Tasan, 2022)

Table A.1 The detailed description of EI₁

Name	Number of accident-free days per year
ID	FD _{Acc}
Type	Lagging
Related main dimension	Economic
Related sub-dimension	Loss
Description	This indicator enables measuring the number of accident-free days in an organization per year.
Formula	$FD_{Acc} = D_Y - D_{Acc}$ where D_Y is the number of days in the year. D_{Acc} is the number of days when an accident is recorded in the year. FD_{Acc} is the number of accident free days in the year. Adapted from Loeppke et al. (2015)
Unit of measure	Quantitative unit (i.e. quantity)
Range	Min: Defined value ; Max: Number of days in a year
Trend	The higher the better
Scope	Organization (e.g. company, institution, or government)
Timing	Periodically (e.g. collected for 5-years, 10-years, or 15-years in an annual period)
Audience	Managers, ergonomists, OHS specialists
Notes	The accident-free days here represent the days that there is no accident in an organization due to unfavourable working conditions. The defined value corresponds to a limit determined specifically by the organization. Diverging from this value represents that working conditions become increasingly favourable.

Table A.2 The detailed description of EI₂

Name	Number of injury-free days per year
ID	FD _{Inj}
Type	Lagging
Related main dimension	Economic
Related sub-dimension	Loss
Description	This indicator enables measuring the number of injury-free days in an organization per year.
Formula	$FD_{Inj} = D_Y - D_{Inj}$ where D_Y is the number of days in the year. D_{Inj} is the number of days when an injury is recorded in the year. FD_{Inj} is the number of injury free days in the year. Adapted from Schöggel et al. (2016)
Unit of measure	Quantitative unit (i.e. quantity)
Range	Min: Defined value ; Max: Number of days in a year
Trend	The higher the better
Scope	Organization (e.g. company, institution, or government)
Timing	Periodically (e.g. collected for 5-years, 10-years, or 15-years in an annual period)
Audience	Managers, ergonomists, OHS specialists
Notes	The injury-free days here represent the days that there is no injury in an organization due to unfavourable working conditions. The defined value corresponds to a limit determined specifically by the organization. Diverging from this value represents that working conditions become increasingly favourable.

Table A.3 The detailed description of EI₃

Name	Percentage of total lost time due to accidents and injuries relative to the total hours worked per year
ID	PLT _{Acc&Inj}
Type	Lagging
Related main dimension	Economic
Related sub-dimension	Loss
Description	This indicator enables measuring the percentage of total lost time due to accidents and injuries relative to the total hours worked in an organization per year.
Formula	$PLT_{Acc\&Inj} = \frac{LT_{Acc\&Inj}}{T_{Total}} \times 100$ where $LT_{Acc\&Inj}$ is the total lost time due to accidents and injuries in the year. T_{Total} is the total hours worked in the year. $PLT_{Acc\&Inj}$ is the percentage of total lost time due to accidents and injuries in the year. Adapted from Mamika et al. (2015), Schöggel et al. (2016), and Popovic et al. (2018)
Unit of measure	%
Range	Min: 0% ; Max: 100%
Trend	The lower the better
Scope	Organization (e.g. company, institution, or government)
Timing	Periodically (e.g. collected for 5-years, 10-years, or 15-years in an annual period)
Audience	Managers, ergonomists, OHS specialists
Notes	The lost time here represents the time that an employee is temporarily incapacitated in an organization due to work-related or occupational accidents, injuries, and diseases. Converging to 0% represents that working conditions become increasingly favourable.

Table A.4 The detailed description of EI₄

Name	Expenditure on medical treatments for accidents, injuries and occupational diseases per year
ID	Exp _{MedTre}
Type	Lagging
Related main dimension	Economic
Related sub-dimension	Loss
Description	This indicator enables measuring the expenditure on medical treatments for accidents, injuries and occupational diseases in an organization per year.
Formula	$Exp_{MedTre} = Exp_{Acc} + Exp_{Inj} + Exp_{OccDis}$ where Exp_{Acc} is the expenditure on medical treatments for accidents in the year. Exp_{Inj} is the expenditure on medical treatments for injuries in the year. Exp_{OccDis} is the expenditure on medical treatments for occupational diseases in the year. Exp_{MedTre} is the total expenditure on medical treatments in the year. Adapted from Popovic et al. (2018)
Unit of measure	Quantitative unit (i.e. quantity)
Range	Min: 0 ; Max: Defined value
Trend	The lower the better
Scope	Organization (e.g. company, institution, or government)
Timing	Periodically (e.g. collected for 5-years, 10-years, or 15-years in an annual period)
Audience	Managers, ergonomists, OHS specialists
Notes	The expenditure here represents the share that an organization allocates for medical treatments due to work-related or occupational accidents, injuries, and diseases. The defined value corresponds to a limit determined specifically by the organization. Converging to this value represents that working conditions become increasingly unfavourable.

Table A.5 The detailed description of EI₅

Name	Number of cases of occupational diseases per year
ID	Case _{OccDis}
Type	Lagging
Related main dimension	Economic
Related sub-dimension	Loss
Description	This indicator enables measuring the number of cases of occupational diseases in an organization per year. $Case_{OccDis} = Case_{Agt} + Case_{TOS} + Case_{OC} + Case_{Other}$ where $Case_{Agt}$ is the number of cases of occupational diseases caused by exposure to agents (chemical, physical, biological) arising from work activities in the year. $Case_{TOS}$ is the number of cases of occupational diseases by target organ systems (respiratory, skin, musculoskeletal, mental and behavioural) in the year. $Case_{OC}$ is the number of cases of occupational cancers in the year. $Case_{Other}$ is the number of cases of other occupational diseases in the year. $Case_{OccDis}$ is the total number of cases of occupational diseases in the year. Adapted from Dočekalová & Kocmanova (2016) and Schöggel et al. (2016)
Formula	
Unit of measure	Quantitative unit (i.e. quantity)
Range	Min: 0 ; Max: Defined value
Trend	The lower the better
Scope	Organization (e.g. company, institution, or government)
Timing	Periodically (e.g. collected for 5-years, 10-years, or 15-years in an annual period)
Audience	Managers, ergonomists, OHS specialists
Notes	The occupational disease represents the disease that occurs due to exposure to risk factors (e.g. physical, biological, chemical, and psychosocial) arising from work activity in an organization, referring to ILO's definition and List of Occupational Diseases. The defined value corresponds to a limit determined specifically by the organization. Converging to this value represents that working conditions become increasingly unfavourable.

Table A.6 The detailed description of EI₆

Name	Annual investment cost for ergonomics interventions and EHS issues
ID	IC _{Erg&EHS}
Type	Leading
Related main dimension	Economic
Related sub-dimension	Investment
Description	This indicator enables measuring the annual investment cost for ergonomics interventions and EHS issues in an organization. $IC_{Erg\&EHS} = IC_{Erg} + IC_{EHS}$ where IC_{Erg} is the investment cost for ergonomics interventions in the year. IC_{EHS} is the investment cost for EHS issues in the year. $IC_{Erg\&EHS}$ is the total investment cost for ergonomics interventions and EHS issues in the year. Adapted from Kocmanova et al. (2017) and Kravchenko et al. (2019)
Formula	
Unit of measure	Quantitative unit (i.e. quantity)
Range	Min: Defined value ; Max: Unlimited
Trend	The higher the better
Scope	Organization (e.g. company, institution, or government)
Timing	Periodically (e.g. collected for 5-years, 10-years, or 15-years in an annual period)
Audience	Managers, ergonomists, OHS specialists
Notes	The investment cost here represents the share that an organization allocates for ergonomics interventions and environment, health, and safety issues to improve working conditions. The defined value corresponds to a limit determined specifically by the organization. Diverging from this value represents that working conditions become increasingly favourable.

Table A.7 The detailed description of EI₇

Name	Cost of EHS training of employees per year
ID	TC _{EHS}
Type	Leading
Related main dimension	Economic
Related sub-dimension	Investment
Description	This indicator enables measuring the cost of EHS training of employees in an organization per year.
Formula	$TC_{EHS} = TC_E + TC_H + TC_S$ where TC_E is the training cost of employees related to environment in the year. TC_H is the training cost of employees related to health in the year. TC_S is the training cost of employees related to safety in the year. TC_{EHS} is the total EHS training cost of employees in the year. Adapted from Kocmanova et al. (2017)
Unit of measure	Quantitative unit (i.e. quantity)
Range	Min: Defined value ; Max: Unlimited
Trend	The higher the better
Scope	Organization (e.g. company, institution, or government)
Timing	Periodically (e.g. collected for 5-years, 10-years, or 15-years in an annual period)
Audience	Managers, ergonomists, OHS specialists
Notes	The EHS training given to employees in an organization comprises various issues such as first aid, personal protective equipment usage, work-related accidents and injuries, risk management, occupational diseases, and physical, biological, chemical, and psychosocial hazards. The training cost here represents the share that an organization allocates for EHS training. The defined value corresponds to a limit determined specifically by the organization. Diverging from this value represents that working conditions become increasingly favourable.

Table A.8 The detailed description of EI₈

Name	Expenditure on employee development per year
ID	EXP _{EmpDev}
Type	Leading
Related main dimension	Economic
Related sub-dimension	Investment
Description	This indicator enables measuring the expenditure on employee development in an organization per year.
Formula	$Exp_{EmpDev} = Exp_{PS} + Exp_{WOS}$ where Exp_{PS} is the expenditure on personal skills development in the year. Exp_{WOS} is the expenditure on work related or occupational skills development in the year. Exp_{EmpDev} is the total expenditure on employee development in the year. Adapted from Popovic et al. (2018)
Unit of measure	Quantitative unit (i.e. quantity)
Range	Min: Defined value ; Max: Unlimited
Trend	The higher the better
Scope	Organization (e.g. company, institution, or government)
Timing	Periodically (e.g. collected for 5-years, 10-years, or 15-years in an annual period)
Audience	Managers, ergonomists, OHS specialists
Notes	The employee development in an organization comprises participating activities in various issues such as workshops, meetings, and training courses to improve personal skills and work-related or occupational skills, competence, and expertise. The expenditure here represents the share that an organization allocates for employee development. The defined value corresponds to a limit determined specifically by the organization. Diverging from this value represents that working conditions become increasingly favourable.

Table A.9 The detailed description of EI₉

Name	Expenditure on research and development, technology, and innovation per year to enhance ergonomically and environmentally-friendly designed processes
ID	Exp _{RDTI}
Type	Leading
Related main dimension	Economic
Related sub-dimension	Investment
Description	This indicator enables measuring the expenditure on research and development, technology, and innovation to enhance ergonomically and environmentally-friendly designed processes in an organization per year. $Exp_{RDTI} = Exp_{RD} + Exp_T + Exp_I$ where Exp_{RD} is the expenditure on research and development in the year. Exp_T is the expenditure on technology in the year. Exp_I is the expenditure on innovation in the year. Exp_{RDTI} is the total expenditure on research and development, technology, and innovation to enhance processes in the year. Adapted from Schöggel et al. (2016), Popovic & Kraslawski (2018), and Hristov & Chinco (2019)
Formula	
Unit of measure	Quantitative unit (i.e. quantity)
Range	Min: Defined value ; Max: Unlimited
Trend	The higher the better
Scope	Organization (e.g. company, institution, or government)
Timing	Periodically (e.g. collected for 5-years, 10-years, or 15-years in an annual period)
Audience	Managers, ergonomists, OHS specialists
Notes	The expenditure here represents the share that an organization allocates for activities and investments on research and development, technology, and innovation per year to enhance ergonomically and environmentally-friendly designed processes. The defined value corresponds to a limit determined specifically by the organization. Diverging from this value represents that working conditions become increasingly favourable.

Table A.10 The detailed description of EI₁₀

Name	Number of complaints due to physical conditions (noise, temperature, odour, dust, etc.) per year
ID	Comp _{PWC}
Type	Lagging
Related main dimension	Ecological
Related sub-dimension	Conditions
Description	This indicator enables measuring the number of complaints from employees due to physical conditions (noise, temperature, odour, dust, etc.) in an organization per year. $Comp_{PWC} = Comp_{Noise} + Comp_{Temp} + Comp_{Odour} + Comp_{Dust} + Comp_{PWCother}$ where $Comp_{Noise}$ is the number of complaints due to noise in the year. $Comp_{Temp}$ is the number of complaints due to temperature in the year. $Comp_{Odour}$ is the number of complaints due to odour in the year. $Comp_{Dust}$ is the number of complaints due to dust in the year. $Comp_{PWCother}$ is the number of complaints due to other physical conditions in the year. $Comp_{PWC}$ is the total number of complaints due to physical conditions in the year. Adapted from Popovic et al. (2018)
Formula	
Unit of measure	Quantitative unit (i.e. quantity)
Range	Min: 0 ; Max: Defined value
Trend	The lower the better
Scope	Organization (e.g. company, institution, or government)
Timing	Periodically (e.g. collected for 5-years, 10-years, or 15-years in an annual period)
Audience	Managers, ergonomists, OHS specialists
Notes	The complaints here represent the feedbacks of employees (i.e. internal customers) related to physical working conditions in an organization. Questionnaires or meetings can assist in collecting these feedbacks. The defined value corresponds to a limit determined specifically by the organization. Converging to this value represents that working conditions become increasingly unfavourable.

Table A.11 The detailed description of EI₁₁

Name	Number of complaints from community per year
ID	Comp _{Comm}
Type	Lagging
Related main dimension	Ecological
Related sub-dimension	Conditions
Description	This indicator enables measuring the number of complaints from the community related to an organization per year. $Comp_{Comm} = Comp_{Dist} + Comp_{Cust} + Comp_{Gov} + Comp_{CommOther}$ where $Comp_{Dist}$ is the number of complaints from distributors in the year. $Comp_{Cust}$ is the number of complaints from customers in the year. $Comp_{Gov}$ is the number of complaints from government in the year. $Comp_{CommOther}$ is the number of complaints from others in the community in the year. $Comp_{Comm}$ is the total number of complaints from community in the year.
Formula	Adapted from Popovic & Kraslawski (2018)
Unit of measure	Quantitative unit (i.e. quantity)
Range	Min: 0 ; Max: Defined value
Trend	The lower the better
Scope	Organization (e.g. company, institution, or government)
Timing	Periodically (e.g. collected for 5-years, 10-years, or 15-years in an annual period)
Audience	Managers, ergonomists, OHS specialists
Notes	The community here represents external customers of an organization (e.g. distributors, customers, government). The complaints here represent the feedbacks of the community related to product/service quality of an organization and accordingly attitude of an organization towards the environment, health, and safety issues. Fewer complaints mean fewer product/service returns, resulting in waste reduction and representing increased awareness of the company to EHS issues. Questionnaires or meetings can assist in collecting these feedbacks. The defined value corresponds to a limit determined specifically by the organization. Converging to this value represents that organization become increasingly less environmentally-friendly.

Table A.12 The detailed description of EI₁₂

Name	Number of days when there are unfavourable physical conditions (noise, temperature, odour, dust, etc.) per year
ID	D _{PWC}
Type	Lagging
Related main dimension	Ecological
Related sub-dimension	Conditions
Description	This indicator enables measuring the number of days when there are unfavourable physical conditions (noise, temperature, odour, dust, etc.) in an organization per year. $D_{PWC} = D_{Noise} + D_{Temp} + D_{Odour} + D_{Dust} + D_{Other}$ where D_{Noise} is the number of days that unfavourable conditions occur due to noise in the year. D_{Temp} is the number of days that unfavourable conditions occur due to temperature in the year. D_{Odour} is the number of days that unfavourable conditions occur due to odour in the year. D_{Dust} is the number of days that unfavourable conditions occur due to dust in the year. D_{Other} is the number of days that other unfavourable physical conditions occur in the year. D_{PWC} is the total number of days that unfavourable physical conditions occur in the year.
Formula	Adapted from Kravchenko et al. (2019)
Unit of measure	Quantitative unit (i.e. quantity)
Range	Min: 0 ; Max: Defined value
Trend	The lower the better
Scope	Organization (e.g. company, institution, or government)
Timing	Periodically (e.g. collected for 5-years, 10-years, or 15-years in an annual period)
Audience	Managers, ergonomists, OHS specialists
Notes	The days here represent the working periods that there are unfavourable physical working conditions in an organization. Periodic measurements for physical conditions in workplaces can assist in recording these days. The defined value corresponds to a limit determined specifically by the organization. Converging to this value represents that working conditions become increasingly unfavourable.

Table A.13 The detailed description of EI₁₃

Name	Percentage of employees working in unfavourable conditions leading to physical and mental health problems per year
ID	PEmp _{WC}
Type	Lagging
Related main dimension	Ecological
Related sub-dimension	Conditions
Description	This indicator enables measuring the percentage of employees working in unfavourable conditions leading to physical and mental health problems in an organization per year.
Formula	$PEmp_{WC} = \frac{Emp_{WC}}{Emp_{Total}} \times 100$ where <i>Emp_{WC}</i> is the number of employees working in unfavourable conditions in the year. <i>Emp_{Total}</i> is the total number of employees in the year. <i>PEmp_{WC}</i> is the percentage of employees working in unfavourable conditions in the year. Adapted from Kravchenko et al. (2019)
Unit of measure	%
Range	Min: 0% ; Max: 100%
Trend	The lower the better
Scope	Organization (e.g. company, institution, or government)
Timing	Periodically (e.g. collected for 5-years, 10-years, or 15-years in an annual period)
Audience	Managers, ergonomists, OHS specialists
Notes	The unfavourable working conditions comprise various risk factors in an organization such as physical, biological, chemical, and psychosocial, leading to physical and mental health problems. Converging to 0% represents that working conditions become increasingly favourable.

Table A.14 The detailed description of EI₁₄

Name	Number of activities made for improving working conditions per year
ID	Act _{WC}
Type	Leading
Related main dimension	Ecological
Related sub-dimension	Conditions
Description	This indicator enables measuring the number of activities made for improving working conditions in an organization per year.
Formula	$Act_{WC} = Act_{WCAud} + Act_{WCR} + Act_{WCM} + Act_{WCAsmt} + Act_{WCothers}$ where <i>Act_{WCAud}</i> is the number of audits performed in the year. <i>Act_{WCR}</i> is the number of reports prepared in the year. <i>Act_{WCM}</i> is the number of meetings made in the year. <i>Act_{WCAsmt}</i> is the number of assessments made in the year. <i>Act_{WCothers}</i> is the number of other activities made in the year. <i>Act_{WC}</i> is the total number of activities made for improving working conditions in the year. Adapted from Loeppke et al. (2015)
Unit of measure	Quantitative unit (i.e. quantity)
Range	Min: Defined value ; Max: Unlimited
Trend	The higher the better
Scope	Organization (e.g. company, institution, or government)
Timing	Periodically (e.g. collected for 5-years, 10-years, or 15-years in an annual period)
Audience	Managers, ergonomists, OHS specialists
Notes	The activities here represent the audits, reports, meetings, and assessments made for improving working conditions in an organization. The defined value corresponds to a limit determined specifically by the organization. Diverging from this value represents that working conditions become increasingly favourable.

Table A.15 The detailed description of EI₁₅

Name	Number of volunteers for making charitable contributions to EHS issues per year
ID	Vol _{EHS}
Type	Leading
Related main dimension	Ecological
Related sub-dimension	Contribution
Description	This indicator enables measuring the number of volunteers for making charitable contributions to EHS issues in an organization per year.
Formula	$Vol_{EHS} = Vol_E + Vol_H + Vol_S$ where Vol_E is the number of volunteers for making charitable contributions to environmental issues in the year. Vol_H is the number of volunteers for making charitable contributions to health issues in the year. Vol_S is the number of volunteers for making charitable contributions to safety issues in the year. Vol_{EHS} is the total number of volunteers for making charitable contributions to EHS issues in the year.
Unit of measure	Quantitative unit (i.e. quantity)
Range	Min: Defined value ; Max: Unlimited
Trend	The higher the better
Scope	Organization (e.g. company, institution, or government)
Timing	Periodically (e.g. collected for 5-years, 10-years, or 15-years in an annual period)
Audience	Managers, ergonomists, OHS specialists
Notes	The volunteers here represent the employees that take roles in projects for making charitable contributions to the environment, health, and safety issues in an organization. The defined value corresponds to a limit determined specifically by the organization. Diverging from this value represents that organization has increasingly more ergonomically and environmentally-friendly designed processes.

Adapted from Kocmanova et al. (2017)

Table A.16 The detailed description of EI₁₆

Name	Percentage of recycled products/raw materials used in ergonomically designed processes per year
ID	PRecyc _{Erg}
Type	Leading
Related main dimension	Ecological
Related sub-dimension	Contribution
Description	This indicator enables measuring the percentage of recycled products/raw materials used in ergonomically designed processes in an organization per year.
Formula	$PRecyc_{Erg} = \frac{Recyc_{Erg}}{CG_{Total}} \times 100$ where $Recyc_{Erg}$ is the number of recycled products/raw materials used in ergonomically designed processes in the year. CG_{Total} is the total number of commercial goods produced in the year. $PRecyc_{Erg}$ is the percentage of recycled products/raw materials used in ergonomically designed processes in the year.
Unit of measure	%
Range	Min: 0% ; Max: 100%
Trend	The higher the better
Scope	Organization (e.g. company, institution, or government)
Timing	Periodically (e.g. collected for 5-years, 10-years, or 15-years in an annual period)
Audience	Managers, ergonomists, OHS specialists
Notes	The products/raw materials here represent the commercial goods/components used in ergonomically designed processes that an organization recycles partially or fully. Converging to 100% represents that organization become increasingly more environmentally-friendly.

Adapted from Dočekalová & Kocmanova (2016), Kravchenko et al. (2019), and Hristov & Chirico (2019)

Table A.17 The detailed description of EI₁₇

Name	Percentage of annual incentives and promotions made for stakeholders to contribute ergonomically and environmentally-friendly designed processes
ID	PIP _{Erg&Env}
Type	Leading
Related main dimension	Ecological
Related sub-dimension	Contribution
Description	This indicator enables measuring the percentage of annual incentives and promotions made for stakeholders to contribute ergonomically and environmentally-friendly designed processes in an organization per year.
Formula	$PIP_{Erg\&Env} = \frac{IP_{Erg\&Env}}{IP_{Total}} \times 100$ where $IP_{Erg\&Env}$ is the number of incentives and promotions made to contribute ergonomically and environmentally friendly designed processes in the year. IP_{Total} is the total number of incentives and promotions made in the year. $PIP_{Erg\&Env}$ is the percentage of incentives and promotions made to contribute ergonomically and environmentally friendly designed processes in the year. Adapted from Dočekalová & Kocmanova (2016)
Unit of measure	%
Range	Min: 0% ; Max: 100%
Trend	The higher the better
Scope	Organization (e.g. company, institution, or government)
Timing	Periodically (e.g. collected for 5-years, 10-years, or 15-years in an annual period)
Audience	Managers, ergonomists, OHS specialists
Notes	The incentives and promotions here represent the motivational supports (e.g. paid day offs, cash bonuses, social events, coupons and gift cards) and marketing strategies (e.g. discounts, giveaways) that an organization provides for leading its employees and customers as stakeholders to contribute to ergonomics interventions and environment, health, and safety issues. Converging to 100% represents that organization has increasingly more ergonomically and environmentally-friendly designed processes.

Table A.18 The detailed description of EI₁₈

Name	Percentage of employees receiving EHS training per year
ID	PEmpT _{EHS}
Type	Leading
Related main dimension	Social
Related sub-dimension	Self-Development
Description	This indicator enables measuring the percentage of employees receiving EHS training in an organization per year.
Formula	$PEmpT_{EHS} = \frac{EmpT_{EHS}}{Emp_{Total}} \times 100$ where $EmpT_{EHS}$ is the number of employees receiving EHS training in the year. Emp_{Total} is the total number of employees in the year. $PEmpT_{EHS}$ is the percentage of employees receiving EHS training in the year. Adapted from Loeppke et al. (2015) and Schöggel et al. (2016)
Unit of measure	%
Range	Min: 0% ; Max: 100%
Trend	The higher the better
Scope	Organization (e.g. company, institution, or government)
Timing	Periodically (e.g. collected for 5-years, 10-years, or 15-years in an annual period)
Audience	Managers, ergonomists, OHS specialists
Notes	The EHS training given to employees in an organization comprises various issues such as first aid, personal protective equipment usage, work-related accidents and injuries, risk management, occupational diseases, and physical, biological, chemical, and psychosocial hazards. Converging to 100% represents that working conditions become increasingly favourable.

Table A.19 The detailed description of EI₁₉

Name	Percentage of total time spent due to EHS training relative to the total hours worked per year
ID	PTT _{EHS}
Type	Leading
Related main dimension	Social
Related sub-dimension	Self-Development
Description	This indicator enables measuring the percentage of total time spent due to EHS training relative to the total hours worked in an organization per year.
Formula	$PTT_{EHS} = \frac{TT_{EHS}}{T_{Total}} \times 100$ where TT_{EHS} is the total time spent due to EHS training in the year. T_{Total} is the total hours worked in the year. PTT_{EHS} is the percentage of total time spent due to EHS training in the year. Adapted from Loeppke et al. (2015), Schöggel et al. (2016), and Popovic & Kraslawski (2018)
Unit of measure	%
Range	Min: 0% ; Max: 100%
Trend	The higher the better
Scope	Organization (e.g. company, institution, or government)
Timing	Periodically (e.g. collected for 5-years, 10-years, or 15-years in an annual period)
Audience	Managers, ergonomists, OHS specialists
Notes	The EHS training given to employees in an organization comprises various issues such as first aid, personal protective equipment usage, work-related accidents and injuries, risk management, occupational diseases, and physical, biological, chemical, and psychosocial hazards. Converging to 100% represents that working conditions become increasingly favourable.

Table A.20 The detailed description of EI₂₀

Name	Number of suggested improvements made by employees per year
ID	SI _{Emp}
Type	Leading
Related main dimension	Social
Related sub-dimension	Self-Development
Description	This indicator enables measuring the number of suggested improvements made by employees in an organization per year.
Formula	$SI_{Emp} = SI_{Erg} + SI_{EHS}$ where SI_{Erg} is the number of suggested improvements related to ergonomics interventions in the year. SI_{EHS} is the number of suggested improvements related to EHS issues in the year. SI_{Emp} is the total number of suggested improvements made by employees in the year. Adapted from Kravchenko et al. (2019)
Unit of measure	Quantitative unit (i.e. quantity)
Range	Min: Defined value ; Max: Unlimited
Trend	The higher the better
Scope	Organization (e.g. company, institution, or government)
Timing	Periodically (e.g. collected for 5-years, 10-years, or 15-years in an annual period)
Audience	Managers, ergonomists, OHS specialists
Notes	The suggested improvements here represent the feedbacks of employees related to ergonomics interventions and environment, health, and safety issues in an organization to improve working conditions. Questionnaires or meetings can assist in collecting these feedbacks. The defined value corresponds to a limit determined specifically by the organization. Diverging from this value represents that working conditions become increasingly favourable.

Table A.21 The detailed description of EI₂₁

Name	Annual number of activities made for the proper implementation of the procedures related to ergonomics interventions and EHS issues
ID	Act _{Proc}
Type	Leading
Related main dimension	Social
Related sub-dimension	Self-Development
Description	This indicator enables measuring the annual number of activities made for the proper implementation of the procedures related to ergonomics interventions and EHS issues in an organization.
Formula	$Act_{Proc} = Act_{ProcR} + Act_{ProcM} + Act_{ProcOther}$ where Act_{ProcR} is the number of reports prepared in the year. Act_{ProcM} is the number of meetings made in the year. $Act_{ProcOther}$ is the number of other activities made in the year. Act_{Proc} is the total number of activities made for the proper implementation of the procedures related to ergonomics interventions and EHS issues in the year. Adapted from Popovic et al. (2018)
Unit of measure	Quantitative unit (i.e. quantity)
Range	Min: Defined value ; Max: Unlimited
Trend	The higher the better
Scope	Organization (e.g. company, institution, or government)
Timing	Periodically (e.g. collected for 5-years, 10-years, or 15-years in an annual period)
Audience	Managers, ergonomists, OHS specialists
Notes	The activities here represent the reports and meetings made for proper recognition, awareness, and implementation of the procedures, policies, regulations, and standards related to ergonomics interventions and environment, health, and safety issues in an organization. The defined value corresponds to a limit determined specifically by the organization. Diverging from this value represents that working conditions become increasingly favourable.

Table A.22 The detailed description of EI₂₂

Name	Annual turnover rate of employees
ID	PTR _{Emp}
Type	Lagging
Related main dimension	Social
Related sub-dimension	Satisfaction
Description	This indicator enables measuring the annual turnover rate of employees in an organization.
Formula	$PTR_{Emp} = \frac{Emp_{Resig} + Emp_{Retir}}{Emp_{Total}} \times 100$ where Emp_{Resig} is the number of employees resigning in the year. Emp_{Retir} is the number of employees retiring in the year. Emp_{Total} is the total number of employees in the year. PTR_{Emp} is the turnover rate of employees in the year. Adapted from Kocmanova et al. (2017), Popovic et al. (2018), and Kravchenko et al. (2019)
Unit of measure	%
Range	Min: 0% ; Max: 100%
Trend	The lower the better
Scope	Organization (e.g. company, institution, or government)
Timing	Periodically (e.g. collected for 5-years, 10-years, or 15-years in an annual period)
Audience	Managers, ergonomists, OHS specialists
Notes	The turnover rate comprises the employees leaving the organization due to various issues such as stress, organizational injustice, low salary, lack of career opportunities, work dissatisfaction, and unfavourable working conditions. This ratio includes resignations and retirements, while dismissals are not included in the calculation. Converging to 0% represents that working conditions become increasingly favourable.

Table A.23 The detailed description of EI₂₃

Name	Percentage of employees who are satisfied with their work
ID	PEmp _{WS}
Type	Leading
Related main dimension	Social
Related sub-dimension	Satisfaction
Description	This indicator enables measuring the percentage of employees who are satisfied with their work in an organization.
Formula	$PEmp_{WS} = \frac{Emp_{WS}}{Emp_{Total}} \times 100$ where <i>Emp_{WS}</i> is the number of employees who are satisfied with their work in the year. <i>Emp_{Total}</i> is the total number of employees in the year. <i>PEmp_{WS}</i> is the percentage of employees who are satisfied with their work in the year. Adapted from Valenzuela-Venegas et al. (2016)
Unit of measure	%
Range	Min: 0% ; Max: 100%
Trend	The higher the better
Scope	Organization (e.g. company, institution, or government)
Timing	Periodically (e.g. collected for 5-years, 10-years, or 15-years in an annual period)
Audience	Managers, ergonomists, OHS specialists
Notes	Work satisfaction represents the pleasure of employees from their work and working conditions in an organization. Questionnaires or meetings made every year can assist in collecting the feedbacks of employees. Converging to 100% represents that working conditions become increasingly favourable.

Table A.24 The detailed description of EI₂₄

Name	Number of complaints due to working conditions not covered by decent work per year
ID	Comp _{WC}
Type	Lagging
Related main dimension	Social
Related sub-dimension	Satisfaction
Description	This indicator enables measuring the number of complaints from employees due to working conditions not covered by decent work in an organization per year.
Formula	$Comp_{WC} = Comp_{WCP} + Comp_{WCPS} + Comp_{WCother}$ where <i>Comp_{WCP}</i> is the number of complaints due to physical working conditions in the year. <i>Comp_{WCPS}</i> is the number of complaints due to psychosocial working conditions in the year. <i>Comp_{WCother}</i> is the number of complaints due to other working conditions in the year. <i>Comp_{WC}</i> is the total number of complaints due to working conditions not covered by decent work in the year. Adapted from Popovic et al. (2018) and Kravchenko et al. (2019)
Unit of measure	Quantitative unit (i.e. quantity)
Range	Min: 0 ; Max: Defined value
Trend	The lower the better
Scope	Organization (e.g. company, institution, or government)
Timing	Periodically (e.g. collected for 5-years, 10-years, or 15-years in an annual period)
Audience	Managers, ergonomists, OHS specialists
Notes	The decent work represents the work that comprises various issues such as fair income, gender equality, social protection, personal development, and workplace security, referring to ILO's definition. The complaints here represent the feedbacks of employees related to working conditions not covered by decent work in an organization. Questionnaires or meetings can assist in collecting these feedbacks. The defined value corresponds to a limit determined specifically by the organization. Converging to this value represents that working conditions become increasingly unfavourable.

Table A.25 The detailed description of EI₂₅

Name	Percentage of employees participating in managerial decisions related to ergonomics interventions and EHS issues per year
ID	$PEmp_{MngDec}$
Type	Leading
Related main dimension	Social
Related sub-dimension	Satisfaction
Description	This indicator enables measuring the percentage of employees participating in managerial decisions related to ergonomics interventions and EHS issues in an organization per year.
Formula	$PEmp_{MngDec} = \frac{Emp_{MngDec}}{Emp_{Total}} \times 100$ where Emp_{MngDec} is the number of employees participating in managerial decisions related to ergonomics interventions and EHS issues in the year. Emp_{Total} is the total number of employees in the year. $PEmp_{MngDec}$ is the percentage of employees participating in managerial decisions related to ergonomics interventions and EHS issues in the year. Adapted from Kravchenko et al. (2019)
Unit of measure	%
Range	Min: 0% ; Max: 100%
Trend	The higher the better
Scope	Organization (e.g. company, institution, or government)
Timing	Periodically (e.g. collected for 5-years, 10-years, or 15-years in an annual period)
Audience	Managers, ergonomists, OHS specialists
Notes	The managerial decisions here represent the decisions related to ergonomics interventions and EHS issues and affect the critical areas such as ecological, financial, organizational, and operational concerning the whole organization. Converging to 100% represents that working conditions become increasingly favourable.

APPENDIX-4: The null hypotheses of the Mann-Whitney U tests

- [illegible]

H95₀: There is no statistically significant difference between education levels on the policy relevance of EI₂₁.

H96₀: There is no statistically significant difference between education levels on the measurability of EI₂₂.

H97₀: There is no statistically significant difference between education levels on the reliability of EI₂₂.

H98₀: There is no statistically significant difference between education levels on the resilience of EI₂₂.

H99₀: There is no statistically significant difference between education levels on the proactiveness of EI₂₂.

H100₀: There is no statistically significant difference between education levels on the policy relevance of EI₂₂.

H101₀: There is no statistically significant difference between education levels on the measurability of EI₂₃.

H102₀: There is no statistically significant difference between education levels on the reliability of EI₂₃.

H103₀: There is no statistically significant difference between education levels on the resilience of EI₂₃.

H104₀: There is no statistically significant difference between education levels on the proactiveness of EI₂₃.

H105₀: There is no statistically significant difference between education levels on the policy relevance of EI₂₃.

H106₀: There is no statistically significant difference between education levels on the measurability of EI₂₄.

H107₀: There is no statistically significant difference between education levels on the reliability of EI₂₄.

H108₀: There is no statistically significant difference between education levels on the resilience of EI₂₄.

H109₀: There is no statistically significant difference between education levels on the proactiveness of EI₂₄.

H110₀: There is no statistically significant difference between education levels on the policy relevance of EI₂₄.

H111₀: There is no statistically significant difference between education levels on the measurability of EI₂₅.

H112₀: There is no statistically significant difference between education levels on the reliability of EI₂₅.

H113₀: There is no statistically significant difference between education levels on the resilience of EI₂₅.

H114₀: There is no statistically significant difference between education levels on the proactiveness of EI₂₅.

H115₀: There is no statistically significant difference between education levels on the policy relevance of EI₂₅.

H210: There is no statistically significant difference between departments on the policy relevance of EI₂₁.

H211: There is no statistically significant difference between departments on the measurability of EI₂₂.

H212: There is no statistically significant difference between departments on the reliability of EI₂₂.

H213: There is no statistically significant difference between departments on the resilience of EI₂₂.

H214: There is no statistically significant difference between departments on the proactiveness of EI₂₂.

H215: There is no statistically significant difference between departments on the policy relevance of EI₂₂.

H216: There is no statistically significant difference between departments on the measurability of EI₂₃.

H217: There is no statistically significant difference between departments on the reliability of EI₂₃.

H218: There is no statistically significant difference between departments on the resilience of EI₂₃.

H219: There is no statistically significant difference between departments on the proactiveness of EI₂₃.

H220: There is no statistically significant difference between departments on the policy relevance of EI₂₃.

H221: There is no statistically significant difference between departments on the measurability of EI₂₄.

H222: There is no statistically significant difference between departments on the reliability of EI₂₄.

H223: There is no statistically significant difference between departments on the resilience of EI₂₄.

H224: There is no statistically significant difference between departments on the proactiveness of EI₂₄.

H225: There is no statistically significant difference between departments on the policy relevance of EI₂₄.

H226: There is no statistically significant difference between departments on the measurability of EI₂₅.

H227: There is no statistically significant difference between departments on the reliability of EI₂₅.

H228: There is no statistically significant difference between departments on the resilience of EI₂₅.

H229: There is no statistically significant difference between departments on the proactiveness of EI₂₅.

H230: There is no statistically significant difference between departments on the policy relevance of EI₂₅.