CHAPTER 1

Introduction

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THIS CHAPTER PROVIDES:

- An introduction to the different roles in production engineering that may need to concern themselves with ergonomics/human factors knowledge.

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- An overview of the wide variety of aspects covered under the umbrella term ergonomics/human factors.
- A brief discussion on the relevance of production ergonomics to the performance of a production system.
- A history lesson of how ergonomics/human factors developed.
- An overview of the contents of this book and how they are organized.

WHY DO I NEED TO KNOW THIS AS AN ENGINEER?

Sometimes, a bit of history goes a long way to explain why certain things in a discipline are considered important. For an engineer, it may be good to know what the starting point was before any real thought was put into methodically improving the human aspects of production work. It will also help you understand why ergonomics covers so many areas and is such a diverse and complex discipline.

The discipline of ergonomics is not nearly as old as medicine, or even industrialization, but it arose as a consequence of an extreme social situation: World War II. With all the able-bodied young men drafted to war, industrialists faced a need to suddenly adapt workplaces to the needs and limitations of a new, more diverse workforce consisting of women, physically disabled, and other previously overlooked groups of society. At the end of the war, society itself had changed to the point where it was acceptable for many of these groups to remain in employment.

While this first effort concerned itself mostly with physical work, later historical developments showed that it was possible to also improve workplaces in relation to human mental capability, teamwork and organizations. Today, it is in the best interests of most industries to build workplaces where the greatest possible diversity of people are able to perform well, meaning that physical, cognitive and organizational sides of ergonomics are equally powerful aspects in the design of inclusive workplaces.

As ergonomics widened its scope, it became the concern of more and more stakeholders. Today, it is worthwhile to know that ergonomics has the potential to concern, engage and/or provoke many more people than just the workplace designer, the ergonomist or the worker.

1.1. What is ergonomics/human factors?

For many people, the word *ergonomic* is associated primarily with comfy office chairs, the correct height of computer screens, computer mice and consumer products that have been (sometimes randomly) labelled "ergonomic", like kitchenware, backpacks or gardening tools. The word itself comes from the Greek roots *ergon* (work) and *nomos* (laws) and roughly translates to "the science of work", focusing on human activity.

> ***Ergonomics***
>
> from the Greek words Έργον [ergon = work], and Νόμος [nomos = natural laws]; "the science of work"

But *ergonomics* (or *human factors,* an equivalent term used more commonly in North America) in general is a very wide term. Ergonomics can signify anything from the physical activities and demands of the job, to how the human mind understands instructions and interfaces, to how work organization, teamwork and motivation influences human well-being and efficiency. Furthermore, it may include aspects of aging, working in extreme environments (such as fire fighting, working in freezer rooms or mines), working with protective gear (such as protection gloves, heavy jackets, helmets, etc.). In short, almost any aspect of work involving human activity can be approached from an HFE (Human Factors and Ergonomics) perspective.

Simply visiting the Human Factors and Ergonomics Society (2015) website reveals that they are organized into as many as 23 different "technical groups" which specialise in applying ergonomics knowledge and practice to the areas in Table 1.1.

1.2. The purpose of production ergonomics

It can be assumed that anyone in charge of a production system would want all of its sub-components to function together with as much ease and efficiency as possible. When part of that production system is human, the performance of the system as a whole may vary depending on the daily form of the human workers. Although humans have great potential to bring flexibility, innovation and problem-solving skills to the production system, they are at risk for developing work-related musculo-skeletal disorders (alternately abbreviated MSDs or WMSDs) as a result of physical work that overloads the human body. Symptoms of such risks include discomfort, pain and recurring

Table 1.1: The 23 technical groups of the Human Factors and Ergonomics Society as of 2015.

• Aerospace Systems • Aging • Augmented Cognition • Cognitive Engineering and Decision Making • Communications • Computer Systems • Education • Environmental Design • Forensics • Health Care • Human Performance Modelling	• Individual Differences in Performance • Internet • Macroergonomics • Occupational Ergonomics • Perception and Performance • Product Design • Safety • Surface Transportation • System Development • Test and Evaluation • Training • Virtual Environments

injuries, and the consequences of unhealthy loading include suffering, inability to work and high costs for the company (in terms of compensation, productivity losses and replacement of personnel). Also, human mental capacities are dependent on sufficient support, stimulation and opportunities for rest. Without these health factors, confusion, irritation, misinterpretation and serious errors can occur, potentially causing material or personal harm. Finally, the interactions between human workers can at best be a source of support, stimulation and a feeling of identity, but if they are dysfunctional they can also cause demotivation, dissatisfaction and lack of engagement. In other words, the purpose of production ergonomics is to design a workplace that is proactively built to remove the risks of injury, pain, discomfort, demotivation and confusion.

How a company chooses to handle production ergonomics may vary with their size, organizational form, previous history of involving ergonomics expertise, project experiences, access to standards, previous knowledge of methods and tools, and expectations of different stakeholders in the company on the person put in charge of ergonomics. A proactive approach towards production ergonomics is characterized by getting ergonomics knowledge into the early planning stages, seeing ergonomics as a source of long-term cost savings and a high regard for keeping the workforce healthy. A reactive approach, on the other hand, usually leaves ergonomics issues and risks unaddressed until problems start cropping up, such as worker pain, injuries and sick leave. Quite frequently, companies with a reactive ergonomics approach will try to solve problems with a healthcare service angle, which only serves to take care of the symptoms and not the root cause of the problem, which then remains as a risk to other workers.

1.3. Historical development of ergonomics and human factors

The modern history of ergonomics in the Western world dates back to the 1940s, during World War II. As a result of the demands of warfare, many able-bodied young men were drafted to participate in the war effort, leaving their civilian work (e.g. in factories). At the same time the war effort demanded new military vehicles, equipment and instruments, giving rise to a new form of industry, which needed to produce products at a high pace with high quality, and therefore required more manpower. This meant that production on the home front needed to be staffed by the population who remained. The shift included re-training and transferring male workers from civilian businesses to the warfare industry, but also called on women, the elderly, disabled and previously excluded social groups to fill the demand. Recruitment efforts resulted in a new form of state propaganda that gently challenged societal norms, such as by stating that women should be capable of performing assembly jobs as it was not completely different from high-precision housework. As a result of this drastic diversification of the working population, industries began investing in physical aids (such as new tools and devices for lifting and supporting heavy machinery) to enable the presumably weaker workers to carry out assembly jobs at a maximum level of efficiency and productivity.

This first shift of the 1940s, where industrial attention was focused on the human functioning in a technical system, is referred to as the “physical generation” of ergonomics developments. The focus was on physical characteristics of the human body, anthropometry, posture, health and safety, perceptual capabilities, and how they affected the design of technology. Scientific and practical developments have since continued in the field of physical ergonomics to the present day, with plenty of influence coming from sports medicine (emphasizing physical performance) and medical monitoring of health (using measurement instruments such as electromyography, EMG, to study human muscle use).

About 20 years later, in the 1960s, scientific developments were made in the area of computers and robotics, which presented many new possibilities but were also perceived by some as a threat to the human worker; would robots take over all human jobs? Would they, indeed, take over the world? While these fears were left hanging, science and engineering underwent a change of perspective; instead of looking at how human needs influenced technology, the demands of technology on humans were highlighted instead, leading to a focus on cognitive psychology, mental workload (and overload), skill, cognitive limitations (e.g. memory) and psychological factors during work. The 1960s brought with them a rapid development of computer interfaces and control rooms.

Yet another 20 years later, in the 1980s, HFE researchers began to realize that in spite of their extensive knowledge in the areas of physical and cognitive ergonomics (uniting the body and the mind), it was seldom that that knowledge was allowed to influence the design of workplaces and machinery. They realized that there was a strong dependency between technology and organizations, and that the effect of interpersonal relationships that influence design outcomes was greater than previously thought. This led to a view of ergonomics work being part of a "sociotechnical system" with greater focus on the context and the stakeholders surrounding ergonomics, leading to the third generation known as "the Macroeconomic generation". Sometimes also referred to as "organizational ergonomics", this branch explores the role of ergonomics within an organizational context with multiple stakeholders with different agendas. It also addresses the fact that working successfully with ergonomics is a balance of considerations; this is especially true for production ergonomics, where the goals of production engineers, economists, managers, human factors professionals and operators can all influence decisions and changes in workplace improvement.

Dray (1985) describes this historical development as the "three generations of ergonomics". However, the evolvement of HFE did not stop in the 1980s. Yet another 20 years onward, in the year 2000, the council of the International Ergonomics Association (IEA) decided to strengthen the industrial relevance of ergonomics by declaring globally that ergonomics was not only focused on the human's well-being, but also on the efficiency, performance and productivity of work systems and machines. There was also a need to signal equality between the terms *ergonomics* and *human factors*, as both terms were used to signify similar concerns, but with some variation both between countries and industrial sectors (for example, Scandinavian countries and the manual assembly industry have a tendency to use the term *ergonomics*, while the term *human factors* is more predominant in North America and in the nuclear industry). Therefore, the association issued the following definition:

Definition of the International Ergonomics Association, IEA (2000):

"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."

This definition remains the official one for ergonomics and human factors, but the IEA recognizes the physical, cognitive and organizational branches as the three main “domains of specialization”.

Modern developments, primarily from the 1990s and onwards, have seen an increase in ergonomics simulation, i.e. the introduction of ergonomics analysis tools into 3-D computer design environments. Specific software has been developed to enable the simulation of work positions and work-related actions in a 3D CAD environment, using a human form called a manikin. Manikins of both genders can be scaled to different sizes in order to investigate whether the extremes of the human population will be able to work in a proposed environment without exposing themselves to physical risk for injury. This type of software is predominantly found in technologically mature, economically profitable industrial sectors producing large, complex products, notably the automotive industry.

Another recent development which has gained popularity over the past decade is an increased emphasis on the effects of aging; demographic developments in the Western world suggest that it will be necessary to keep production employees in the workforce for a longer working life, since an outflux of retirees would cause industries a lot of brain-drain, or loss of know-how and competence. This will pose challenges in terms of designing and adapting the workplace to the changed prerequisites and demands of the human body as it ages, while at the same time supporting the worker in performing their job without loss of precision, productivity or efficiency. At the same time, workplaces must be designed to attract and support a new generation of workers, who will most likely be required to perform increasingly complex jobs from the beginning of their working lives. Today, this combination of challenges has notably gained attention from governments and the academic world since the 2010s, resulting in an increased focus on placing social sustainability alongside economic and environmental sustainability.

1.4. How are ergonomics and human factors connected to engineering?

Engineers have a distinct advantage as workplace designers and improvers: companies that hire engineers expect them to independently come up with analyses and suggestions for change as part of improving systems and operations. Expectations from company leadership on an engineer’s mind-set and skills often lead to a role where they are trusted to come up with practical suggestions and even make decisions that change the workplace.

Other roles with ergonomics and human factors knowledge, such as ergonomists, occupational health and safety (OHS) agents, medical/ health service staff, consultants, etc. may not always have the same mandate, expectation or training to suggest design changes, purchases, work task modifications, etc. – and if they do, those with a medical or physiotherapeutic background may be limited in scope to merely providing an analysis output, but not to contribute towards a new design solution (unless the company in question is ergonomically mature enough to make this possible using cross-functional teams; but this practice is not to be taken for granted). Also, a disadvantage of addressing ergonomics and human factors from the medical/ health angle is that they are often not able to act until workers have actually been complaining or have gotten injured – and in such cases, interventions may end up tailored to easing the situation only for the injured worker on an individual basis. It may be hard from that angle to argue for any comprehensive changes in a proactive manner, if management is not convinced that the problem can recur and cause trouble again. Therefore, workplace change agents with an engineering role have a greater leverage to make sustainable improvements, because they may be able to do something to address the root cause in the work system that may be a risk for many workers. In other words, an engineer who has good knowledge of ergonomics (and its monetary value) can have a very positive long-term impact on business because their knowledge about human needs and capabilities can be translated into feasible system design changes that can avert systemic health and safety risks. That is, engineers can do this, *if* they are educated and trained to recognize matters of human well-being and system performance as part of their work to make a workplace more efficient, productive and socially and economically sustainable.

1.5. What's in this book?

Preface	This section explains how and why this book was written. Reading it may result in understanding the authors' intentions better.
1. Introduction	In this chapter, we introduce background knowledge of the ergonomics/human factors domain and how it relates to production engineering.
PART 1 – Understanding the Human in the System	
2. Basic Anatomy and Physiology	The human body is amazing in many ways, but its needs, abilities and limitations change over time. Getting to know how it responds both in sickness and in health is a good basis for doing engineering work to support and save it.
3. Physical Loading	Here, the basic knowledge we have of anatomy and physiology is combined with principles of classical mechanics to translate it into engineering terms.
4. Anthropometry	Designing a workplace is something you do for more than one person to include as many potential users as possible – this chapter helps you figure out how to design for populations, rather than just a few people.
5. Cognitive Ergonomics	Here we devote our attentions to the human mind and senses, and gain an understanding of the needs and limitations that affect our ability to understand information and take action.
6. Psychosocial Factors and Worker Involvement	The human does not operate alone, but is influenced by interactions with others and has needs and limits for how that interaction should take place. Here, we examine workplace health factors having to do with organization, support, stress, mandate and freedom to act and influence the workplace.
PART 2 – Engineering the System around Humans	
7. Data Collection and Task Analysis	This chapter introduces data collection for the purpose of improving workplaces, and the basics of Task Analysis in order to structure the engineer's understanding of intended and/or existing operations.

8. Ergonomics Evaluation Methods	This chapter introduces methods for determining if there are ergonomic injury risks present in an existing (or simulated) workplace.
9. Digital Human Modeling	This chapter briefly introduces how ergonomics simulation can be used to test a workplace in a CAD (computer-aided design) environment at early stages of development without the need for costly mock-ups and costly materials.
10. Manual Materials Handling	This chapter explains some different ways that the handling, moving and storage of material significantly affects ergonomics and productivity.
11. The Economics of Ergonomics	It is often not enough to know why and how ergonomics is good for the human body and its abilities – quite often, improved work conditions mean better productivity and economic returns. Knowing how can make you skilled at persuading management to invest in workplace improvements.
12. Environmental Factors	Here, the effects on our well-being and performance that stem from our environmental surroundings are described, as well as the concept of "comfort zones" for creating optimal work conditions.
13. Social Sustainability	Here, the long-term impacts of what you can do as a work designer are explained. Sustainability has to do with making long-lived, healthy, competitive workplaces that contribute to creativity and innovation.
Notes for Teachers	This section is aimed at instructors and explains the wider perspectives of using this book as part of an engineering curriculum.
PART 3 – Workplace Design Guidelines	
This section contains a compilation of design guidelines for the different topics covered in the book.	

1.6. Different engineering roles act on different types of knowledge

Engineers may end up playing a variety of different (sometimes overlapping) roles in their professional career, each with their distinct scope, system level and operational concerns – some switch between several of these throughout their working life, depending on how specialized their working role is and at what system level they are expected to address problem solving. For example, an engineer may act on a specialized, operative level with responsibility for a single production line, which would require specific methods and knowledge to optimize for human well-being and performance. Other engineers end up at a management level, where they are perhaps not served by anatomical knowledge and ergonomics evaluation methods, but may impact it greatly by having responsibilities for economics, personnel well-being and approving investments in new equipment. Yet others may act in a more visionary way to orchestrate a production system on a macro scale, involving supply chain operations and a sustainability vision.

At any one of these levels, knowledge of ergonomics and human factors can be a vital part of continuous improvement work, as well as a sound business practice where the value of healthy, knowledgeable and motivated workers is proactively supported and preserved before any problems or system inefficiencies arise, thanks to the engineer understanding what is required of a system for its human components to perform at their best.

Since this book aims to give both detailed knowledge about the human body and mind's capabilities and prerequisites (Part 1) as well as to provide actionable ways to design and improve work systems (Part 2), we have identified some different engineering roles (see Figure 1.1) that may be useful as "filters" to sift through the knowledge in this book, both while studying (if you have a future work role in mind) and later in life as a practicing professional. For the latter group, we hope that the book can continue to serve as a handy reference for making prioritizations, business cases and design decisions. It may also be helpful to be aware of the perspectives of other actors in a production organization, as they may require a tailored set of arguments to become convinced of the benefits of a workplace change initiative.

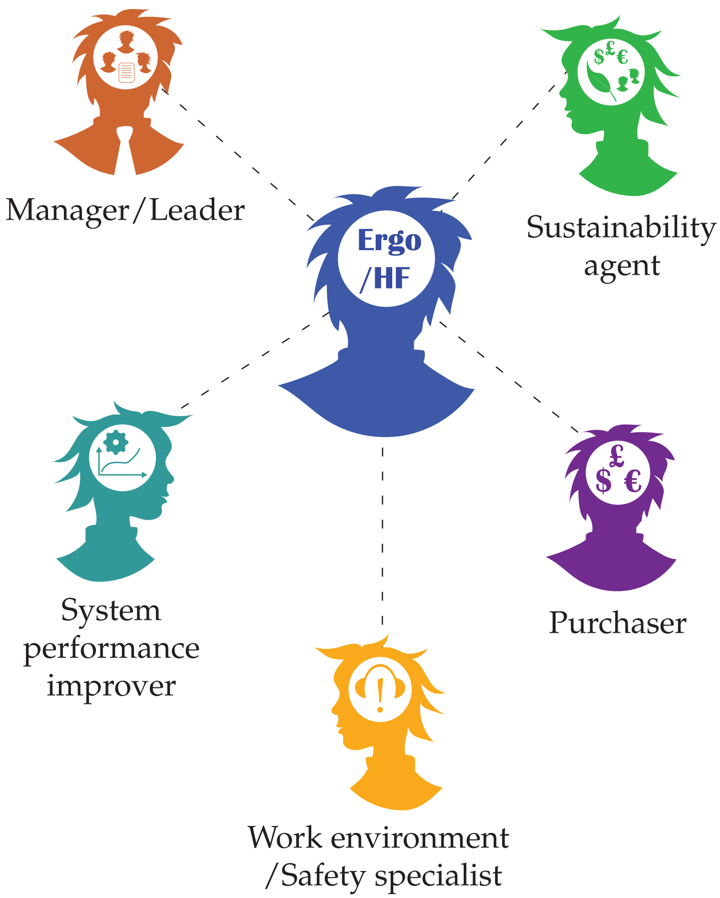

Figure 1.1: Working roles in which an engineer can use ergonomics and human factors knowledge to positively impact a workplace.

Illustration by C. Berlin.

The manager / leader 	This person has a wide scope of responsibility in a company, addressing aspects like: the recruitment, training, performance and well-being of employees; having the mandate of whether to approve improvement projects and make investments; running a productive and feasible business, where employees are treated as a valuable asset; and aligning operations with an overall organizational vision, such as a sustainability strategy. This person needs a macro-system view, an understanding of conditions that support worker well-being on an individual and team level, and economical aspects of work system performance.
The system performance improver 	This person is responsible for the performance and improvement of a particular system or sub-system (for example, the efficiency of a production line) and acts independently to make a current-state analysis, which in turn acts as a basis for suggesting improvements. This role must understand the economic gains of good ergonomics to make a compelling business case for changes, and relies on data collection, ergonomics evaluation methods and tools, and an understanding of which conditions allow humans to perform physical and mental work well.
The work environment / Safety specialist 	This person has a particular focus on the workers' well-being and safety. This means that a solid knowledge of the capabilities and limitations of the human body and mind at work is essential for this role, in order to avoid harmful loading, distraction and repetitive strain. This person also needs to understand how work environmental factors influence human performance, and need to be able to use guidelines and standards to ensure the design of safe high-performance work environments.
The purchaser 	Although perhaps not the most typical engineering role, this one has a considerable say in whether an improvement is made possible or not (and may overlap with other roles). When this person has an understanding for the type of investments that lead to an economically sustainable work environment with few worker ill-health issues, then money can be used wisely to invest in solutions with a synergetic systems perspective (rather than a reactive, individual-based one) that will have a lasting beneficial impact. They often need to consider legislative demands and time-horizons for expected payback on an investment.
The sustainability agent 	Finally, an increasing concern for many organizations is that of sustainability in all business aspects; this means balancing social, economic and environmental aspects in order to ensure that continued operations will have a positive impact on people, planet and profit. But how is this connected to ergonomics and human factors? We argue that sustainability – particularly social and economical aspects – can be addressed both in a global macro-perspective and a local, company-level perspective, and that with a solid understanding of human needs and how they translate into requirements on a workplace, engineers who design and improve workplaces can contribute to more socially and economically sustainable production systems.

At the beginning of each topic chapter (Chapters 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 and 13), a short statement is given explaining how particular roles can use the knowledge in each chapter to have a beneficial impact on worker well-being and system performance, including the perspective of good business sense.

1.7. References

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