ELISA GRANHA LIRA

LEAN MOTION AND TIME STUDY

Continuously Improving Work Design through Methods Engineering

This book is dedicated to its target audience: students, professors, and professionals in Industrial Engineering, who represent the origin, the route, and the destination of this work.

Speed is meaningless without continuity. Just remember the tortoise and the hare. Moreover, we cannot fail to notice that machines not designed for endurance at high speeds will have shortened lifespans if we speed them up.

TAIICHI OHNO

Elisa Granha Lira

Elisa Granha Lira is a professor in the Industrial Engineering department at Universidade Federal do Rio de Janeiro (UFRJ). She is a PhD candidate in the Production Engineering Program at the Universidade Federal do Rio de Janeiro. She also holds a Master's degree in Business Administration, with a focus on Operations and Logistics Management, from the Universidade Federal de Minas Gerais (UFMG), as well as a Bachelor's degree in Industrial Engineering from the same institution. During her undergraduate studies, she participated in an academic exchange program in Industrial and Manufacturing Engineering at Kettering University (formerly General Motors Institute of Technology) in the United States. She has professional experience in Industrial Engineering, having worked in both public and private sectors in Brazil and abroad. Her expertise includes Lean Manufacturing, Quality Management, Methods Engineering, Work Design, and Artificial Intelligence.

FOREWORD

Professionals have increasingly sought to improve production processes by implementing Six Sigma and Lean Manufacturing programs. Pursuing greater efficiency and quality remains a prevalent objective in these organizations. Recently, such programs have been intensively applied in industrial organizations, the service sector, and public institutions. These approaches require systematic and detailed knowledge of the activities that comprise productive processes. In this context, effective process redesign and improvement proposals involve thoroughly analyzing the organizational and structural possibilities of these activities.

Despite the abundance of Industrial Engineering literature, few texts carefully address motion and time studies, which are essential topics for process improvement initiatives. In this regard, Elisa Granha Lira's book stands out for its didactic approach and the depth it provides for Industrial Engineering professionals and students seeking a more comprehensive understanding of the subject.

The author's approach is well-founded, drawing on her extensive professional experience and academic background. In addition to describing the techniques, Elisa explains the context in which they should be applied and the rationale behind their use. The book is enriched with practical examples from her professional experience that help readers understand how to apply each technique presented. Moreover, the author critically reflects on the subject, contextualizing the application of these techniques from a Lean Manufacturing perspective.

It is widely acknowledged that the most skilled professionals across various fields recognize the importance of attention to detail in executing their work effectively. This book explicitly addresses the details underlying the valuable analysis of productive processes. It provides the necessary knowledge to apply motion and time studies, emphasizing the importance of continuous practice to develop the expertise and proficiency required to analyze productive processes effectively.

Noel Torres Júnior
Professor at the Universidade Federal de Minas Gerais, Brazil.

ENGLISH PREFACE

A preface to an English translation, in the age of artificial intelligence (AI), becomes indispensable. Before the reader assumes that I uploaded the Portuguese PDF to an AI system and that it produced this book instantaneously, I would like to note that more than half of this work had already been translated before the release of ChatGPT.

Moving on to the history of this book, when I published the Portuguese edition of "Lean Motion and Time Study" in 2020, many people asked whether I had an English version they could share with individuals in other countries. Honestly, this question initially surprised me, but from that moment on, I recognized the need to translate the book into English. After all, during my experience working for multinational companies, it became clear that we shared a common language and that our needs were the same: to continuously improve our methods and processes through philosophies such as lean, and by applying techniques and methodologies derived from motion and time studies.

In 2021, I began to transform this idea into reality—more precisely, onto my laptop screen. And so, five years passed. I cannot deny that the writing of this book was marked by several pauses to catch my breath, shaped by life's unpredictability, a doctorate, and other books. As always, we make plans, and life happens. Given that all knowledge should be shared to contribute to a better world, this book was gradually developed during this period from my practical experience, the projects I participated in, and my academic journey, both in the United States and in Brazil.

Moreover, I have endeavored to preserve the essence of the Portuguese version; however, I must acknowledge that the Elisa of 2020 is not the same as the Elisa of 2026. For this reason, certain sections underwent significant transformations, particularly Chapter 2. Writing the book

“Lean Flow: A Quick Guide to Transform with Lean Digital”, which I published in 2023/2024, strongly influenced this work.

I also find it important to emphasize that translating into a non-native language is an effort to approach a reality that differs from my own. Empathy and patience are essential. In this regard, I revisited the English-language references that originally supported the Portuguese version. My objective was to employ the same technical terminology used by those authors. I deeply value the craft behind the translation process. A single word can transform not only a context but also reality itself; it should never be underestimated. Thus, the only assurance I can offer is that I have made every effort to reach you, dear reader.

During the revision process, my faithful companion was Grammarly. I appreciate writing tools not only for correcting me, but also for teaching me how to improve continuously. After revising the text with Grammarly, I reviewed the book numerous times through the time-honored practice of pen and paper.

In conclusion, this book is the result of both my mistakes and my successes, shaped by the other works I have written. Every aspect was carefully conceived with you, esteemed reader, in mind—not only the text, but also the images, the graphic design, the cover, and even the title.

That said, I wish you an enjoyable reading experience!

Elisa Granha Lira

PORTUGUESE PREFACE

Writing this book emerged as a response to the needs experienced in academia and practice. It was not a singular event but rather a continuous process of reflection that motivated me to embark on this project.

As an undergraduate student in Industrial Engineering at the Universidade Federal de Minas Gerais (UFMG), I never had a course that specifically addressed this topic. Could it be that this subject was not important? Surely not. Fortunately, the opportunity to participate in an academic exchange program and the practical experience as an engineer opened my eyes to new possibilities. I participated in the Science Without Borders program in the United States, studying at Kettering University, formerly known as the General Motors Institute of Technology. We attended classes at General Motors' first factory in Flint, Michigan. There, I took a course in Work Design, where I began to understand the significance of motion and time studies. Alongside theoretical lectures, we had practical classes in a laboratory equipped with thousands of LEGO pieces. The objective was to design workstations for an assembly line producing two distinct types of padlocks. It might sound like child's play, but the project spanned an entire semester, and my group of five colleagues dedicated an average of eight hours per week outside class to complete the activities and assignments. This experience made me a better engineer. I only wish many other industrial engineers could have had the same opportunity.

Interestingly, this "ghost" of motion and time studies followed me throughout my internships and professional engineering activities. As a project manager at the Junior Enterprise of UFMG's Industrial Engineering program, I vividly remember drafting project proposals for motion and time studies. During the Science Without Borders program, I worked for five months at a major automotive parts supplier near Detroit. The automotive industry, which relentlessly seeks to improve its work methods, provided an invaluable opportunity to address this fundamental need to study the specific times and movements of operations. In addition to cost-reduction projects that employed these tools, we planned the layout of a new factory dedicated to producing parts for a Japanese automaker. During this experience, I conducted several studies using Predetermined Time Standards Systems (PTSS) based on video recordings of operations. These studies aimed to identify opportunities for process improvement and design a new layout that would enable a single operator to control more machines. During the same period, I was introduced to lean manufacturing—or simply "lean," as it is often called—and quickly realized that motion and time study tools complement lean methods, such as value stream mapping, the identification of the eight wastes, and spaghetti diagrams. Today, I understand the importance of applying motion and time study tools from a lean perspective to optimize and sustain results over time.

Upon returning from the United States, I was hired by a steel company in Belo Horizonte as an internal consultant on lean manufacturing improvement projects. During this professional experience, I recognized the need to write a book on this topic that combines technical rigor with practical insights. Allow me to explain in more detail. In 2014, Brazil entered a recession, and many companies striving to remain competitive launched large-scale cost-reduction projects. The company I worked for was no exception, and it hired a consulting firm to conduct motion and time studies. The ultimate goal was to define cost-reduction targets for each department. As I worked alongside the consultants, I became increasingly frustrated by their approach. They often provided recommendations on "what" needed to be done, but failed to explain the "why" or "how." When I questioned them, their responses were either shallow or evasive. This led me to doubt whether they possessed the necessary expertise to execute these projects effectively. In some cases, I observed that the methods were not correctly applied.

This experience reinforced the need for a book that guides the appropriate selection and use of motion and time studies, using accessible language. After all, not only industrial engineers but also metallurgical, chemical, and mechanical engineers, as well as managers, economists, and other professionals, may encounter projects involving work design at some point in their careers—be it in an industrial setting, a hospital, a bank, a public office, or even in their personal lives. Nonetheless, the primary audience for this book comprises industrial engineers, both students and professionals, who often work directly with these topics in practice.

Reflecting on my time as an engineer, I realized that while there was almost no time in the industry to critically select a method, there was always time to rework problems caused by poor choices. Eventually, I reached a point where I felt I was unlearning more than learning. This reflection led me to leave the industry and pursue a master's degree in operations and logistics management to deepen my knowledge in process improvement. I also wanted to explore teaching opportunities. While delivering training sessions at the steel company, I discovered my passion for teaching, even though I had initially resisted following in my parents' footsteps as educators.

When I completed my master's degree, the first course I taught was, surprisingly, on Methods Engineering, specifically addressing motion and time studies. While preparing course materials, I realized that the only book on the subject in the library was from the 1970s and did not engage students in a meaningful exploration of the topic. This realization became the final motivation to start writing this book during my first semester teaching this course.

That same year, I participated in an extension project focused on the digital transformation of a public organization, which aimed to map and time their process. However, during data collection at the organization's agencies, it became evident that the lack of planning and a systemic vision inadvertently increased process inefficiencies. This project involved multiple teams of industrial engineers in various cities across Brazil. Interestingly, during the presentation of results to the national project coordinator and a senior official from the public organization, they were impressed, as our team was the only one to raise such critical questions about the project. This case highlights the ongoing gap in crucial understanding of motion and studies among industrial engineers in Brazil.

In conclusion, this book was written primarily for those learning Industrial Engineering. However, it can also assist students and professionals from various fields in designing and improving work methods, as well as selecting and applying time measurement procedures. We live in a world of constant change that demands continuous process improvement. While many methods claim to solve our problems, many struggle to use them effectively. Thus, understanding and correctly applying these methods has become increasingly crucial.

Therefore, this book aims to develop readers' critical perspectives by presenting existing motion and time study methods and explaining when, why, and how to apply them. The goal is not to promote the "best" method, as the most suitable method depends on the specific situation. Additionally, the book adopts a lean, holistic approach that helps identify waste and achieve global efficiency gains across processes, making them more efficient and delivering sustainable results.

As good professors empower their students to surpass them, this is my greatest aspiration. I hope this book helps students and professionals to gain a deeper understanding of the subject and, consequently, improve the quality of their work in future projects.

Elisa Granha Lira

BRIEF CONTENTS

Training and development

ORGANIZATION OF THE UNITS

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This book aims to answer the following questions:

- What are the principles that should guide a motion and time study?
- What are the methods of work design?
- What are the existing work measurement procedures? And when should we use each of them?
- How can we sustain the achieved results?

Consequently, this work is divided into four units:

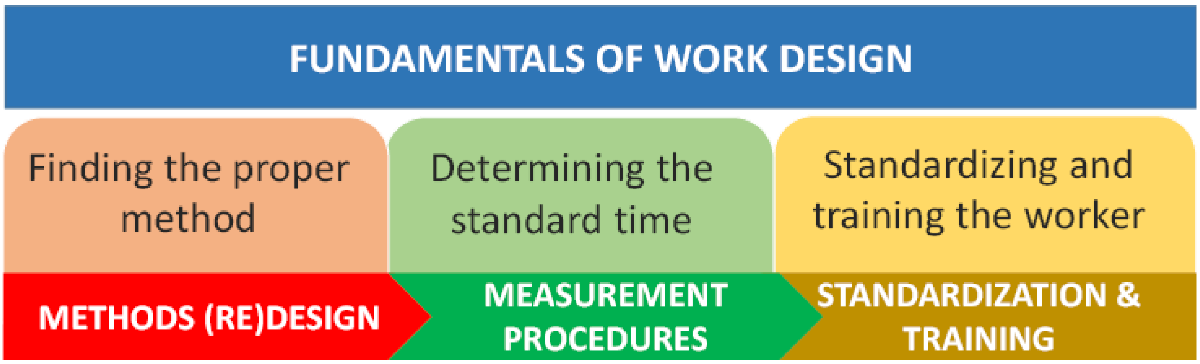
1. Fundamentals of work design.
2. Methods design and redesign.
3. Work measurement procedures.
4. Standardization and training.

The book is organized as follows.

The first unit addresses the fundamentals of work design that underlie the other units, including its historical background and the importance of focusing on flow efficiency. It also explores problem-solving methodologies (PDCA and DMAIC) and presents concepts in ergonomics and ergomotricity.

Once these fundamentals are internalized, the work method can be designed. Unit 2, therefore, covers techniques for selecting the most appropriate work method to eliminate waste; analyzing flow (flow process chart, flow diagram, and value stream map); analyzing operations (activity chart and worker-machine chart); and balancing a production line.

- **Chapter 1:** History of motion and time study
- **Chapter 2:** Lean Manufacturing
- **Chapter 3:** Problem-solving methods
- **Chapter 4:** Ergonomics and ergomotricity



- **Chapter 5:** Principles of waste elimination
- **Chapter 6:** Process analysis (Flow process chart, flow diagram, and value stream mapping)
- **Chapter 7:** Operation analysis (Activity chart and operator/machine chart)
- **Chapter 8:** Line balancing
- **Chapter 9:** Roadmap for defining the measurement procedure
- **Chapter 10:** Stopwatch time study
- **Chapter 11:** Predetermined time standards systems (PTSS)
- **Chapter 12:** Work sampling
- **Chapter 13:** Process standardization
- **Chapter 14:** Training and development

Now that the work method is established, we proceed to determine its standard time (Unit 3). This can be done through measurement procedures such as: stopwatch time study, predetermined time standards systems (PTSS), and work sampling. It is worth noting, however, that each of these procedures must be selected based on the objectives, constraints, and context of a motion and time study.

Finally, with the method and standard time defined, we can create or update work standards and train employees to sustain the results achieved.

UNIT 1

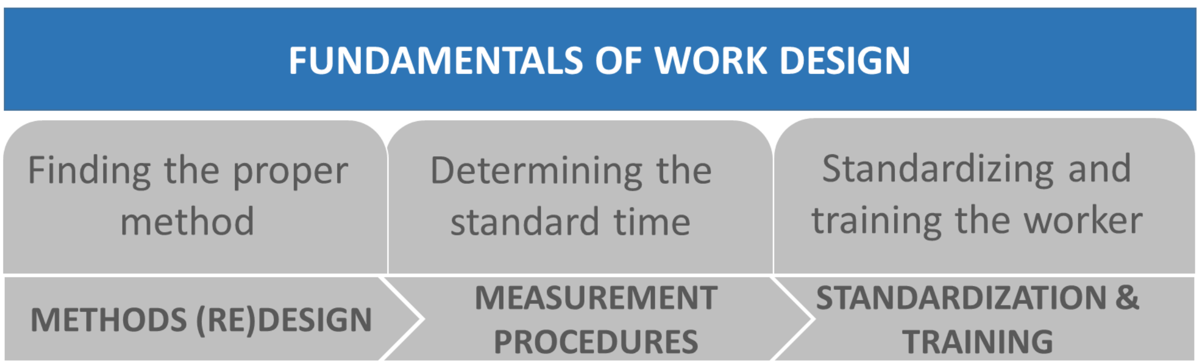
FUNDAMENTALS OF WORK DESIGN

- History of motion and time study
- Lean Manufacturing
- Problem-solving methods
- Ergonomics and ergomotricity

UNIT 1: FUNDAMENTALS OF WORK DESIGN

Unit 1 is the basis for the other units. It is divided into four chapters as shown below.

- **Chapter 1:** History of motion and time study
- **Chapter 2:** Lean Manufacturing
- **Chapter 3:** Problem-solving methods
- **Chapter 4:** Ergonomics and ergomotricity

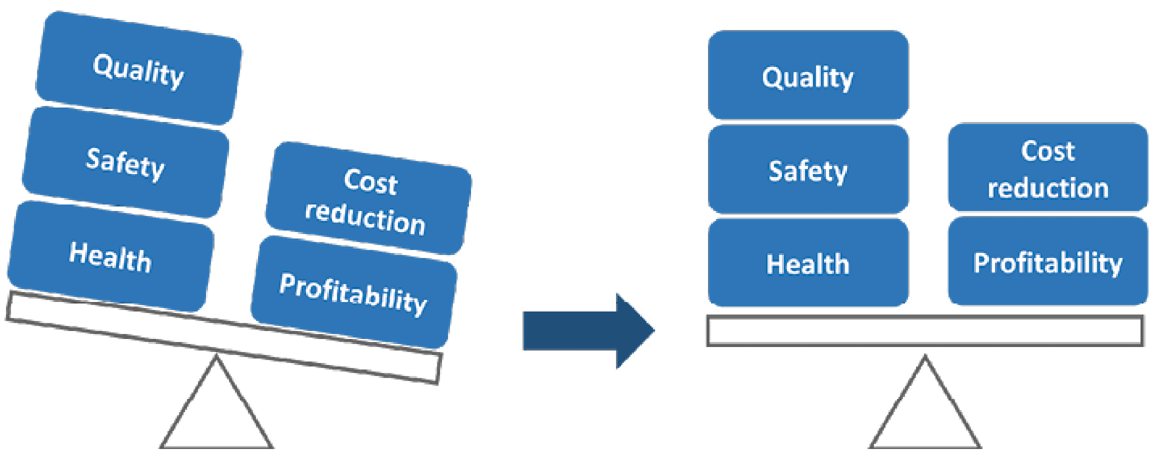


First, the historical background of motion and time studies will be presented. After all, Taylor and the Gilbreths adopted systematic procedures a long time ago to simplify work. Nowadays, continuous improvement in work design is a fundamental premise for any organization aiming to maintain its competitive advantage.

The second chapter presents flow efficiency. Motion and time studies can be used to design a job, produce a product, or provide a service. Regardless of the context in which they are used, they aim to increase process efficiency. This theme must be carefully studied, as it involves counterintuitive relationships. Generally, when we focus on improving resource efficiency, overall process efficiency suffers.

Nowadays, many companies focus on resource efficiency to increase profits and reduce costs through short-term actions. This “anxiety” can create risks related to the safety and health of employees and defects in the products or services offered. These problems, in turn, can compromise long-term results. Accordingly, the second chapter addresses Lean Manufacturing and the concept of flow efficiency, how it can be achieved and sustained within an organization.

It is noteworthy that satisfactory results can be achieved simultaneously across cost, quality, safety, and health. However, for this purpose, a systematic study must be conducted with clear phases of planning, execution, correction, and standardization. Thus, the third chapter will present problem-solving methodologies such as PDCA (Plan, Do, Check, and Act) and DMAIC (Define, Measure, Analyze, Improve, and Check).



Finally, since many concepts related to ergonomics and ergomotricity are used to support method improvement, the fourth chapter will focus on these two themes. There is no point in accelerating employees if we compromise their health and employability. The movements of the human body, the workplace, and the locations of tools and materials should be designed to optimize productivity while also satisfying the employee’s bio, psycho, and social needs.

CHAPTER 1: HISTORY OF MOTION AND TIME STUDY

Motion and time studies were developed according to economic, social, and technological stimuli. In pre-industrial society (before the 18th century), craftwork artisans produced goods in small workshops. The workers determined the time and rules, while master artisans controlled them. Thus, the masters held comprehensive knowledge of the production process and created “unique” products that reflected their region’s geographical and cultural characteristics. Due to the low production volume, the cost per unit was high.

However, society evolved, and a consumer-driven culture emerged, demanding larger quantities of products at lower prices. Time was treated as an input, and motion and time studies emerged as a natural response to this need. These studies enabled operators to produce more items, reducing the unit cost.

Accordingly, work has become increasingly specialized. In other words, individuals began to perform smaller portions of a task. Simultaneously, products became more standardized, which, combined with higher production volumes, made them cheaper and more accessible.

This trend continues today: global competition drives organizations to rethink their work methods and optimize operational times to enhance process efficiency. Hence, it is essential to understand the historical evolution of motion and time studies, as well as their techniques. Furthermore, it is critical to understand the context in which these methods were created, as necessity is the mother of invention. This understanding helps determine when a technique should be applied and what adaptations may be needed based on the problem at hand.

This chapter, therefore, aims to contextualize the historical evolution of motion and time studies. To this end, major pioneers will be presented: Frederick Taylor, Frank Gilbreth, and Lillian Gilbreth. While Taylor is renowned for his stopwatch time studies, the Gilbreths became famous for their motion studies.

Additionally, two production models will be presented: Fordism and Toyotism. Ford's mass production of automobiles would not have been possible without the extensive application of motion and time studies. On the other hand, it is also crucial to examine the Toyota Production System (TPS), whose philosophy underpins the continuous optimization of work through waste elimination and flow management — key concepts behind motion and time studies.

Before delving into these topics, it is necessary to distinguish among the levels of abstraction in this chapter, as they are often misunderstood in practice. When Taylor and the Gilbreths are presented, the focus is on the techniques they employed in their studies. These tools operate at a lower level of abstraction, which is more tangible and objective.

In contrast, when discussing production models such as Fordism and Toyotism, one must be more cautious, as they encompass multiple levels of abstraction. This distinction is exemplified by lean manufacturing, a term popularized by the 1990 book "The Machine That Changed the World," authored by MIT researchers based on their visits to Japan and investigations into the TPS. Lean manufacturing is a management philosophy inspired by the practices and outcomes of Toyotism and other quality tools. The term "lean" emphasizes the importance of eliminating waste in TPS, aiming to "streamline" the production system as much as possible by removing inefficiencies.

The literature on lean often blends different levels of abstraction, frequently leading to confusion among readers. Lean can be defined across three levels of abstraction (Figure 1.1).

At a higher level of abstraction, lean can be defined as a philosophy of production, that is, as a way of living and thinking. In other words, a lean organization aims to develop a culture and values in which all employees collaborate to continuously improve their daily tasks by eliminating waste.

At an intermediate level of abstraction, lean can be seen as a method of planning and control: the production system advocated (pull system), in which customer needs pull what should be produced; the kanban system; production leveling (heijunka); and synchronization. Finally, at the most tangible level, lean is also a toolbox for managing an organization, not necessarily exclusive to or created by Toyotism. Lean uses methods such as 5S, the Single Minute Exchange of Die (SMED), and even methodologies for motion and time studies developed by Taylor and the Gilbreths.

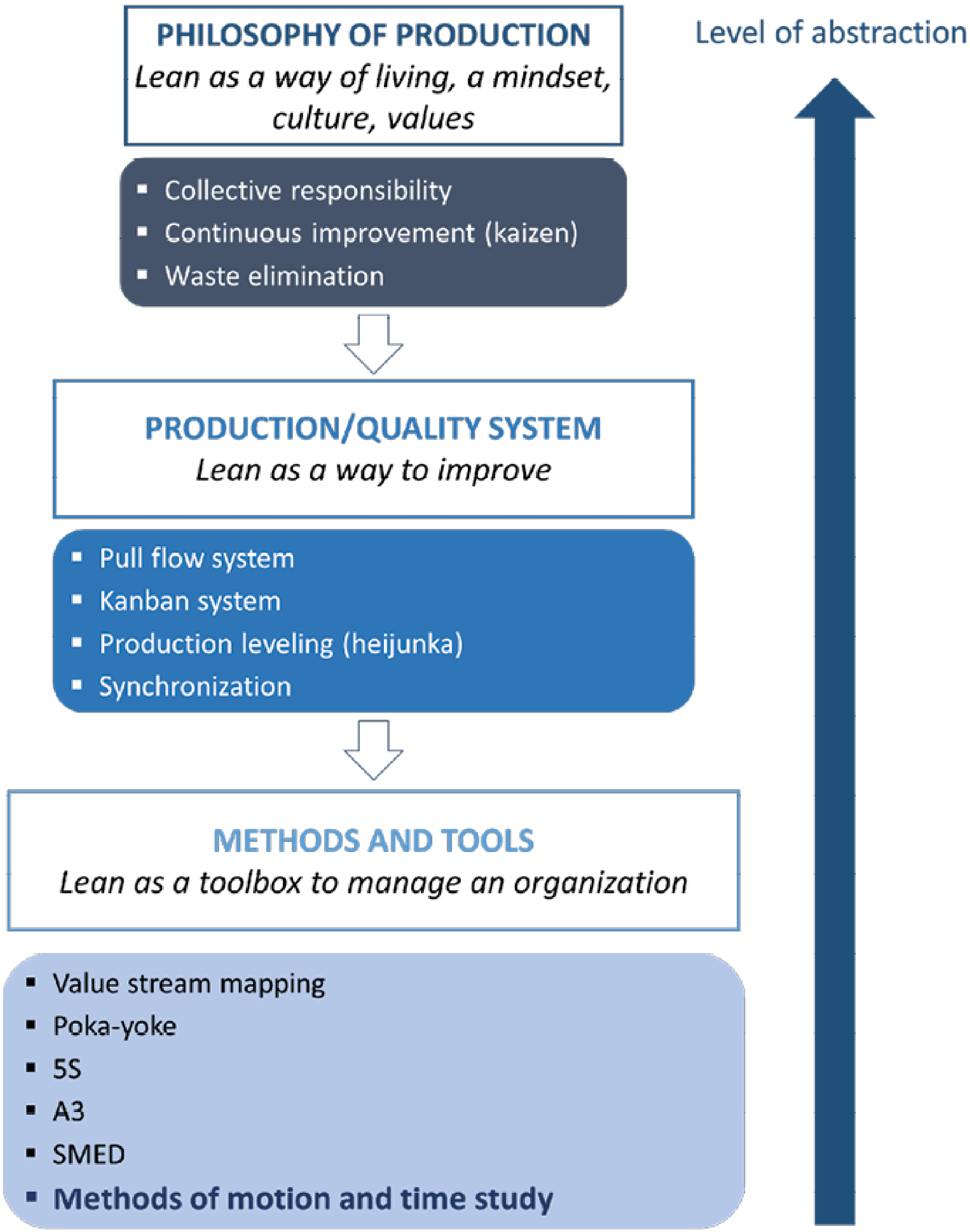


Figure 1.1 – The different levels of abstraction of lean manufacturing

1.1 Historical developments

This section will present the great precursors of motion and time studies, notably Frederick Taylor and the Gilbreths.

1.1.1 Frederick W. Taylor

Before Taylor's book "Scientific Management," empirical methods in business management predominated. Frederick Winslow Taylor (Figure 1.2) was one of the first to study work systematically. That is why he is known as the father of scientific management.

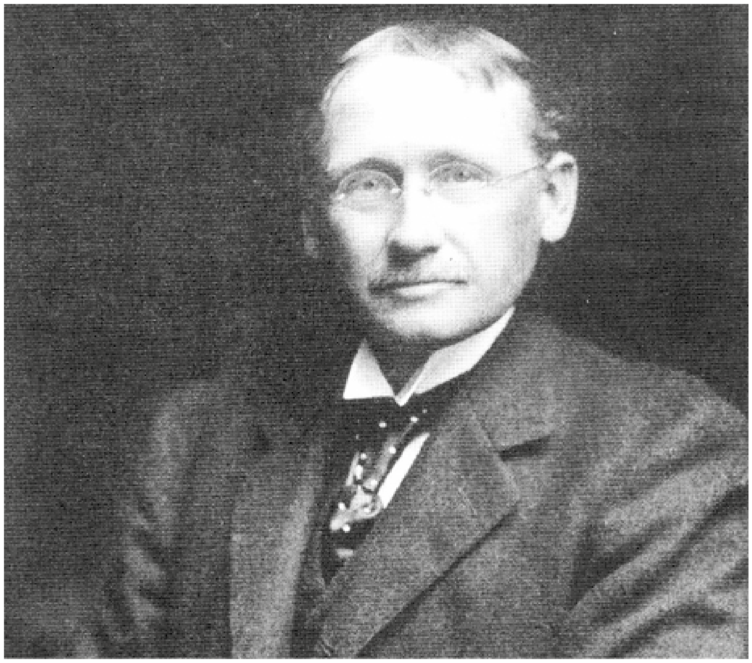


Figure 1.2 – Frederick Taylor

When Taylor started working, the economy was not doing very well, and his first profession was as an apprentice patternmaker and machinist. Being highly determined, Taylor advanced over time and registered numerous patents for inventions related to machines, tools, and work processes. For example, he invented a new method for cutting steel that enabled tools of the time to last three times longer than earlier versions.

Taylor's book, "The Principles of Scientific Management," had as its primary objective increasing productivity and organizational efficiency through the specialization and standardization of work. It is important to note that Adam Smith's concept of the manufacturing division of labor already existed; however, Taylor refined this concept to standardize the time required for each operation. His most significant contribution was the "scientific method," as he advocated for standardizing times and methods to remove workers' subjectivity in task execution. Manual operations were to be reduced to elementary movements that could be timed, described, and taught to anyone. Taylor sought to answer two fundamental questions: "What is the best way to perform a task?" and "How much can a worker produce in a single workday?"

While working at the Midvale Steel Company, Taylor conducted studies that concluded that the amount of work an operator could perform depended on three factors: the percentage of the day spent working, the percentage of the day spent resting, and the duration and frequency of rest periods.

The principles of scientific management presented by Taylor are as follows:

- Principle of Planning: The development of a science of work to replace individual worker judgment.
- Principle of Preparation: The selection and continuous improvement of workers. This process should not occur randomly but be carried out in a structured and scientifically standardized manner. The physical arrangement of machines and equipment should also be organized rationally.
- Principle of Control: Work must be monitored to ensure it is performed in accordance with established methods. Management should cooperate with workers to resolve problems.
- Principle of Execution: Duties and responsibilities should be distributed to ensure disciplined work execution.

In this way, Taylor applies the scientific method to the study of work, grounded in economic logic. His study aims to improve management accounting by analyzing operator time as an accounting measure.

Taylor's analytical study of the shop floor is worth noting, but the concept of production is broader than physical production.

Taylor's scientific method is well-illustrated in his study of shoveling (Figure 1.3).

In this study, Taylor investigated the principles underlying this operation and conducted several experiments to optimize the outcome for each shoveler. Accordingly, he studied the relationship between the time an operator spent on this operation, the shovel load and shape, the horizontal distance, and the throw height. After the study, Taylor determined the load per shovel that would maximize the amount of material the operator could handle without causing fatigue. Consequently, different types of shovels were required for each material, depending on its density. Smaller shovels should be used for denser materials, such as ores, while larger shovels should be allocated for less dense materials, such as ashes. Furthermore, time-study analyses were conducted to develop formulas for estimating the standard time for a given activity based on the weight handled and the distances traveled.

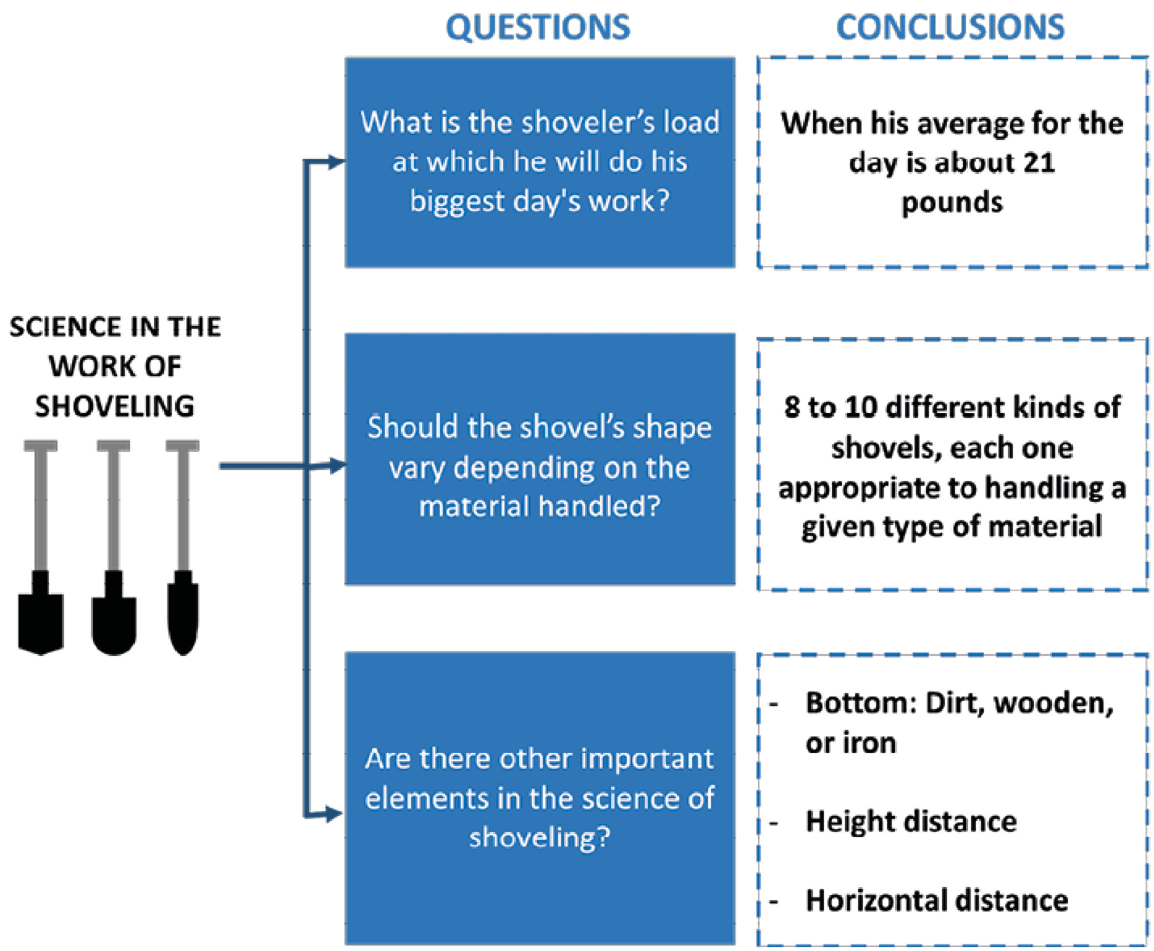


Figure 1.3 – Science in the work of shoveling

Taylor also introduced a visual system to motivate operators to continuously improve this activity. At the end of each shift, each operator received a card indicating their daily outcome. If the card had been white, the worker's performance would have been satisfactory. However, if the card was yellow, it served as a warning, indicating that the operator needed to improve or risk replacement.

The results of these studies and the standards developed are presented in Table 1.1.

According to Taylor, this system ensured the prosperity of both employees and employers. As shown in Table 1.1, both parties benefited financially from increased productivity.

	Old Plan	New Plan Task Work
Average number of yard laborers	400-600	140
Average number of tons per man per day	16	59
Average earnings per man per day	$1.15	$1.88
Average cost of handling a ton of 2240 lbs	$0.072	$0.033

Table 1.1 - Results of Taylor's Study on Shovel Handling

This study clearly illustrates Taylor's principles:

- Systematic study of work instead of individual guidelines.
- Harmony rather than discord.
- Cooperation instead of individualism.
- Development of each individual to their maximum potential for efficiency and prosperity.

1.1.2 Frank (1868–1924) and Lillian Gilbreth (1878–1972)

Frank and Lillian Gilbreth (Figure 1.4), pioneers in the field of motion study, also sought to research management scientifically; however, while Taylor's focus was on "time," the Gilbreths concentrated on "motion." Through their research and methodologies, the Gilbreths contributed not only to the field of motion and time studies but also to ergonomics and the psychology of management.

Figure 1.4 – Frank and Lillian Gilbreth

The Gilbreths' contributions spanned various fields, including civil construction, industry, and healthcare — they even conducted motion studies for people with disabilities. Frank developed a pitching technique for Major League Baseball that was later adopted by the U.S. Army for grenade throwing. Regardless of the field of application, their objective was always to improve workplace procedures to enhance productivity by eliminating unnecessary movements in the execution of a given task.

In other words, long and fatiguing movements should be replaced by shorter, less tiring ones. Ultimately, the most efficient sequence of movements would be selected. After all, the Gilbreths aimed to identify the best way to perform an operation.

A classic example is Frank Gilbreth's study on bricklaying. Frank developed a scaffold with an adjustable height and a platform where laborers could place bricks and mortar. This innovation eliminated the unnecessary and exhausting movement of bending down required to pick up a brick from the scaffold floor. Furthermore, Frank devised a solution to quickly handle bricks without having to choose the best ones from a pile. Bricks were to be inspected upon delivery and placed in molds side by side. As a result, laborers could perform this operation more efficiently using both hands simultaneously: one hand picked up the brick while the other grabbed the trowel with mortar. These improvements increased the number of bricks laid per hour from 120 to 350 – a nearly 200% increase.

The Gilbreths also applied the scientific method in hospital operating rooms. They recognized a significant opportunity in this area, as surgical instrumentation practices varied widely across the United States at the time. According to Frank, surgeons had more to learn from motion and time studies, waste elimination, and scientific management from industrial experiences than the industries could learn from hospitals.

Their studies revealed that surgeons spent more time searching for instruments than actually performing surgeries. As a result, surgical instruments were organized and aligned in regular, consistent patterns. Additionally, nurses began handling the necessary instruments for doctors to optimize surgery time.

Frank and Lillian Gilbreth are also renowned for developing several other techniques, including the flow process chart, micromotion studies, and cyclegraphic and chronocyclegraphic analysis.

Moreover, the Gilbreths created a classification of human body movements, a precursor to the flow process chart, that could be used to micro-analyze operator behavior. This list of movements was named "Therbligs" by its creators—a term derived from the word "Gilbreth" spelled backward. It consisted of a categorized list of movements (Table 1.2). Based on these categories, cycle motion charts could be plotted, with body parts on the horizontal axis and elapsed time on the vertical axis.

Symbol	Symbol Description	Symbol	Symbol Description

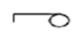
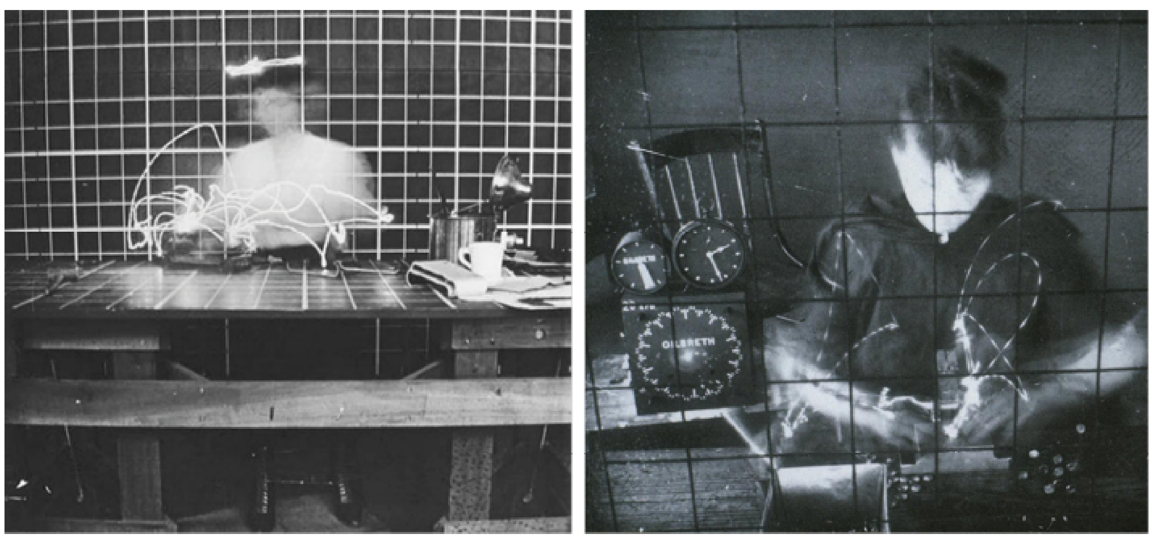
	Search		Inspect
	Find		Pre-position
	Select		Transport loaded
	Grasp		Transport empty
	Hold		Release load
	Use		Avoidable delay
	Assemble		Unavoidable delay
	Disassemble		Plan
	Position		Rest for overcoming fatigue

Table 1.2 – The Gilbreths' therbligs symbols

The micromotion study was made possible by the advent of the video camera. Basically, it involves studying movements using slow-motion footage. So, while Taylor directly timed his operations, the Gilbreths performed indirect timing through photo and video cameras. This footage served several purposes. First, there was a visual record of how to perform a task. Second, by studying these videos, the Gilbreths could identify several opportunities for improvement. Furthermore, the videos could be used in training.

The cyclographic method (Figure 1.5) consists of attaching a small electric lightbulb to the worker's finger, hand, or another part of the body. The movement of the light creates a bright line on a single time-exposed photograph. Accordingly, this motion pattern can be permanently recorded and analyzed to identify inefficient movements, such as twists and turns.

The chronocyclograph (Figure 1.5) is an improvement of the cyclograph, which interrupts the electric circuit regularly to obtain, in the resulting sequence of flashes, short dashes spaced according to the speed and acceleration of a body motion pattern. The greater the spacing, the faster the movement. If the movement is accelerated, the distance between these lines will increase continuously. On the other hand, when decelerating, this distance will decrease continuously. Consequently, the chronocyclegraphic technique enables analysis of the timing, speed, acceleration, and deceleration of the movements involved in an operation.



Cyclegraph   Chronocyclegraph

Figure 1.5 – Cyclegraphic and chronocyclegraphic analysis techniques

After Frank's death, the Gilbreths' reputation only increased: Lillian began publicizing their work, emphasizing their differences from Taylor. In addition, technological advances in photo and video cameras made their use more accessible and convenient for motion studies.

Thus, Taylor's time studies and the Gilbreths' motion studies began to be seen as complementary and used jointly, gaining greater acceptance in the scientific community.

Curiosities About Frank and Lillian Gilbreth

There are some interesting facts about Frank and Lillian Gilbreth. At the age of 17, Frank passed the entrance exam for the Massachusetts Institute of Technology (MIT) — one of the world's leading engineering schools. However, he decided to forgo higher education and became an assistant bricklayer. Demonstrating exceptional competence and discipline, Frank was quickly promoted and, in 1895, founded his own contracting firm, which became known for completing projects ahead of schedule and under budget. In 1902, Frank's firm completed construction of a laboratory for MIT in 11 weeks, a feat that impressed the university. Ultimately, Frank completely abandoned his construction work to devote himself exclusively to motion studies.

Lillian was also an extraordinary woman. In 1896, she began her studies at the University of California, where she became the first woman to deliver a commencement address. In 1915, she completed her PhD at Brown University with a dissertation titled "The Psychology of Management." Additionally, in 1935, she became the first woman to serve as a professor of management at Purdue University.

Frank and Lillian met in Boston in 1903 through a mutual friend, who was also Frank's cousin. Six months after their first meeting, they became engaged. The marriage of Lillian's expertise in psychology with Frank's engineering knowledge laid the foundation for their pioneering research, which focused on understanding the human factor in conjunction with motion-economy engineering.

Frank and Lillian were so immersed in process optimization that it was difficult to determine where their business ended and family life began. The couple had 12 children, and to "manage" them effectively, why not apply the methods they developed? Frank filmed his children performing routine tasks, such as washing dishes, and installed process diagrams in the bathroom to coordinate daily activities (e.g., homework, toothbrushing, and bathing). At the end of the day, each child was expected to self-assess and plot a graph. It is said that Frank even had all 12 of his children undergo tonsillectomies on the same day so he could study the method used for the surgical procedure. Not surprisingly, one of the couple's children later published a memoir titled Cheaper by the Dozen, which was later adapted into a film. One of Frank's favorite jokes was that, when asked why he had 12 children, he would reply that it was cheaper by the dozen.

Scientific management was applied not only to the children but also to every detail of Frank's life. He buttoned his clothes using the bottom-up strategy (rather than the top-down approach) because, according to his calculations, it saved four seconds. Frank even attempted to shave with two razors simultaneously, believing it to be the most efficient method, though he eventually abandoned the practice.

1.1.3 Other historical contributions

It is essential to highlight other individuals who also contributed to motion and time studies in addition to Taylor and the Gilbreths' notable and historical contributions:

- Carl Barth (1886–1968): An associate of Taylor, Barth developed a standard method to determine the most efficient combinations of inputs for metal cutting.
- Elton Mayo (1880–1949): Conducted research at the Western Electric Company's Hawthorne plant, laying the foundation for the humanist approach in management.

- Harrington Emerson (1853–1931): Authored the book The Twelve Principles of Efficiency, which introduced a work methodology that achieved savings exceeding 1.5 million dollars and became known as efficiency engineering.
- Henry Laurence Gantt (1861–1919): Designed simple charts that simultaneously represented performance measurement and planned schedules. These charts allowed current performance to be compared against planned outcomes, enabling daily adjustments based on capacity, backlogs, and client requirements. Gantt also devised a payment system that rewarded workers with superior performance. He believed that human relationships should be prioritized and that scientific management should not be applied solely to productivity.

After these pioneers, other milestones in the development of motion and time studies emerged from the major world wars and the arms and space races during the Cold War. These conflicts required high rates of production of weapons, aircraft, tanks, missiles, and other technologies within a short time frame. During World War I, for instance, England had a specialized group — the British Industrial Fatigue Board — that conducted numerous studies to improve efficiency and worker health. Similarly, the United States established military psychological engineering laboratories during World War II. Later, both the arms race and space race contributed to advancements in work design and the psychological management of labor.

1.2 Production systems

This section presents production models, such as Fordism and Toyotism, since the methods used in these models are often confused with the models themselves. Furthermore, these production models significantly improved motion and time study techniques.

It is worth noting that this book does not aim to present all the main models of production organization. The focus is on understanding how these models and their methods were applied according to the specific needs of the contexts in which these organizations operated.

1.2.1 Fordism

We begin by presenting Henry Ford (1863–1947) as described by Taiichi Ohno (1988, p.97):

"I, for one, am in awe of Ford's greatness. I think that if the American king of cars were still alive, he would be headed in the same direction as Toyota. I believe Ford was a born rationalist — and I feel more so every time I read his writings. He had a deliberate and scientific way of thinking about industry in America. For example, on the issues of standardization and the nature of waste in business, Ford's perception of things was orthodox and universal."

It is essential to begin with the excerpt above to reinforce the importance of viewing each person presented in this chapter as complementary rather than antagonistic. Ford was undoubtedly a genius who employed methodologies tailored to the problems he faced. The key point is that he lived in a very particular era: the dawn of mass consumption, which naturally demanded mass production of automobiles to meet the burgeoning demand.

Indeed, many companies today encounter contexts like Toyota's and naturally draw upon concepts such as lean manufacturing to improve their business models. However, we must avoid being constrained by labels and slogans. For instance, many principles of lean practices existed long before the label was formally established. Therefore, the goal is to critically evaluate each philosophy and methodology to select the most appropriate one for a specific problem.

One should always be skeptical of pre-packaged, ready-made solutions that lack a thorough, well-grounded investigation of the problem. While this may seem obvious, it is not. Today, many companies and professionals are lured by “miracle” solutions, seeking to use them as shortcuts to rapid, yet hollow, professional advancement.

Returning to Ford, he was deeply concerned with the continuous improvement of his automobiles, components, and methods — an approach not observed among other manufacturers of his time, who prioritized profit over all else. Ford consistently questioned the excessive focus on money at the expense of product quality, asserting that companies should strive to provide beneficial services to society.

Consequently, Ford believed a short-term focus on profit could jeopardize a company’s long-term success. In his view, profit should be seen as a consequence rather than the primary objective. When the process is prioritized, the desired outcomes are naturally achieved.

Ford valued efficiency in work methods. For instance, by employing standardized methods and components, it has become possible to offer affordable, superior-quality products. After all, the customer can have a car painted any color he wants, as long as it is black.

Figure 1.6 depicts Ford alongside his famous black Model T.

Figure 1.6 – Ford Model T

After all, producing cars in only one color significantly reduced process variation and, consequently, costs. This made the products more suitable for mass consumption, allowing a larger segment of society to access this consumer good. Ford ultimately aimed for a universal automobile model capable of serving everyone — a goal that was, to some extent, achieved with the Model T.

Moreover, innovation and quality improvement are recurring themes in Ford's writings. He emphasized that mistakes should not be a cause for excessive concern but rather seen as opportunities for improvement. In this context, innovation is the relentless pursuit of better products and processes.

Ford is also widely recognized for creating the automobile assembly line. This innovation drew inspiration from Chicago meatpacking plants and conveyor belts used in the cereal milling industry. It is essential to note that the secret to mass vehicle production was not merely the assembly line itself — a technology already used in other sectors. Instead, Ford's significant contribution lay in innovations that made the automobile assembly line feasible, such as the consistent, complete interchangeability of parts and their simplicity of fit.

Based on the previously discussed concepts, it is crucial to highlight four principles applied by Ford:

- Interchangeability of parts.
- Continuous flow.
- Division of labor.
- Waste reduction.

The production of interchangeable parts refers to manufacturing car components with minimal variability, meaning standardized production: any valve would fit into an engine, or any steering wheel would fit onto any chassis. Alongside the production of interchangeable parts, the cutting machines and tools used to make these components also had to be improved to ensure that any operator, even those with low qualifications, could use them effectively.

Regarding continuous flow, work in Ford's factories was organized so that as soon as one task ended, the next would begin with the shortest setup time. Another key aspect was that the product was brought to the worker instead of the worker moving to it. This is the fundamental idea behind the assembly line: reducing waste from excessive worker movement, thereby increasing production efficiency.

The division of labor is exemplified by the production of the Model T, in which Ford divided the manufacturing process into 84 steps. Each step was assigned to a specific worker, who was trained to perform it, significantly reducing training costs.

It becomes evident that Taylor's principles of scientific management influenced Ford's work: motion and time studies were essential to ensuring these 84 steps flowed harmoniously and in balance. It was necessary to determine precisely the pace at which tasks should be performed and the workers' movements. Consequently, unnecessary movements and other forms of waste were eliminated during the process. This is another constant in Ford's approach: waste reduction. Reflecting on the growing importance of the parts recovery sector, Ford once asked himself: Why do we have so much to recover? Are we paying more attention to fixing defects than to preventing waste in the first place?

When discussing waste elimination, one inevitably associates it with Toyota's production system. However, it is essential to note that Ford had already adopted this vision. Even though he might not have been familiar with the term "value-added," Ford strived for it in his operations.

Based on these four principles, Ford achieved outstanding results. The time required to assemble a chassis was reduced from 728 minutes to 93 minutes. Ultimately, a Model T was completed every 24 seconds on the assembly line. As a result, the price of Ford vehicles dropped dramatically — from an initial $950 to just $280 — making the automobiles accessible to the broader public, fulfilling Ford's aspiration to make car ownership a reality for the majority.

1.2.2 The Toyota Production System

The Toyota Production System (TPS), also known as "Toyota-ism" and the inspiration for lean manufacturing, is a production model developed by Toyota in Japan. It has gained increasing importance over the past decades, as many companies today face challenges similar to those Toyota encountered and subsequently adopt some of its tools, methods, and philosophy.

Toyota's approach rose to prominence during the 1970s oil crisis, which affected numerous governments and organizations. Japan was no exception, facing economic stagnation and organizational struggles.

However, despite reduced profits, Toyota was significantly more resilient than many other companies. This prompted questions about what Toyota was doing differently.

According to Taiichi Ohno (Figure 1.7), the Japanese industry had grown accustomed to the notion that if you produce, you will sell. However, socioeconomic conditions had shifted, and the mass production paradigm was no longer sufficient. The industry had to evolve accordingly.

Toyota's innovations began well before the oil crisis. After World War II, Toyoda Kiichiro, then-president of Toyota Motor Company, declared that the survival of Japan's automobile industry depended on matching U.S. efficiency within three years. This ambitious goal necessitated increasing Japanese workers' productivity so that tasks previously performed by almost 100 individuals could be handled by just 10. At that time, a German worker was three times as productive as a Japanese worker, and an American worker was three times as productive as a German worker.

In other words, it was as if nine Japanese individuals were needed to accomplish the work of one American. But what could be the cause of this difference in productivity? An American could not be almost ten times physically and intellectually more capable than a Japanese individual. Indeed, some form of waste justified such a disparity in productivity. This philosophy of waste elimination is the foundation of the Toyota Production System.

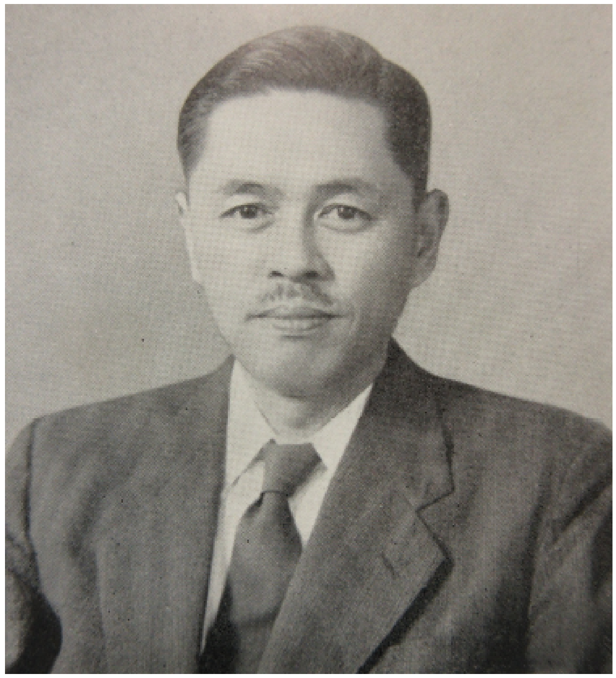


Figure 1.7 – Taiichi Ohno

A prime example of this philosophy is the reduction in changeover time for stamping machines at Toyota. The machines in the United States were developed to mass-produce over a million parts per year — meaning that many American manufacturers operated machines dedicated to producing only one type of product to maximize output within a specific timeframe. However, this approach did not make sense for Toyota since the company produced no more than a few thousand cars annually for different market niches post-war.

Ohno's strategy was to increase the frequency of press changeovers so that a single machine could produce many distinct parts. Nonetheless, the changeover time was very long: it generally took an entire day from the last part made on the outgoing presses to the first good part produced on the new presses. Thus, Ohno began developing simple techniques to optimize this setup time. For instance, presses were adapted for belt swapping, with simple mechanisms for proper positioning and adjustment. After numerous improvement experiments, changeovers were made every 3 hours instead of every 3 months.

Furthermore, the changeover time was reduced from one day to three minutes. Counterintuitively, Ohno discovered that working with smaller batches reduced the cost per part.

Two main reasons explain this phenomenon. Firstly, the costs of extensive inventories created by mass production were reduced, as inventory represents the cost of immobilized capital. In other words, the larger the inventory, the longer the time between the investment in purchasing raw materials and the financial return from the finished product sold to the customer. Moreover, inventory incurs other costs: storage, handling, and quality losses.

Secondly, quality issues were detected more quickly because batches were smaller, making problems easier to identify, track, and correct, thereby preventing the loss of defective products.

Thus, many forms of waste, such as inventory and quality losses, can be eliminated. Accordingly, this production philosophy is based on two key principles: Just-in-Time (JIT) and autonomation (also known as jidoka in Japanese).

JIT means supplying each process with the right items in the exact quantity and at the moment they are needed. The keyword here is NEED. Ohno strongly believed that necessity is the mother of invention. If done correctly, inventories can be reduced to minimal levels.

Autonomation, on the other hand, should not be confused with automation. Autonomation refers to machines that can autonomously stop working when an abnormality is detected. This principle emerged long before Toyota itself began producing cars. Before entering the automotive market, the Toyoda family worked in weaving, where Toyoda Sakichi developed a self-activating loom that automatically stopped when a thread broke. While the loom was operating, the presence of an operator was generally unnecessary; human intervention was required only when the loom stopped. Maybe this is why Ohno defined jidoka as an automation with a human touch. The invention enabled one operator to control several looms simultaneously. When Sakichi founded the Toyota Motor Company, he continued to lean on this pillar of autonomation.

Figure 1.8 presents the concepts within the Toyota Production System (TPS).

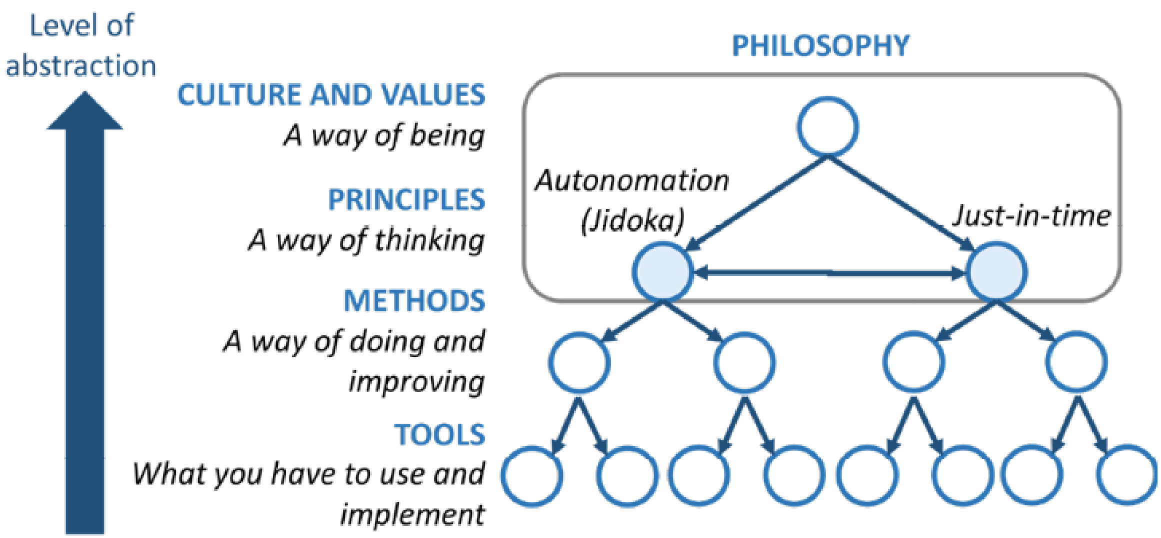


Figure 1.8 – Concepts of the Toyota Production System.

The TPS philosophy is based on values and principles. While values define a way of being, principles guide how we ought to think and what we should prioritize. Accordingly, just-in-time and jidoka are pillars of operational design. At a lower level of abstraction, methods refer to ways of doing and to ways of improving. In other words, they are the engines that push in the desired direction. A method, on the other hand, consists of tools, that is, what is necessary to use and implement.

The TPS is the mother of lean manufacturing. The term lean gained worldwide notoriety after the publication of the book "The Machine That Changed the World". Regardless of the term used, there is no doubt about the historical contributions of TPS, developed by the brilliant minds of Taiichi Ohno and Shigeo Shingo.

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CHAPTER 2: LEAN MANUFACTURING

As the primary objective of motion and time studies is to increase the efficiency of a process or workstation, it is essential to present the concept of lean manufacturing, which, in short, means having a lean process and focusing on satisfying the needs of the flow unit. Next, guidelines to make a process flow are presented — after all, they are the basis for making a process increasingly lean. Then, what is NOT lean will also be presented: the waste of focusing on resources and the productivity paradigm. Finally, a digital transformation case study will be offered to make these concepts more tangible.

It is essential to note that this chapter will be based primarily on the book "This is Lean: Resolving the Efficiency Paradox," by Niklas Modig and Pär Åhlström. However, some terms in this book were changed to align more closely with other lean and operations management references.

2.1 What is lean?

First, to understand a process, it is crucial to understand what flows. We will, therefore, name these objects transformed by the process as flow units, which can be materials, information, or people:

- Materials: In industries, materials are processed by machines and people until a product is produced, such as a car or a refrigerator.
- Information: Administrative functions process information such as spreadsheets and other types of documents, whether physical or digital.
- People: In services, the flow units can usually be people "transformed" by the process activities. For example, in a beauty salon, a person's hair is transformed by the hairdresser and beauty

products. In a hospital, doctors and other healthcare professionals treat a patient for an illness.

It is essential to draw attention to this to show how lean is universal regardless of context. We often encounter the terms "lean healthcare," "lean office," and "lean digital," but their essence is always the same.

Another issue is that being lean is not an attribute: a process is lean or not. In fact, it is a continuous variable, and we can always become leaner.

Therefore, when we want to define the degree to which a process is lean, we are interested in the time the flow unit receives value relative to the lead time it spends in the entire process.

$$Value\ added\ ratio = \frac{Value\ added\ time}{Lead\ time}$$

That is, how lean a process is can be evaluated by calculating the value-added ratio, which measures the time from identifying a need to satisfying it. Thus, the higher the value-added percentage (%VA), the leaner the process is.

It is also worth noting that an activity adds value when it meets the needs of the flow unit, while another that does not add value is a time-consuming activity that transfers no value to the flow unit.

Lead time is the time required to complete a process from start to finish. Thus, during a flow unit's lead time, it will undergo value-added activities and spend time on non-value-added activities, such as transportation and inventory.

Therefore, improving the time spent on activities that add value to the process is not a good strategy for increasing the value-added ratio. After all, this time is relatively short compared to the lead time. Accordingly, the value transfer ratio should be maximized by eliminating waste.

The value-added ratio shows a process's focus. A process with a low value-added percentage focuses on resource use, such as equipment and people (Process A in Figure 2.1). Meanwhile, a process with a high value-added percentage focuses on satisfying the flow unit's needs (Process B in Figure 2.1).

Even today, most organizations adopt such a perspective. There is a compelling reason why this approach dominates today's business world: it appears, at first glance, to make economic sense by focusing on the internal productivity of resources based on the opportunity cost. The issue is that if we focus too much on resources, we end up at a local optimum, which is unlikely to be translated into a global optimum for an organization. A good practical example is the cost-reduction projects that companies often promote. How many improvements to these projects have their departmental financial gains directly translated into gains for the company as a whole?

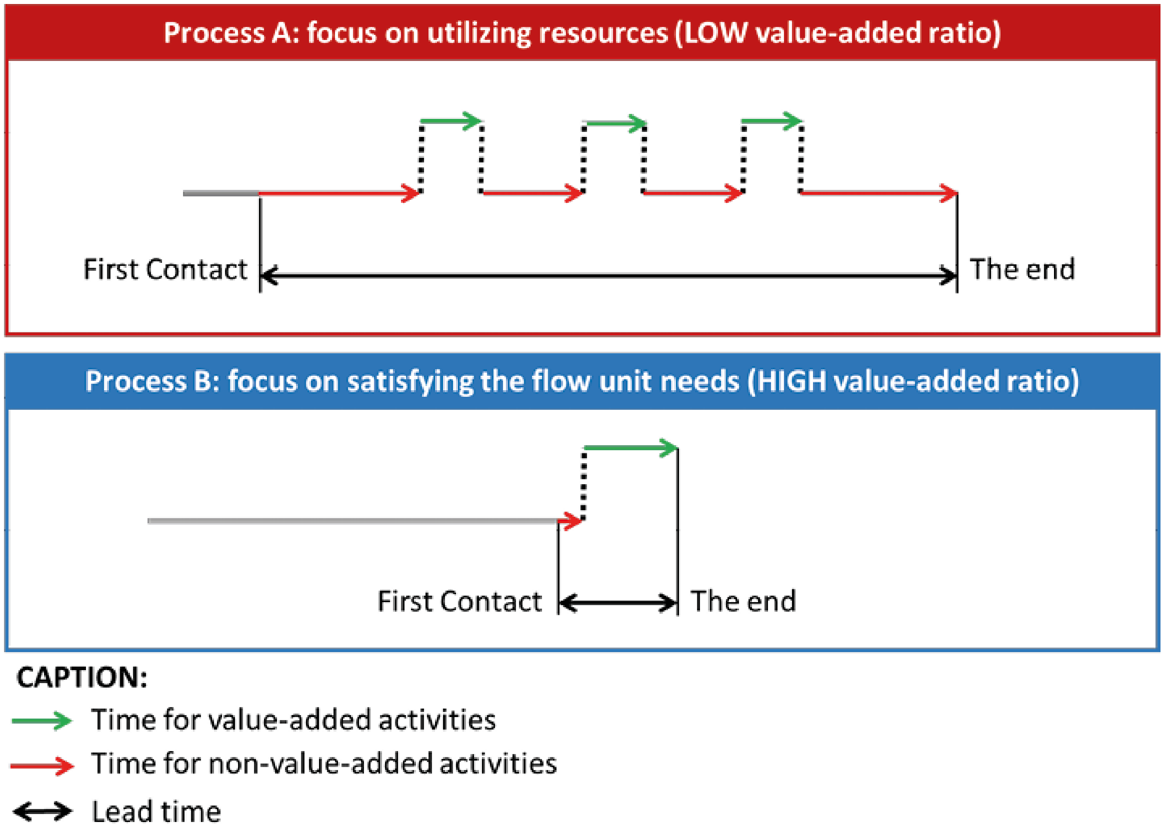

Figure 2.1 – Processes with different organizational focus

In conclusion, while in a resource-focused process, the flow unit adapts to the organization; in a process focused on the flow unit, the organization adapts to the unit, transforming it to satisfy its needs as quickly as possible (Figure 2.2).

For example, in a decentralized breast cancer diagnosis process (with several independent organizations and functions being responsible for different stages of the process: local doctor's surgery, mammography/ultrasound, breast clinic, and cytology), if we go to an ultrasound clinic, we will see equipment (resource) always busy with the intention of processing (performing tests) as many patients as possible. That is, it is a resource-focused process. However, there are specialized centers where a single organization centralizes all these activities. In this way, a patient can complete all activities in a single day, optimizing the time required for diagnosis and treatment outcomes. That is, in this second case, the focus is on satisfying the flow unit's needs (diagnosis of breast cancer in a patient) and not on occupying a resource as much as possible.

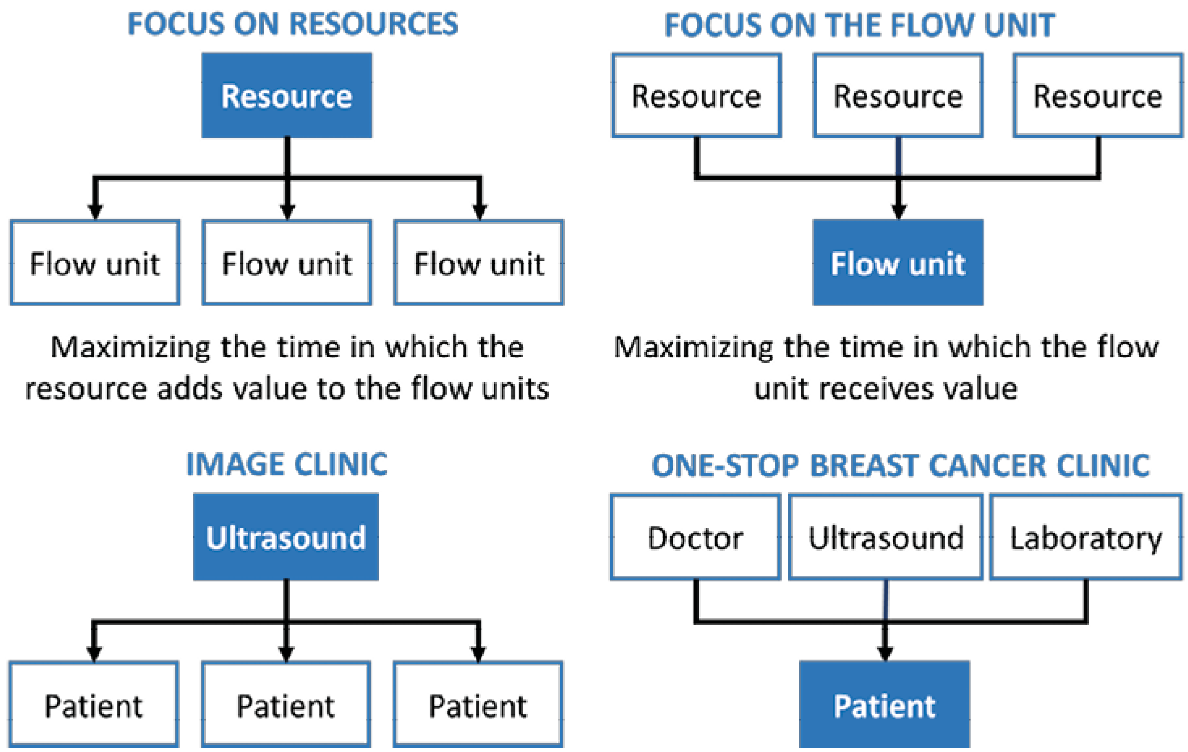

Figure 2.2 – Processes with different organizational focus (example of a breast cancer diagnosis)

The following section presents the principles behind the processes, which are crucial to understanding why focusing on resources compromises the value-added percentage of the overall process.

2.2 How to become lean?

An organization's processes are defined by activities that specify the route for transforming the flow unit to satisfy its needs. Thus, to make a process increasingly lean, it is necessary to understand the principles that govern it. These "laws" are universal and apply to any flow unit (materials, information, or people).

As previously shown, we can determine how lean a process is using the value-added ratio, which depends on the lead time. Thus, we are interested in understanding what factors affect the time required to complete a process.

2.2.1 Little's Law

The first principle is Little's Law, which is important insofar as, when managing the flows of a process, three essential questions must be answered:

- How many flow units pass through the process in one unit of time (throughput)?
- How long does a flow unit spend on average within the process boundaries (lead time)?
- How many flow units are at the process boundaries (Work in Progress - WIP)?

This law relates these three concepts:

$$Lead\ time = \frac{Work\ In\ Progress\ (WIP)}{Throughput}$$

As previously presented, lead time is the time required to complete a process from start to finish within the system's limits.

In-process flow units are those that have started the process but have not yet finished. They are the work in progress of flow units within the process boundaries.

Throughput is the rate at which flow units pass through the process boundaries, expressed as flow units per unit of time.

Figure 2.3 illustrates Little's Law logic.

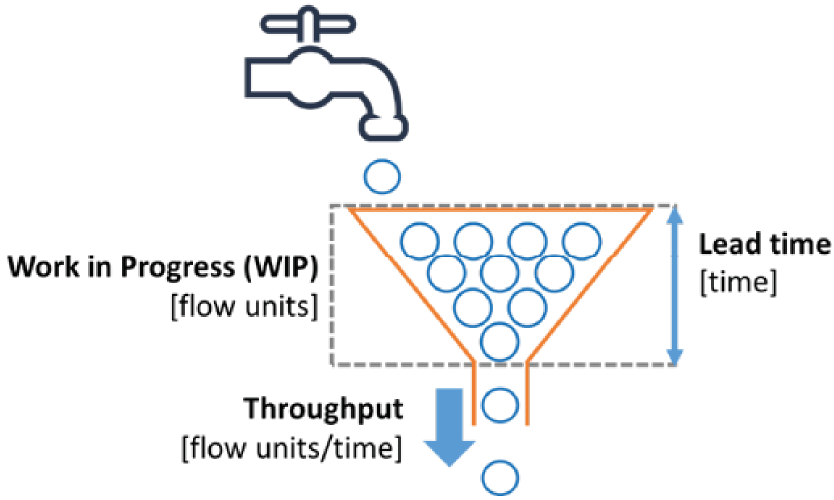

Figure 2.3 – Little's Law

Let's illustrate Little's Law using the example of a bank. If ten people are in a queue (WIP) at this bank and the cashier attends one customer every two minutes (2 minutes per customer = 0.5 customers per minute), the lead time is 20 minutes:

$$Lead\ time = \frac{10\ customers}{0.5\ customers\ per\ minute} = 20\ minutes$$

That is, the tenth customer in that queue will wait, on average, 20 minutes to be attended by a cashier (Figure 2.4).

Little's Law demonstrates, then, that the lead time is affected by two variables: the number of flow units in the process (WIP) and the throughput. Consequently, the higher the WIP and the lower the throughput, the greater the lead time.

This explains why the focus on resources compromises the process flow. To use resources most effectively, a "queue" of flow units should be created in front of these resources, reducing their idle time. The logic is that the flow unit, not the resources, must wait, thereby increasing lead time and reducing the value-added ratio. Another critical point is that the resources are so busy that they do not even have time to think (a waste of non-utilized talent) or to reflect critically on any rework that this logic generates in their work routine.

For example, in a bank, we often face a queue of customers (flow units) waiting to be attended by a manager (resource). Thus, the logic of a resource-focused process is that customers should wait while the manager is always busy. This overcrowding often leads to quality issues and rework for managers, as the focus is on serving as many customers as possible rather than assertively addressing people's needs.

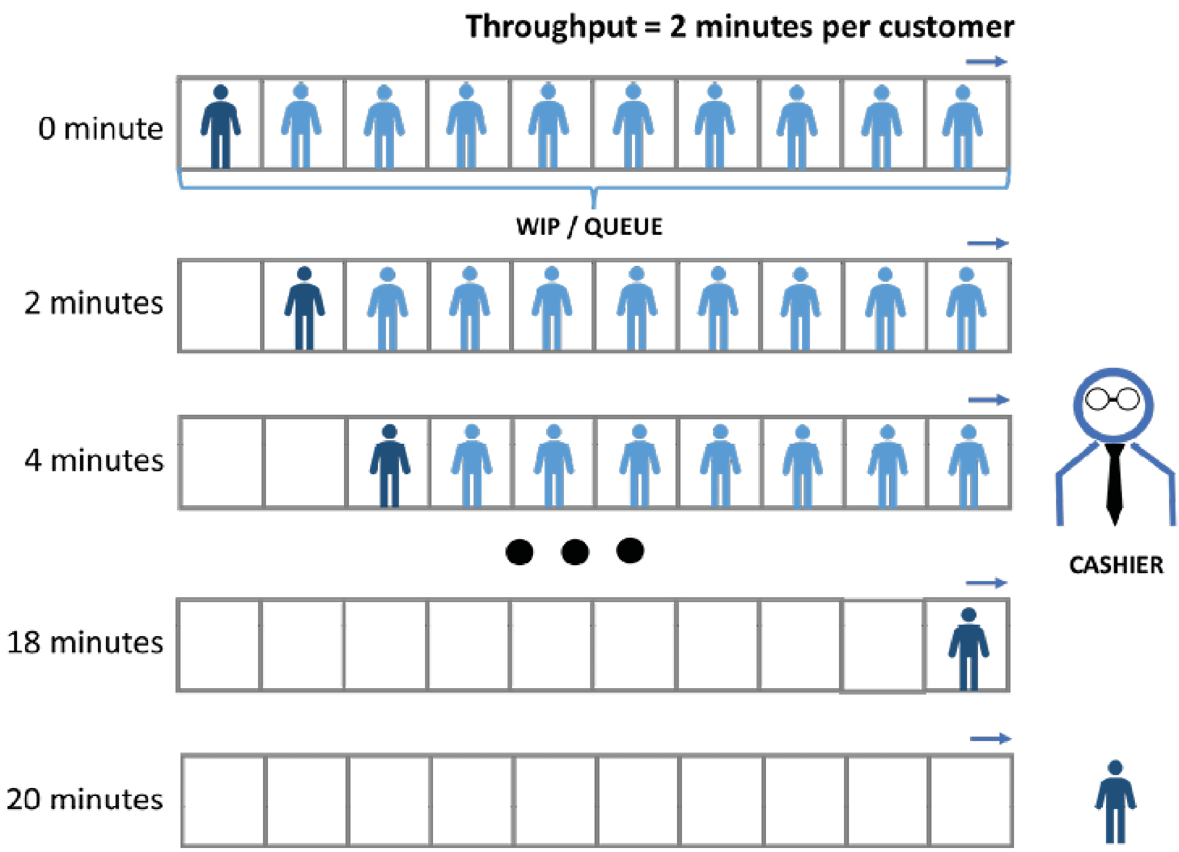

Figure 2.4 – Little's Law (Bank example)

2.2.2 The theory of constraints

Bottlenecks are process stages or activities that restrict the flow of units. Restricting this flow affects lead time, as the stage with the lowest flow rate constrains other resources.

Bottlenecks are a natural phenomenon in processes, given their sequential execution and the variation in flow rates across process stages or sub-processes. In the book "The Goal: A Process of Ongoing Improvement," Eliyahu Goldratt and Jeff Cox illustrate how to identify a bottleneck from the following symptoms (Figure 2.5):

- Before a bottleneck, there is always a queue/WIP: when the flow unit is physical, this is readily visualized. But when it is digital, the bottleneck can be camouflaged and go unnoticed.
- After the bottleneck, process activities have idle capacity.

Therefore, as bottlenecks generate queues of flow units awaiting processing, the Theory of Constraints shows that they increase lead time and reduce the value-added ratio.

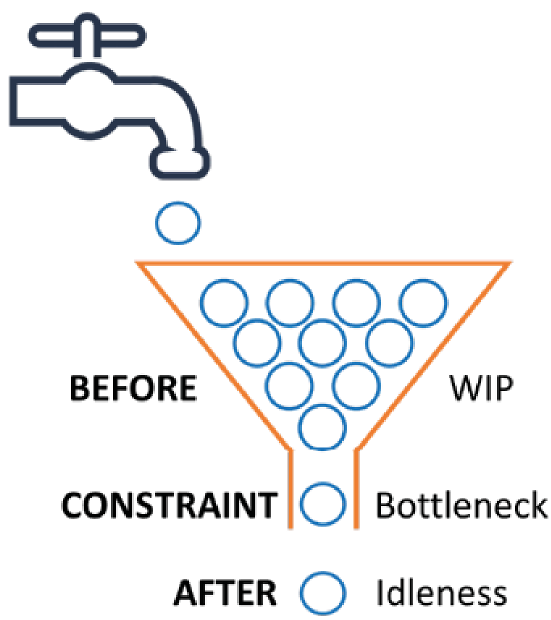

Figure 2.5 – The Theory of Constraints

2.2.3 The variability

The Japanese word mura can be translated as "unevenness," "fluctuation," or "variation." It is a significant source of waste, generating both muda (a Japanese term meaning "waste") and muri (a Japanese term meaning "overburdened"). Because of their initials, these three sources of waste (muda, mura, and muri) are known in lean as the "3Ms" (Figure 2.6).

Ideally, processes should be respected in their ideal capacity, without muda, muri, or mura — that is, without overloads, underutilization, and the least possible variability. Consequently, costs would be optimized, and the risks of quality and safety issues would be reduced.

Variability is also inherent in processes and affects the lead time. A good example is vehicle traffic in large Brazilian cities. If all cars on a large avenue stayed in their proper lanes and maintained the same speed, traffic problems would be avoided. But the reality is that the avenues are often chaotic: vehicle speeds vary, cars constantly change lanes, and unexpected encounters with pedestrians, cyclists, or animals can occur. These variabilities limit vehicle flow and create queues in the traffic lanes.

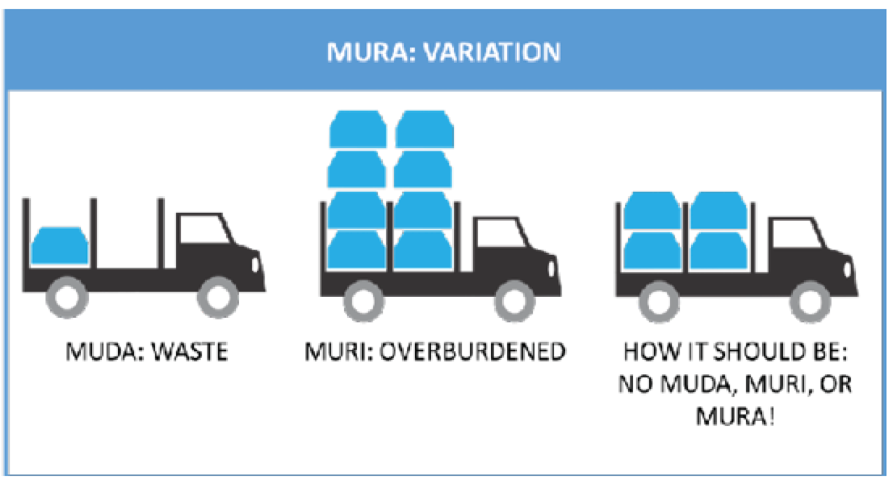

Figure 2.6 – The 3Ms

Thus, the greater the process variation, the longer the lead time. When the lead time increases, the process becomes less lean.

2.2.4 Creating a lean process based on the three principles

Therefore, based on the three guidelines presented, the lead time is affected by the following process variables: number of flow units (WIP), throughput, bottlenecks, and degree of variation (variability).

We can, therefore, develop a lean process from the following actions:

- Reducing the number of flow units in the process boundaries (queues/WIP).
- Increasing the throughput, i.e., processing more flow units per unit of time.
- Identifying and eliminating bottlenecks.
- Controlling the sources of process variability.

These principles also demonstrate the impossibility of simultaneously focusing on the flow unit's needs and resources. Imagine that a manager aims to achieve 100% utilization of their equipment; that is, the manager wants the equipment to produce good parts 100% of the time.

The natural logic is to work with a queue of flow units to be processed to achieve this. The greater the process variation, the more WIP is needed to buffer variability and keep resources at maximum capacity. In addition, bottlenecks also create additional rows of flow units.

According to Little's Law, a greater number of flow units within the process limits (WIP) increases lead time and reduces the percentage of value added. Thus, focusing on increasing resource use compromises the value-added ratio.

Another problem with focusing mainly on resource use is that superfluous work, which does not add value to the process, is generated by the creation of secondary needs. This is known as the productivity paradigm: it holds that maximizing resource utilization is more productive. However, as many of its activities are unnecessary or avoidable, it is actually an unproductive resource. It is the famous and shallow pop productivity: the more I do, the busier I am, the more productive I am. Am I?

In economics, productivity refers to how much output can be produced with a given set of inputs. However, a deeper analysis shows that productivity doesn't make sense when seen in isolation; it should be linked to other concepts, such as efficiency and effectiveness. If I produce 10 parts per day but 2 have quality issues, I am less productive than someone who makes 9 good parts per day.

After all, who is more productive: an employee who works day and night to meet their goals or another who delivers the same results within their regular workday? The productivity paradigm can be explained using the logic of the Overall Equipment Effectiveness (OEE) performance indicator (Figure 2.7). To maximize the utilization of our resources, we try to use them as much as possible. That is, we focus only on decreasing their availability loss. However, this blindness leads to performance and quality losses (defects, reworks, secondary needs), compromising our effectiveness. We don't see these issues because they are the hidden, intangible part of the iceberg: it is easy to see whether a person is working, but not easy to determine whether this work adds value or is a waste.

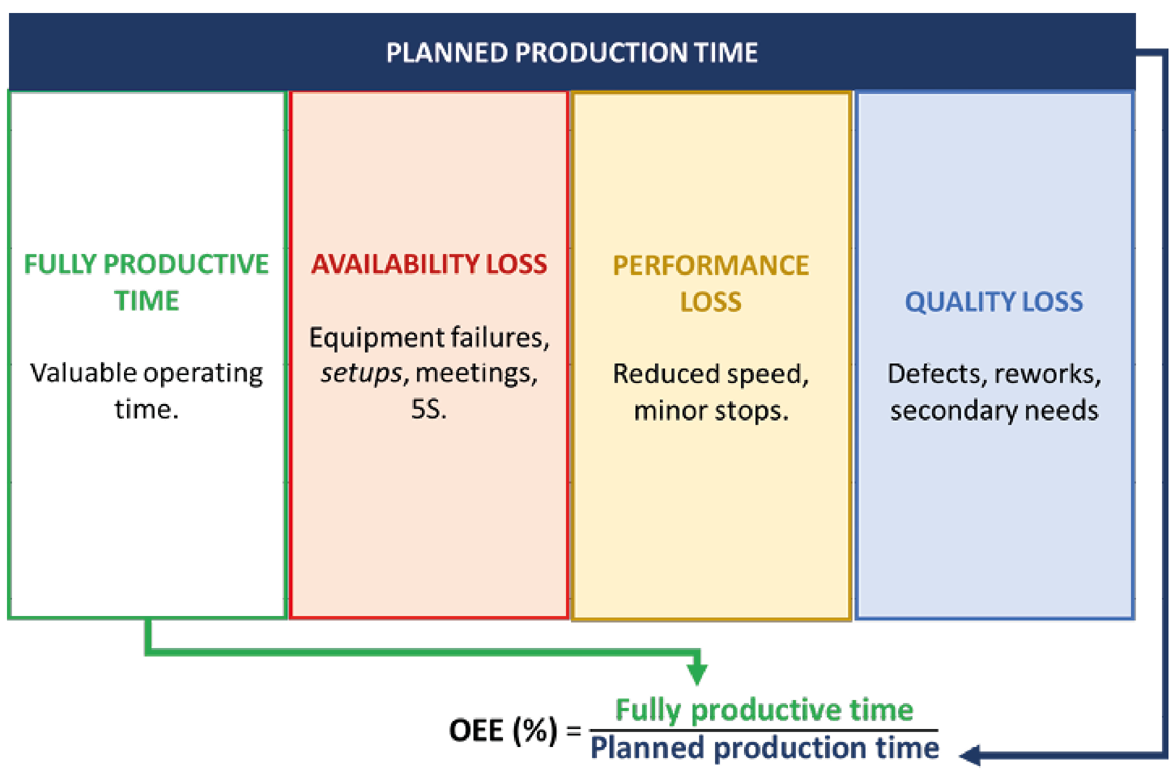

Figure 2.7 – OEE

Believe it or not, being lean starts with ourselves. Not to mention the potential harm of this overallocation of resources in terms of equipment and people in the medium/long term. Quoting once more, Taiichi Ohno: "Speed is meaningless without continuity. Just remember the tortoise and the hare. Moreover, we cannot fail to notice that machines not designed for endurance at high speeds will have shortened lifespans if we speed them up".

2.3 What isn't lean?

As we have seen, focusing solely on resources without considering the entire process reduces overall efficiency. This is because primary actions generate secondary needs that, although necessary and valuable, are often unnecessary and represent a waste of time and money for organizations. Thus, although many organizations recommend increasing the use of their resources as a primary objective, much of this work would be unnecessary if the organization focused on meeting the flow unit's needs from the beginning. This section will present the problems of focusing on resources and the productivity paradigm.

2.3.1 The problem of not learning to see

The exaggerated focus on resources can be easily diagnosed from three symptoms that are sources of inefficiency, according to what was seen about the principles of becoming lean:

- Long lead time.
- Many flow units (high WIP).
- Many restarts per flow unit.

These three symptoms, in turn, create waste in the system through a domino effect that compromises the value-added ratio (Figure 2.8), as they consume resources without addressing the flow unit's needs.

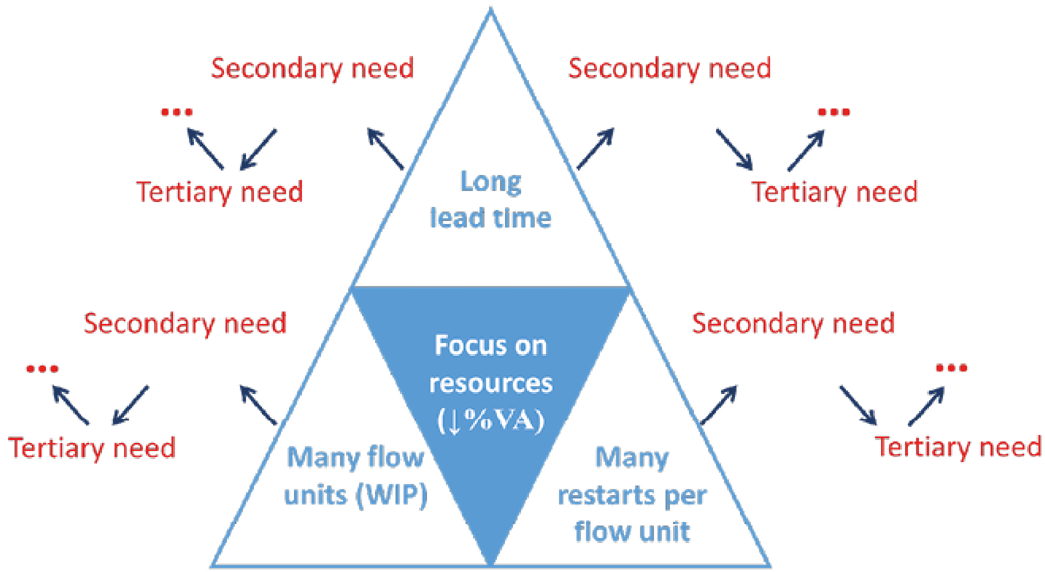

Figure 2.8 – Domino effect of waste

Table 2.1 presents the inefficiencies created by a process that focuses on resources without considering the whole, as reflected in each of these three symptoms.

These inefficiencies arising from a resource-focused process will be illustrated with several examples.

SOURCES OF INEFFICIENCY
LONG LEAD TIME
Generates secondary needs
Closes windows of opportunity
MANY FLOW UNITS (HIGH WIP)
Require additional resources
Generate secondary needs
Trigger stress

Stimulate loss of control
MANY RESTARTS PER FLOW UNIT
Require mental set-up time
Generate secondary needs
Risk of transfer of responsibility

Table 2.1 – Sources of inefficiency

The long lead time generates secondary needs and closes windows of opportunity. Let's take, as an example, the typical activity of organizing receipts during a trip for future reimbursement requests. This is an everyday reality for many of us: we keep adding receipts in a disorganized way to our wallets, and usually, when we return from the trip and have free time, we take the opportunity to fill in a spreadsheet with this information, scan the receipts, and enter the refund request in the system.

The point is that many secondary needs arise in this process, from organizing receipts to finding them all. See: if, as soon as we had lunch, we would take a photo of the receipt and enter the amount into a refund system via an app, for example, it would not be necessary to fill out a spreadsheet, organize the receipts, pick them up, and there would be no risk of losing them. For this reason, not entering this data right away and creating secondary needs can cause us to miss the window of opportunity to do "first time right."

The symptom "many flow units in the process" is harmful because it generates secondary needs, masks problems, and fosters a sense of loss of control. Accordingly, the high WIP demands additional resources to overcome these inefficiencies.

An example of this is the excess of information we need to deal with nowadays via email, app messages, and social networks. Have advances in information technology made us more efficient? High volumes of information make it difficult for us to have an overview of what is a priority and what is not. As a result, we waste a lot of time looking for and organizing information (secondary needs). Not to mention that quality problems are generated, which tend to be hidden by the high WIP.

In addition, this second source of inefficiency (many flow units in the process) creates productivism stimuli, overloading existing resources. Doing too many things simultaneously increases the risk of losing control, leaving people frustrated and stressed, causing communication problems, and creating secondary needs (meetings, searches, organization, and action plans). If even machines are limited resources, why shouldn't humans be?

Returning to the example of the excess of information we deal with nowadays, its adverse effect on people's physical and mental health is a fact. We are always busy and continuously receiving new demands. As a result, we end up doing a series of reworks because, instead of thinking and planning, we get stuck in a "do" loop. Sometimes, it is essential to ask ourselves: Is it worth it?

In the end, organizations create many routines to address problems arising from the high number of flow units in the process, which would not be necessary if the organization focused on meeting each flow unit's needs.

The third source of inefficiency – many restarts per unit of flow – is the famous "start and stop." When we restart a task, we need time to prepare mentally. In addition, when we repeatedly shift our focus from one task to another, we mentally tire ourselves out, which can lead to a continuous increase in the time needed for mental preparation.

For example, when we deal with many emails, we often have to read the same message more than once, especially when it has many details and is more complex. Thus, we prefer to postpone this task to a more opportune moment. Restarts, therefore, generate secondary needs for rereading, searching, and organizing these emails, as well as the risk of forgetting and reworking. It also increases the risk of responsibility being transferred during vacations, maternity leave, or employee turnover.

If we need time to remember and mentally prepare ourselves for an activity we restart, imagine what it will be like when a new person takes over. This reallocation of responsibilities creates distortions in information and communication, which, in turn, can lead to defects and quality issues. That is, this inefficiency leads to rework, which negatively affects customer satisfaction.

As can be seen, inefficiency propagates in a domino effect, with each of these three sources influencing the others. As previously discussed, focusing on the local optimum and prioritizing resources over flow units results in many process flow units and long lead times, which are directly linked by Little's Law. These two symptoms lead to a third source of secondary needs: the need to repeatedly restart the same task.

2.3.2 The productivity paradigm

As we have seen, the focus on resources creates "productive" islands, where the needs of flow units are subdivided into minor steps performed by resources with high utilization. However, each island sees only itself and has no vision of the whole. Consequently, the process is sub-optimized, with multiple local optima, while the global optimum is compromised, creating secondary needs and reducing its value-added ratio. This is what we call the productivity paradigm: the illusion that we are productive when, in fact, we are not, because activities that appear to "add value" are, in fact, camouflaged waste.

It is worth noting that this productivity paradigm exists at both the individual and organizational levels across all contexts, including private services, industries, and even public offices.

For example, imagine a metallurgical company with several departments, such as a steel mill, hot rolling, and wire drawing. These departments are also subdivided into subprocesses, each with its own manager or coordinator. Suppose the organization is unconcerned and makes no effective effort toward global improvement. In that case, the manager of each department will naturally favor local interests, which may not be in the organization's best interests.

Thus, to optimize a system, all those involved must understand its overall objective and think differently, as local interests do not always align with global interests. In addition, it is crucial to have engaged leadership and to share performance metrics among departments/functions.

From an individual perspective, this superfluous work often goes unnoticed: We think we are adding value by being continually busy, but in reality, much of our work is avoidable waste. An engineer, for example, often spends considerable time reading emails, gathering data for performance indicators, completing reports, and attending meetings.

Obviously, some of these activities are necessary, but does all this work add value to the organization? That is why we must always ask ourselves: How much of our staff and equipment time is spent on activities that do not necessarily add value and were created to meet secondary needs?

One can be sure that there is always hidden waste to eliminate, and self-questioning is the first step in addressing the productivity paradigm. When we question this productivity paradigm, we face the challenge of examining the flow throughout the process and aiming for global gains. The lead time is short in a system focused on satisfying the flow unit's needs, and few flow units are within the process boundaries (low WIP). This ends up avoiding unnecessary restarts. Secondary needs and superfluous work are therefore avoided. Literally, everything flows.

Lean is a strategy that aims to optimize process efficiency and effectiveness. We need to recall its philosophy, as presented in Chapter 1: We seek to eliminate waste by adopting a global vision in which everyone is responsible for continuous improvement based on customers' real needs, rather than individual thoughts and stimuli. This book, therefore, adopts a lean approach to motion and time studies. The following chapters will introduce several lean concepts to help readers understand how to achieve a high percentage of value-added in a process.

2.4 Case study: Digital transformation – Part 1 (Answer in Appendix 5)

An organization has launched a project to digitalize its processes. As a result, services that were previously provided in person are now conducted remotely. The long-term objective is to enable analysts to perform their work from home. This shift is expected to yield significant efficiency gains for the organization, as it will require less physical infrastructure. Furthermore, with a more "controlled" work environment and fewer interruptions, analysts are expected to process more requests per day.

Their activities were mapped to establish productivity targets for these analysts, and time studies were conducted to assess the time required for each task. Thus, Process 1 was evaluated by measuring the time taken before and after its digitalization. It is essential to highlight that when a required document is missing, the analyst issues a request to the applicant, which must be fulfilled for the request analysis to proceed.

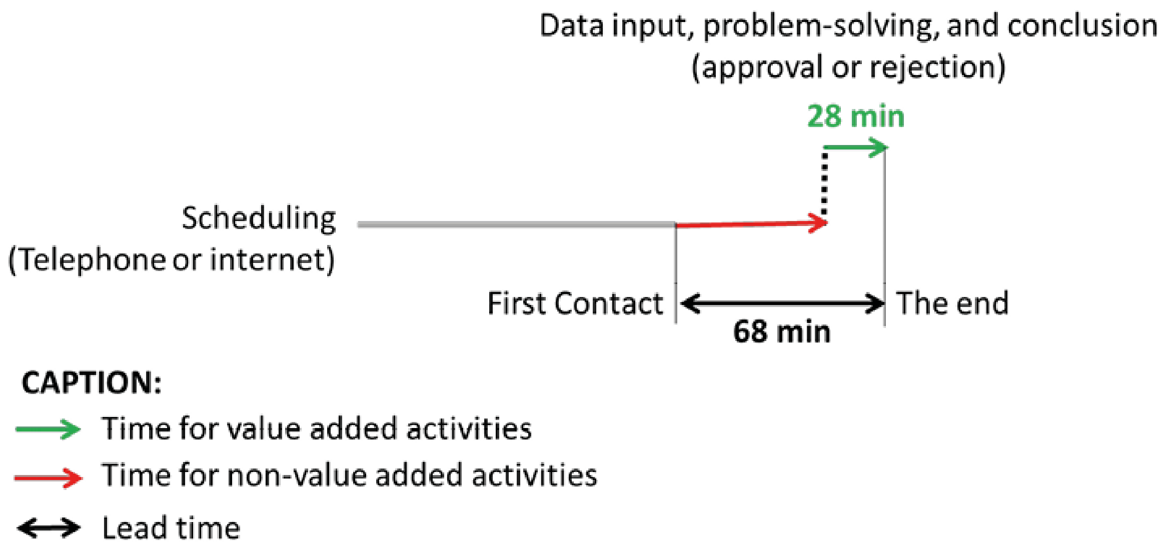

Figure 2.9 – Process BEFORE digital transformation

Figure 2.9 illustrates how Process 1 was carried out before it was digitalized. The applicant would schedule an appointment at one of the organization's units by phone or online. Upon arrival on the scheduled date, they would wait to be called. When their turn came, they would be assisted directly by an analyst, who would analyze the case in the applicant's presence. If any documentation were missing, the analyst would request it from the applicant.

In most cases, the applicant had the document on hand and could provide it immediately, allowing the analyst to proceed. In the analyzed case, the applicant spent 28 minutes on value-adding activities (such as consultation and resolving pending issues) out of a total of 68 minutes spent at the agency. The remaining 40 minutes were spent waiting for service.

Figure 2.10 represents Process 1 after digitalization. In the future, applicants will still need to schedule their appointments by phone or online. However, on the scheduled date, they will be assisted by an intern, who will be responsible for handling the applicant and digitalizing all necessary documents for case analysis. A predetermined time of 20 minutes has been allocated for each appointment. Following this initial service, the request will be added to a virtual queue of pending requests awaiting analysis. In Figure 2.10, the green arrows represent activities performed by analysts that add value to the process.

In contrast, the red arrows indicate when the application was waiting for the upload of the missing documents and the subsequent analysis in the system. When the first problem was solved, the analyst verified that other documents were missing and had to request them again. The analyst spent 90 minutes analyzing the data during the 18 days (25,920 minutes) of lead time from the first contact to the process conclusion.

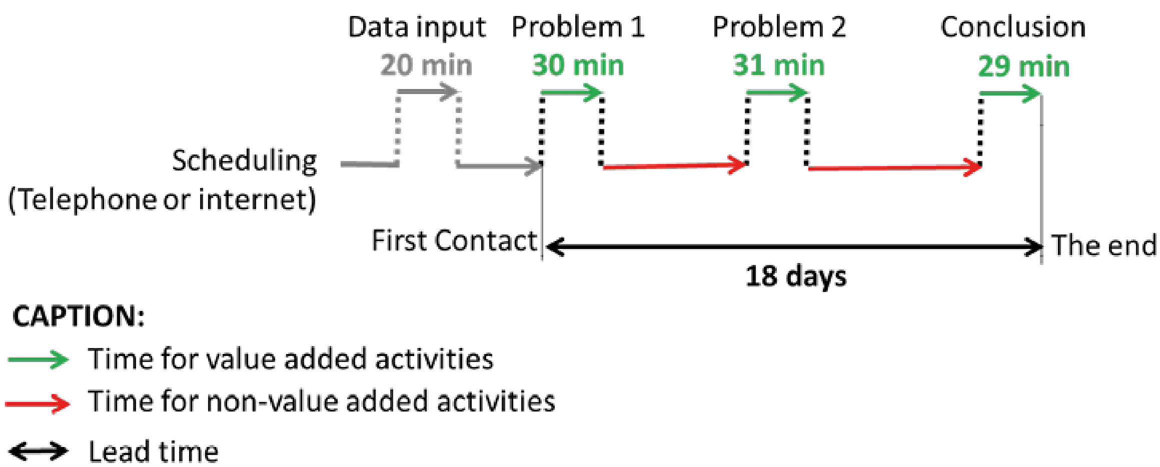

Figure 2.10 – Process AFTER digital transformation

Based on this case study, answer the following questions.

1. Complete the table below, calculating the percentage of value-added time before and after the digital transformation from the first contact until the end of the process; and defining the focus of each scenario: flow unit or resources?

	Process BEFORE digital transformation	Process AFTER digital transformation

% value added time		
Focus (flow unit or resources)		

2. How would the three symptoms of the low percentage of value-added time (long lead time, many flow units, and many restarts per flow unit) be verified in this example?
3. Discuss the following statement based on your previous answers.

"A digital transformation project will always increase productivity."

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Websites

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Niklas Modig – https://niklasmodig.com/

CHAPTER 3: PROBLEM-SOLVING METHODS

A systematic structure is essential for guiding the implementation of a motion and time study. In this regard, the PDCA and DMAIC cycles can be employed to achieve greater accuracy in studying the problem and its causes, and to optimize the sustainability of the results.

These methods generally consist of the following stages:

- Problem definition.
- Problem analysis.
- Research on possible solutions.
- Evaluation of alternatives.
- Recommendation for action.

The PDCA cycle (Plan, Do, Check, Act) and the DMAIC methodology (Define, Measure, Analyze, Improve, Control) are managerial methodologies used for decision-making and problem-solving to achieve goals and ensure an organization remains competitive. Thus, these are systematic procedures that follow a scientific methodology for problem resolution.

In this book, another phase will be added at the end of the DMAIC cycle: Standardize, since achieving results is of no value if they cannot be sustained. Accordingly, this cycle will appear as DMAICS.

PDCA and DMAICS are used for similar purposes. The main difference is that DMAICS places greater emphasis on the Planning phase of PDCA, breaking it down into the Definition, Measurement, and Analysis stages. It is also worth noting that DMAICS is generally used in Six Sigma and Lean projects.

The following subsections will discuss each of these management methods in detail. At the end of this chapter, a case study will be presented to reinforce and internalize the concepts discussed.

3.1 PDCA cycle and its variants

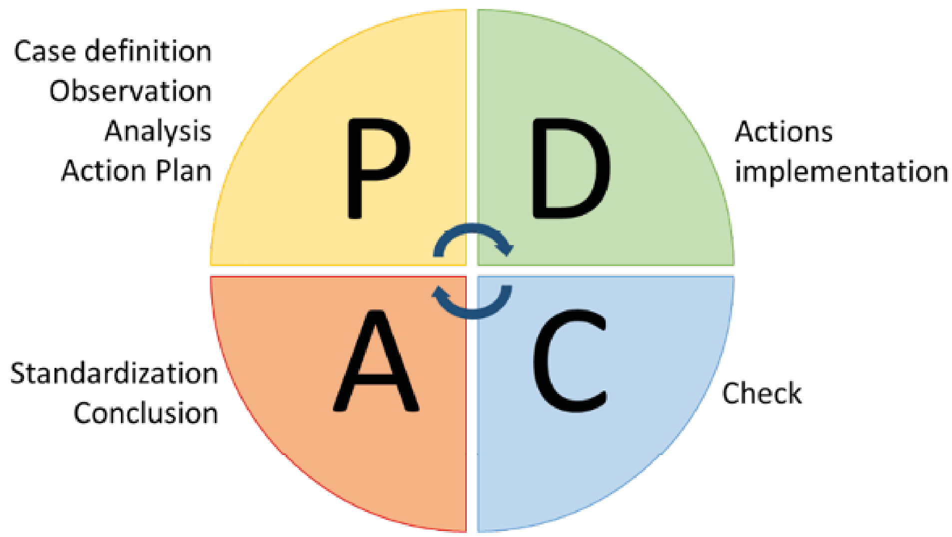

Figure 3.1 – PDCA cycle

The PDCA cycle (Figure 3.1) is used for process and product control and for continuous improvement. The acronym PDCA refers to the initials in English of its cycle stages:

- P: Plan.
- D: Do.
- C: Check.
- A: Act.

PDCA, also known as the Deming cycle, was created in the 1920s by Walter Shewhart but became famous through William Edward Deming. It is a widely used method for controlling an organization's activities, mainly those related to improvements.

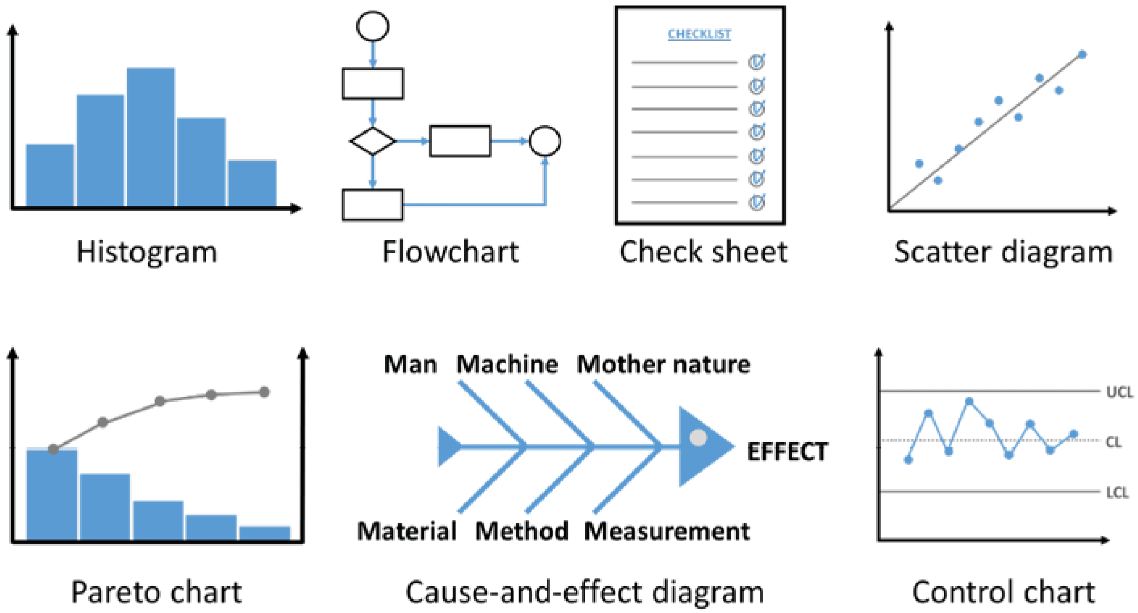

Figure 3.2 – The seven basic quality tools

It is, therefore, a managerial method that helps managers while making decisions to achieve their goals. When rotating the PDCA cycle, statistical techniques are used during data collection, processing, and analysis. Among these techniques, we can mention the seven quality tools (Figure 3.2): histogram, flowchart, check sheet, scatter diagram, Pareto chart, Ishikawa diagram, and control chart.

Since both PDCA (Plan, Do, Check, Act) and SDCA (Standardize, Do, Check, and Act) aim to achieve goals, it is important to highlight their differences. In this analysis, it is essential to distinguish between the two types of targets (Figure 3.3):

- Improvement targets: Goals that not only aim to maintain a nominal state, but also challenge to produce a product or provide a service more competitively. As an example, if our goal is "to reduce by 20% in 2023 the percentage of scrap due to nonconforming length", the PDCA cycle must be used;
- Maintenance targets: These goals are represented by the specification limits of a product. For example, if "the tube must not

have a length variation greater than 1% in relation to the value requested by the customer", the SDCA cycle must be used to respect these specification limits.

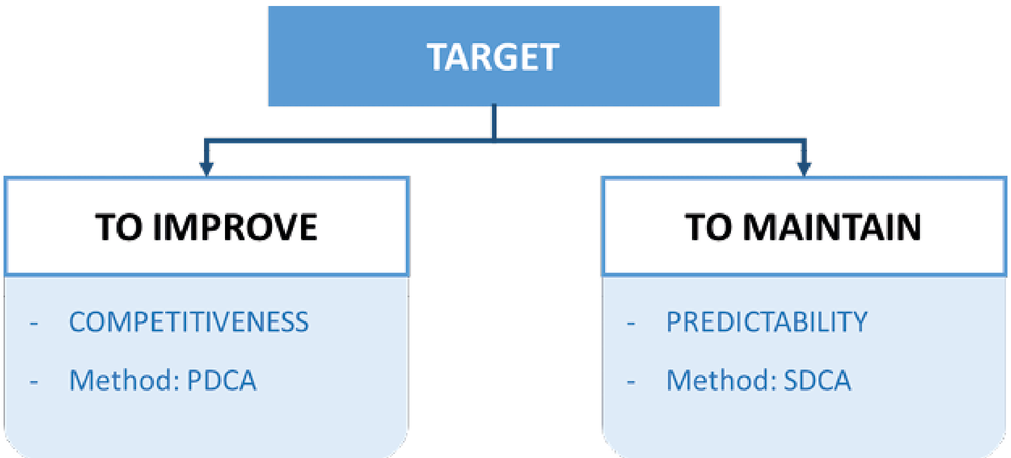

Figure 3.3 – Improvement and maintenance targets

The PDCA cycle, used to solve problems and achieve improvement goals, has variants such as the Methodology for Analyzing and Solving Problems (MASP) and the Quality Control Story (QC Story). Figure 3.4 provides a detailed overview of the stages and sub-stages of the PDCA cycle.

Table 3.1 outlines the MASP stages to facilitate comparison with the improvement-oriented PDCA stages. Essentially, MASP breaks down the PDCA cycle, highlighting its micro-stages. Additionally, the table presents potential tools and techniques that can be applied at each stage.

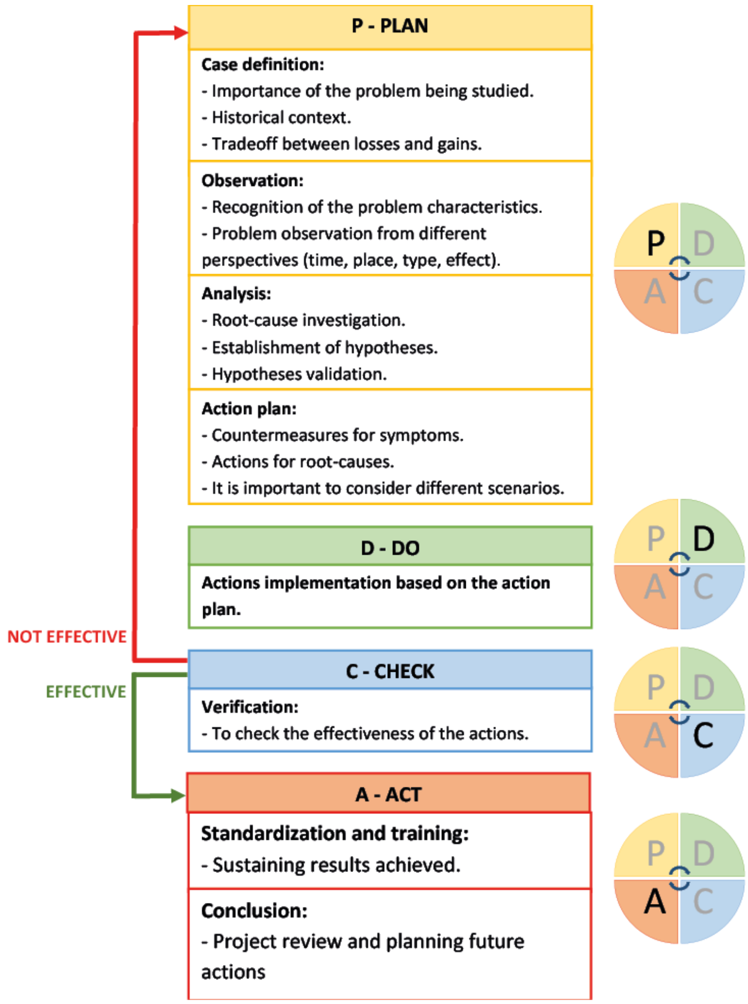

Figure 3.4 – PDCA stages

#	Stage	Objective	Tools and Techniques
1	Problem Identification	Define the scope of the problem to be studied, its significance, and the motivation for carrying out the project.	Graphs, photographs, and decision matrix.
2	Observation	Study the problem's behavior from multiple perspectives (stratification) to gather information that helps identify its root cause.	Observation, interviews, flowcharts, stratification, and Pareto chart.
3	Analysis	Identify the fundamental causes that originated the problem.	Brainstorming, cause-and-effect diagram (Ishikawa), 5 Whys method, Pareto chart, histogram, and other graphical tools.
4	Action	Define and	5W2H and

		implement actions, specifying those responsible and setting deadlines.	training.
5	Verification	Assess the effectiveness of the actions taken.	Performance indicator monitoring, graphs, photographs, and observation.
6	Standardization	Ensure results are sustained to prevent recurrence of the problem caused by deterioration in procedures, controls, or mechanisms.	Standardization, training, and audits
7	Conclusion	Reflect on the project and its activities, document its history, and plan future work.	Project summary form

Table 3.1 – Tools and techniques to be applied at each stage of MASP

In contrast, maintenance goals are achieved through standardized operations. To achieve these goals, SDCA is recommended. The “P” for Plan in the PDCA cycle is replaced by the “S” from the English verb Standardize in SDCA. Figure 3.5 illustrates the components of each stage of the SDCA cycle.

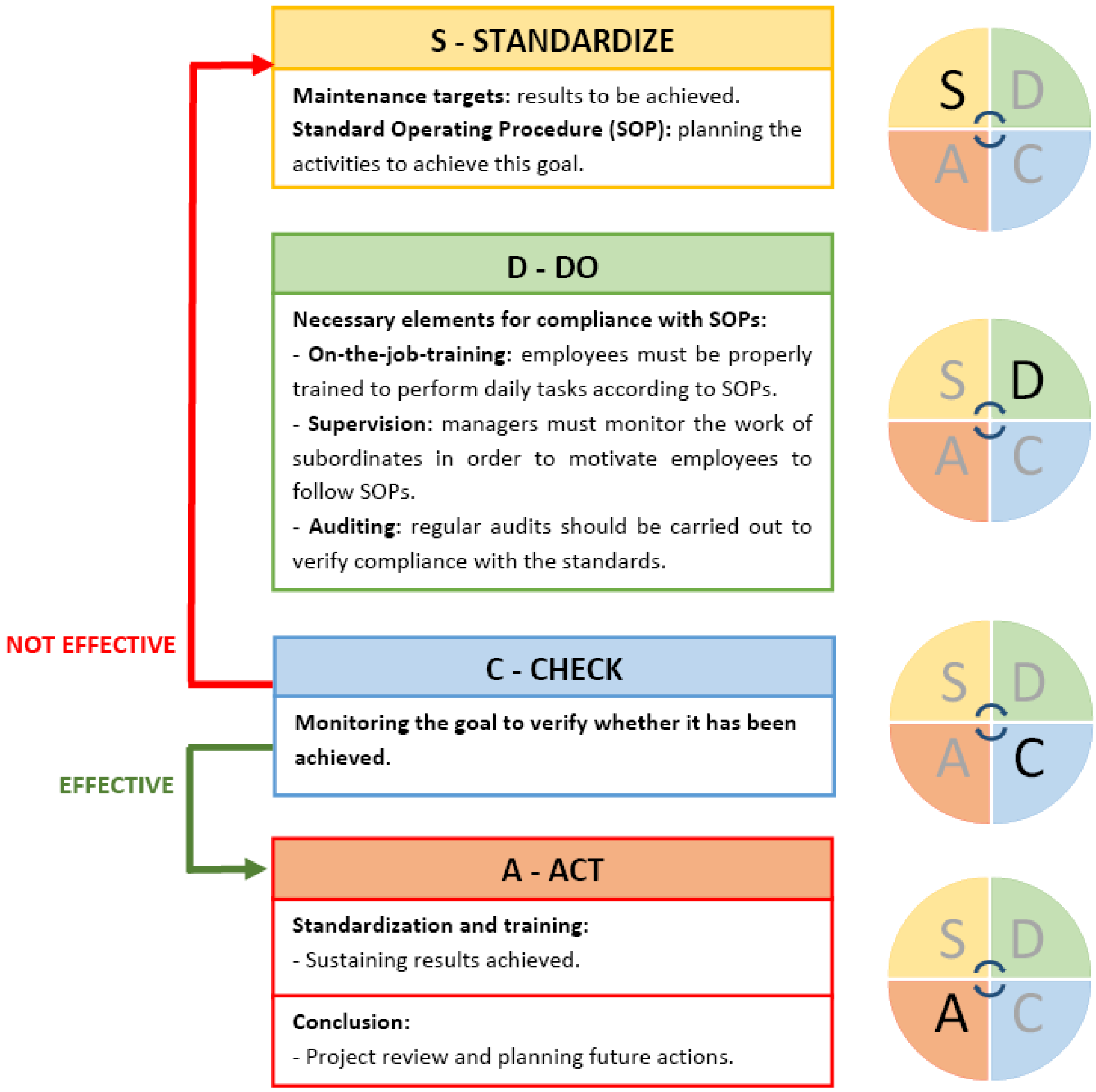

Figure 3.5 – SDCA stages

Figure 3.6 illustrates the combined use of the PDCA and SDCA cycles. As previously explained, the PDCA cycle is used to pursue improvement goals. In this process, problems to be solved are identified and then prioritized to achieve annual improvement targets. The filtered problems are then studied and resolved in accordance with the PDCA stages. The next challenge is to sustain the achieved results, which can be facilitated by the SDCA cycle. Initially, the actions performed during the PDCA cycle are standardized, and key personnel are trained. If future deviations are detected, corrective actions should be taken and standards updated. This combined use is intuitive: once an improvement is implemented through the PDCA cycle, an effort should be made to sustain the achieved results through the SDCA cycle.

After introducing the PDCA cycle and its variants, the DMAICS methodology will be discussed to highlight its similarities and differences. However, it is essential to emphasize that both the PDCA variants and the DMAIC methodology are employed to achieve similar objectives.

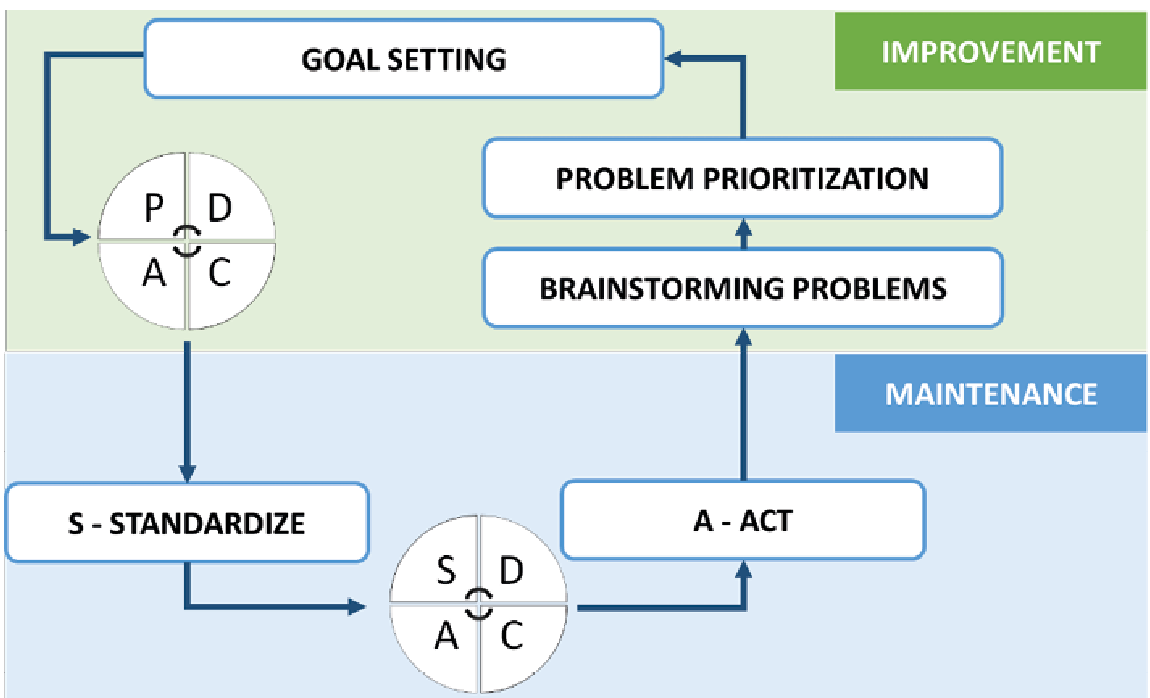

Figure 3.6 – PDCA and SDCA cycles

3.2 DMAIC

DMAIC is the problem-solving methodology used in Lean Six Sigma projects (Figure 3.7). It's a five-phase method:

- D: Define.
- M: Measure.
- A: Analyze.
- I: Improve.
- C: Check.

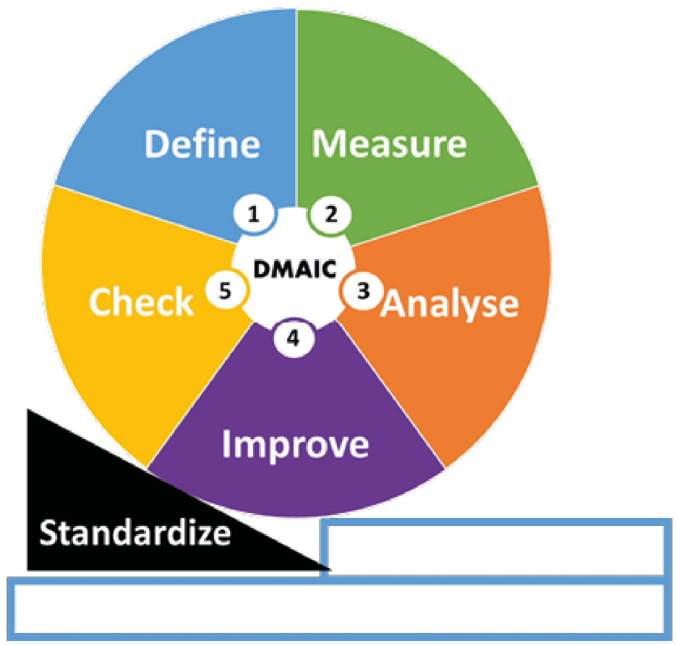

Figure 3.7 – DMAICS cycle

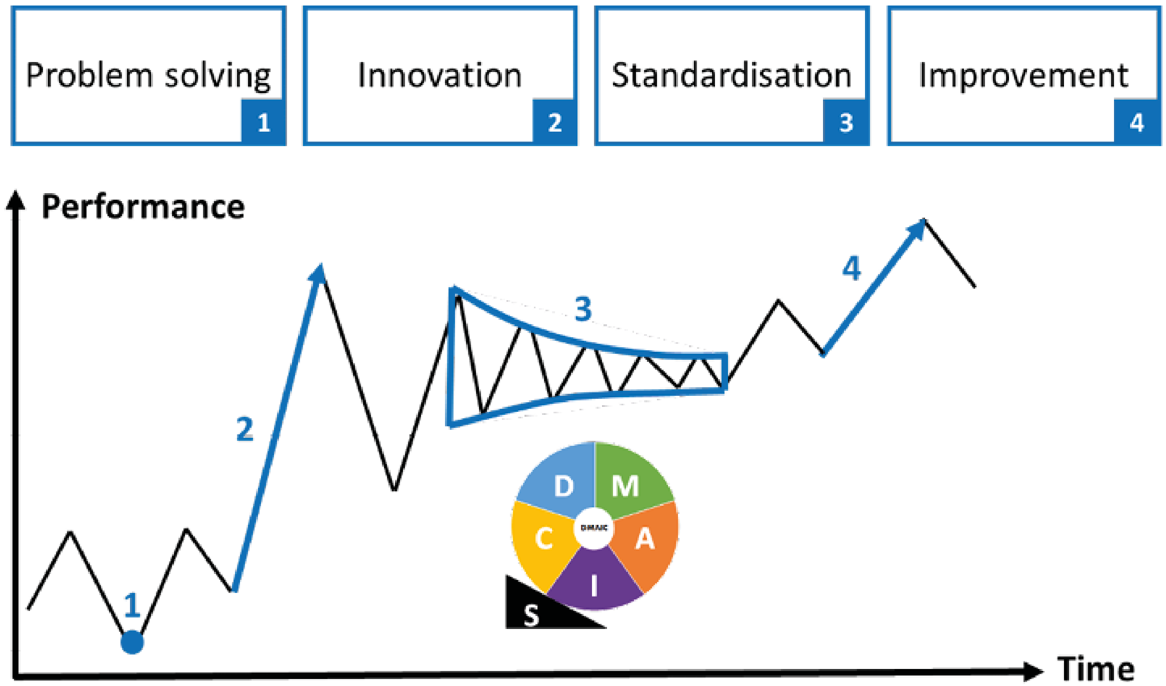

Figure 3.8 – DMAICS applications

In this book, we will consider a sixth phase, Standardize (S), to reinforce the importance of standardization. After all, if there is no concern for sustaining the results, the improvements achieved are lost. Metaphorically, the DMAIC cycle rolls down the stairs without standardization to maintain it. DMAICS can be used for various purposes, including problem-solving, standardization (to reduce variability), innovation, and continuous improvement (Figure 3.8).

Other versions of this methodology include DMADV (Define, Measure, Analyze, Design, Verify) and DMEDI (Define, Measure, Explore, Develop, Implement), both designed to develop or redesign products, processes, and services. However, these alternative versions will not be presented as they are not the focus of this work. Nevertheless, it is advisable to follow all these steps to ensure the project's success.

When solving any problem using the DMAICS methodology, it is always recommended to conduct knowledge management in parallel. This can be accomplished through the A3 report, which aims to summarize the project on a single sheet. A3 refers to the international paper size, equivalent to two A4 sheets (Figure 3.9), measuring 420 mm by 297 mm. However, according to the Lean philosophy, the A3 has a much broader significance: it serves as the record of the entire history of any project implemented by an organization.

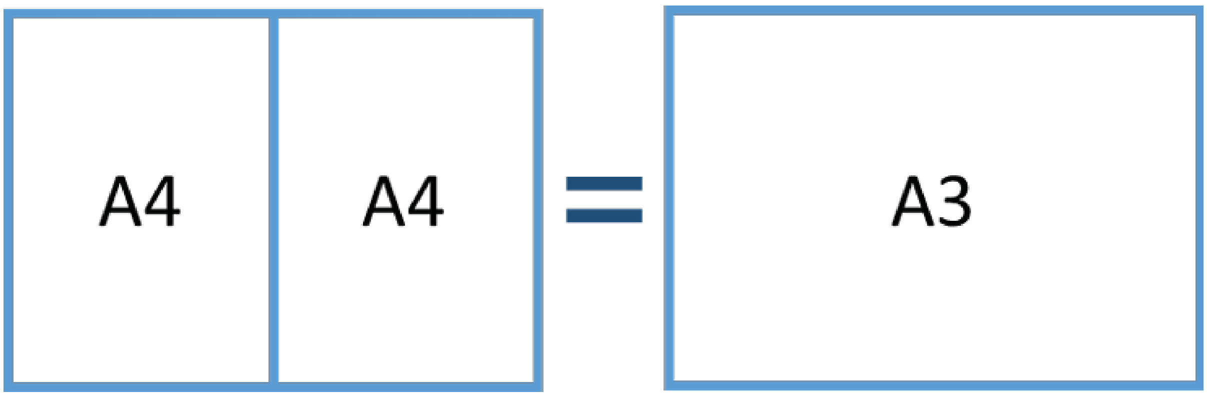

Figure 3.9 – The A3

In general, the A3 report consists of a single A3-sized sheet, subdivided into sections based on the DMAICS methodology, and must be completed by project leaders and team members (Figure 3.10). A blank A3 form is available in Appendix 4 of this book.

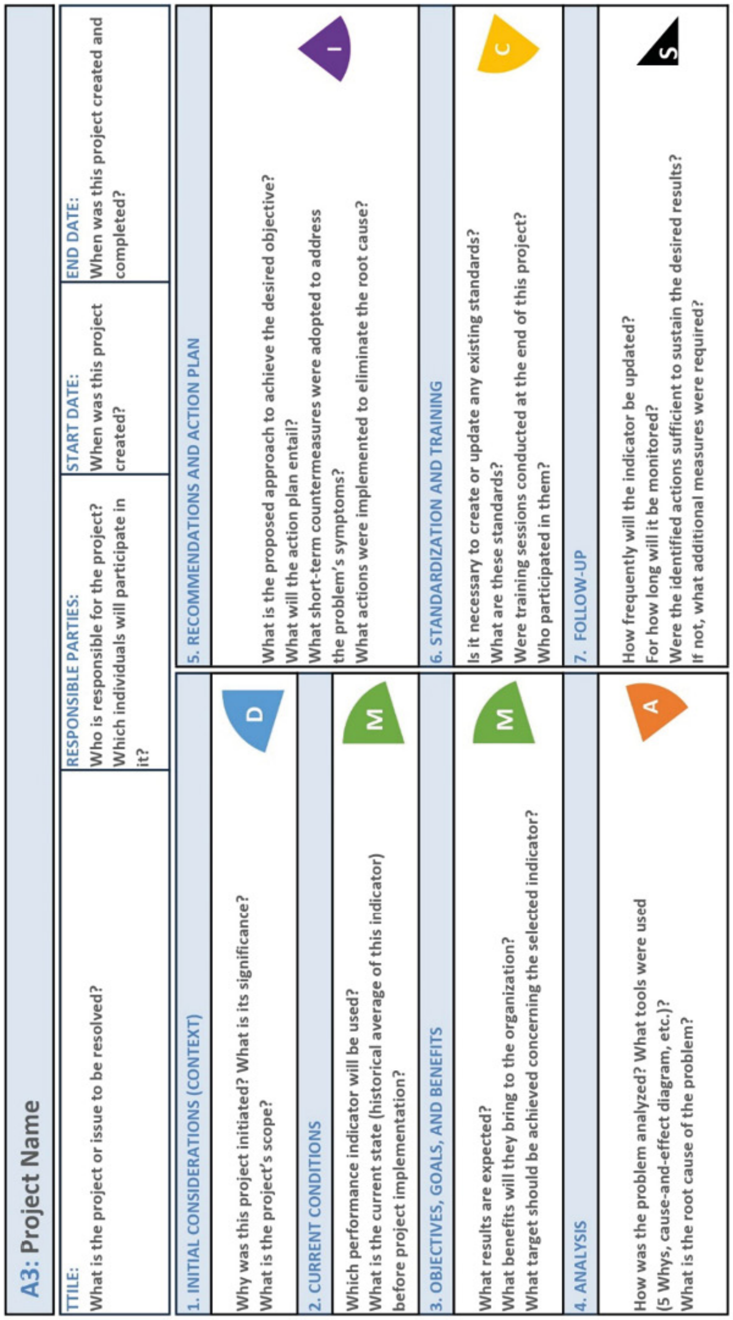

Figure 3.10 – A3 filling tips

The primary objective of the A3 methodology is to promote simplicity and synthesis, thereby optimizing knowledge management in completed projects. This approach helps prevent issues associated with lengthy reports, which are often difficult to access and have limited future utility.

The A3 document is typically structured into the following sections, designed to guide project development by addressing the following questions:

- Title: What is the project or issue to be resolved?
- Responsible parties: Who is responsible for the project? Which individuals will participate in it?
- Date: When was this project created and completed?
- Initial considerations (context): Why was this project initiated? What is its significance? What is the project's scope?
- Current conditions: Which performance indicator will be used? What is the current state (historical average of this indicator) before project implementation?
- Objectives, goals, and benefits: What results are expected? What benefits will they bring to the organization? What target should be achieved concerning the selected indicator?
- Analysis: How was the problem analyzed? What tools were used (5 Whys, cause-and-effect diagram, etc.)? What is the root cause of the problem?
- Recommendations and action plan: What is the proposed approach to achieve the desired objective? What will the action plan entail? What short-term countermeasures were adopted to address the problem's symptoms? What actions were implemented to eliminate the root cause?
- Standardization and training: Is it necessary to create or update any existing standards? What are these standards? Were training

sessions conducted at the end of this project? Who participated in them?

- Follow-up: How frequently will the indicator be updated? For how long will it be monitored? Were the identified actions sufficient to sustain the desired results? If not, what additional measures were required?

The A3 document is often written in pencil to facilitate and encourage future revisions and modifications. It is a “living” document that should be actively used throughout the project’s duration and remain readily accessible. Rather than a one-time investment, it is an ongoing process that, when properly utilized, becomes a powerful tool for problem-solving, implementing improvements, and sustaining results.

3.3 Case study: Digital transformation – Part 2 (Answer in Appendix 5)

This section continues the case study presented in Chapter 2. After identifying the previously described problem, its root cause was investigated. This analysis found that the bottleneck in the process after the digital transformation was resolving pending issues. Consequently, rework and the low percentage of value added were a consequence of doing “first time wrong” (Figure 3.11). This poor data input quality triggers successive rework cycles, which, in turn, lead to a high backlog of requests awaiting analysis (a long virtual queue) and also lead to overloaded resources that are highly efficient at rework.

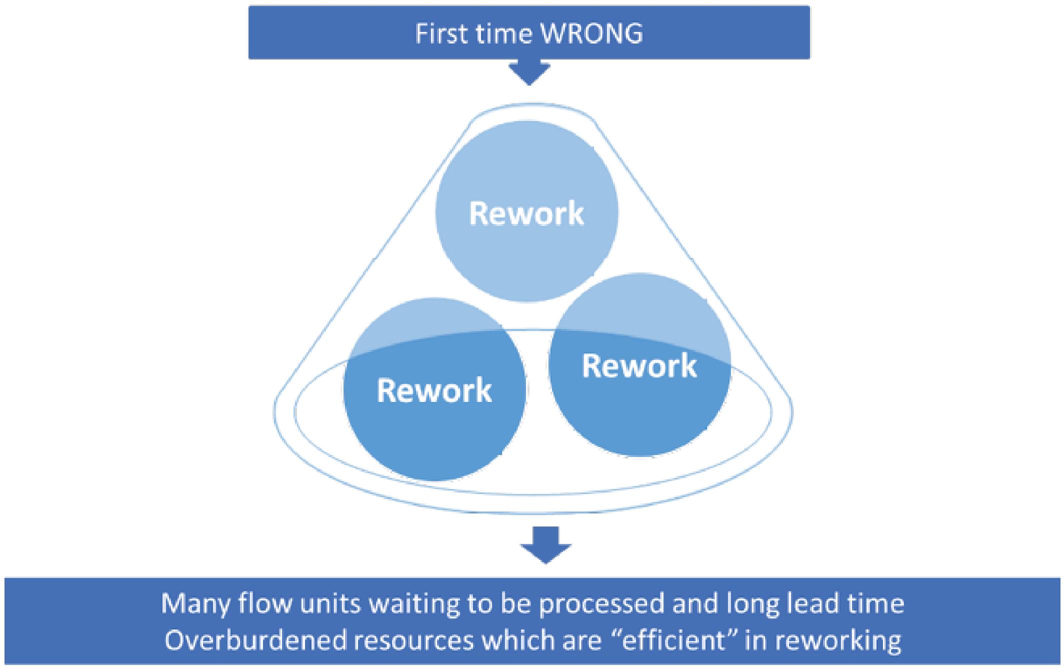

Figure 3.11 – Problems generated by doing "first time wrong"

As a result of this finding, the organization decided to investigate the root cause of the bottleneck using the 5 Whys methodology (a simple problem-solving tool that asks "Why?" five times to identify the root cause). This investigation is presented below and in Figure 3.12.

Why is it necessary to request additional documents?

Because not all required documents are available to the analyst, the process cannot be completed, and approval cannot be determined.

Why are the necessary documents missing in the benefit evaluation?

This issue primarily arises because applicants often have low levels of education and, in many cases, are functionally illiterate. As a result, even though they are informed about the required documents, they frequently struggle to understand what is being requested.

Another contributing factor is the poor quality of the data input. This inefficiency results in additional document requests that could have been avoided if the initial service had been properly performed.

Why is the initial service process inefficient?

The initial service process is inefficient because there is insufficient time to digitize essential documents and, if necessary, request additional ones. There is also high work pressure, and the number of appointments directly impacts the quality of service provided.

Why is there not enough time to provide quality service?

Firstly, the staff responsible for the service process often lack sufficient expertise: less experienced employees, such as interns, are assigned to this role. Consequently, many issues that could have been anticipated during the initial service go unnoticed and later become additional document requests.

Secondly, appointments are scheduled every 20 minutes in the system, which is already a very short timeframe for completing even basic tasks. As a result, service agents often anticipate future requirements and may already be aware that applicants may have the missing documents on hand. However, they are instructed not to intervene in the process, as doing so could cause cumulative delays in subsequent appointments.

Given the above, the following questions arise:

1. Considering problem-solving methodologies such as PDCA, which stage of this methodology was neglected, leading to a low percentage of value added? Why?
2. What would you recommend to reduce the need for additional document requests in the already digitalized process?

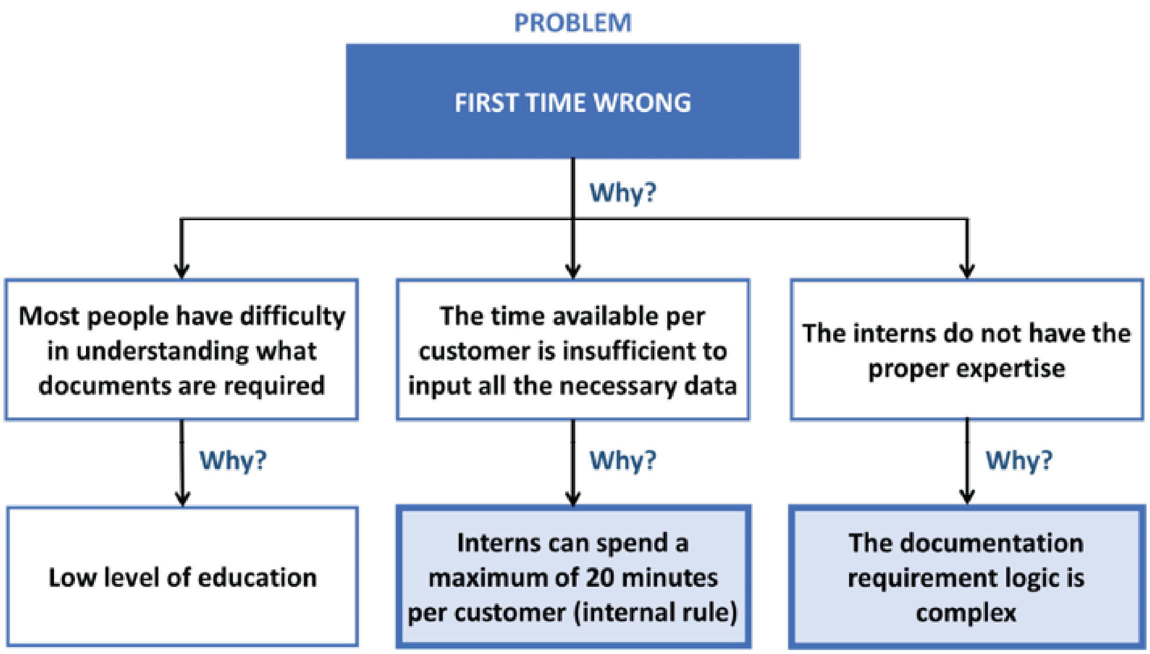

Figure 3.12 – 5 Whys root cause analysis

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CHAPTER 4: ERGONOMICS AND ERGOMOTRICITY

This chapter introduces the concepts of ergonomics and ergomotricity, which serve as the foundation for the upcoming units. The following quote by Taiichi Ohno captures the chapter's central aim:

"Speed is meaningless without continuity. Just remember the tortoise and the hare. Moreover, we cannot fail to notice that machines not designed for endurance at high speeds will have shortened lifespans if we speed them up."

Now, imagine human beings... Treating people as machines is illogical. To put it into perspective, a machine with an OEE above 60% is often considered a benchmark. If even machines have limitations, the same must apply to humans. After all, the human being is not an infinite resource, but a complex organism with constraints and finite capacities. Accordingly, it is essential to understand how the human body functions to optimize work efficiency and employability.

Consequently, grasping key concepts such as health, ergonomics, and ergomotricity, task and activity, stress and strain, and symptom and root cause is vital for conducting a motion and time study. Moreover, it is equally essential to be aware of the main pathologies that may arise from poorly designed workstations and how we can manage stress and reduce strain throughout the execution of such studies.

4.1 Basic concepts

4.1.1 Health

Since 1948, the World Health Organization (WHO) has defined health as a state of complete physical, mental, and social well-being, not merely the absence of disease or infirmity (Figure 4.1). People often perceive health solely in terms of tangible, biological aspects. However, according to the WHO's definition, health must be understood holistically.

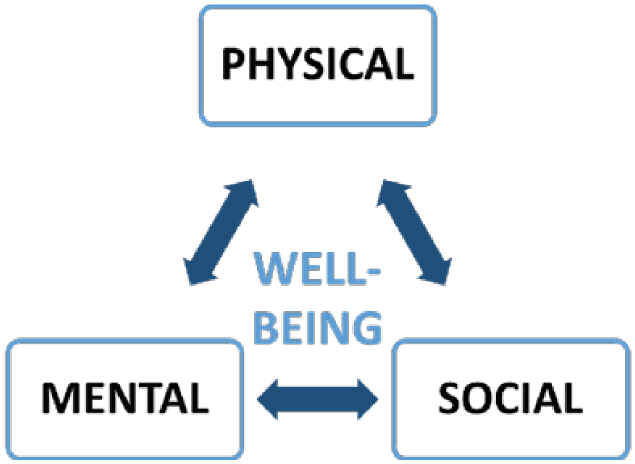

Figure 4.1 – The health concept of the WHO

Therefore, a person who shows no observable symptoms of illness cannot necessarily be considered healthy. Additionally, many work tasks today are performed with the aid of computers. The rapid evolution of technology in recent decades has significantly increased the incidence of mental health issues. It is important to emphasize that mental health involves much more than just the absence of mental illness. As these are often "invisible diseases," they tend to go unnoticed and neglected by organizations until they become symptomatic.

Thus, before implementing any improvement project related to methods engineering, it is essential to consider key aspects of ergonomics and ergomotricity to ensure employees' medium– and long-term health. Organizational productivity and health should not be viewed as mutually exclusive. In fact, to sustain organizational productivity, the health and safety of employees must always be prioritized to maintain their employability regardless of age.

4.1.2 Ergonomics and ergomotricity

The word "ergonomics" originates from Ancient Greek:

- *Ergon*: Work.
- *Nomos*: Laws, norms, or rules.

Ergonomics can therefore be defined as the set of laws or norms concerning work. In other words, ergonomics is the science that adapts the work environment to humans (Figure 4.2). Note that, generally, there is a tendency to adjust the worker to the job. However, since the worker is not a machine, the reasoning must be reversed: the work should be designed for the worker. This science thus encompasses the study of the workstation, the surrounding environment, its organization, and the workflows involved. In conclusion, ergonomics embraces the entire work environment.

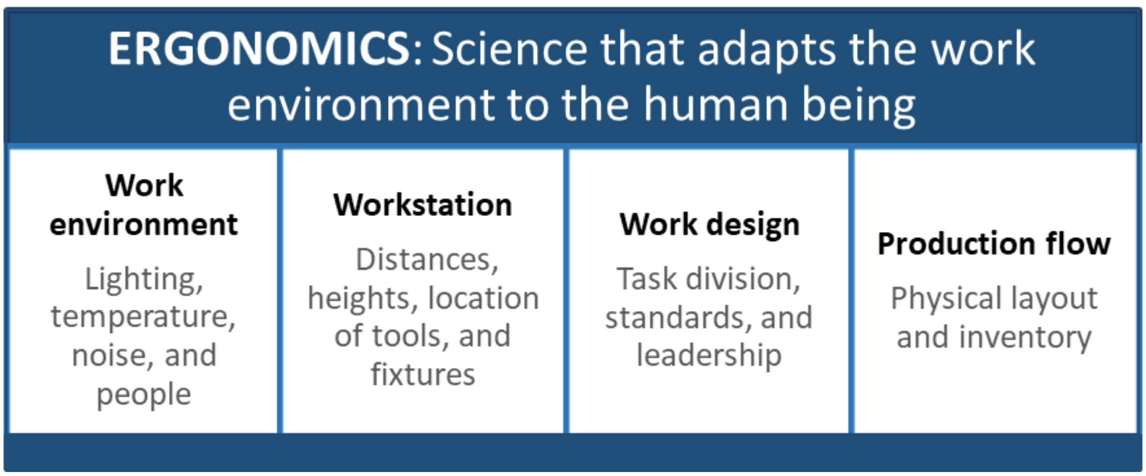

Figure 4.2 – Ergonomics concept

Ergonomics can be applied in various types of projects:

- Work reorganization aiming to reduce stress.
- Adaptation of work demands to human capabilities.
- Development of new layouts or modifications in production flow.
- Design of workstations and equipment.
- Creation and revision of work standards.
- Improvement projects related to work methods and time management.

In Brazil and the United States, ergonomics is addressed broadly, encompassing cognitive, organizational, psychological, social, environmental, and physical aspects. However, as this book focuses on motion and time studies, special attention must be given to the branch of ergonomics concerning the dynamic movements of the human body. In France, this branch is treated as an independent discipline due to its importance in job design, and is referred to as ergomotricité. This term can be translated as "ergomotricity." The neologism was first introduced at a European congress in 1980 by Michel Gendrier.

The term "ergomotricity" has its roots in Ancient Greek and Latin. While *ergon* means "work" in Greek, *motricity* derives from the Latin word *moveo*, which means "to move." Thus:

- *Ergon*: Work.
- *Moveo*: The idea of movement.

Ergomotricity, therefore, studies movements performed during work, aiming to adapt the operational pattern to the individual performing them (Figure 4.3). This field examines a person's motor potential, gestural and postural movements, and psychological potential. As such, ergomotricity represents the application of physics to the human body. Joints function like levers, and muscles exert forces that perform work through angles, distances, and weights.

ERGOMOTRICITY: Science that adapts an operational pattern to the individual executing it			
Motor potential	**Gestures**	**Postures**	**Psychological potential**
The physical and tangible capacity of a being, such as energy and muscle tone	Movements of specific body joints, such as wrists, elbows, and neck	Spatial positions of the body and its parts	This subjective capacity of a being, including their thoughts and mental health

Figure 4.3 – Ergomotricity concept

If we reflect on it, ergomotricity is a widely applied concept in sports, as teams seek to enhance athletes' performance while also mitigating the risk of medium— and long-term occupational issues. The same idea should apply in the workplace: increasing employee productivity while preserving their medium- and long-term employability.

Another interesting point when discussing ergomotricity is that some authors view it as a response to the two-body syndrome. For instance, when engaging in sports, our bodies are fully integrated and become the center of our attention. We listen to it, warm it up, stretch it, regulate it, and care for it. However, at work or during daily activities, we often act automatically. Bodily awareness is neglected or even absent. We do not care for, prepare, stretch, or warm up our bodies. It is almost as if we disconnect from our physical selves, no longer perceiving them. As such, we behave as though we have two distinct bodies: one physical and one mental. However, these two aspects must be integrated into a single whole to promote coherence and health in our lives. Today, we spend most of our time in our weekly work routine, and it is precisely there that our concern for the body should be greatest.

4.1.3 Task and activity

A task refers to what a person is required to do in their role. That is, it is the work prescribed in the operational procedures. Thus, the task answers the question: WHAT work is to be done?

Activity, on the other hand, is a broader concept that encompasses all tangible and intangible aspects inherent in a task. It refers to the actual work that takes place in reality, involving gestures, postures, communication, behaviours, and thoughts. Therefore, the activity seeks to answer the question: HOW should the work be carried out?

Many managers and work standards focus solely on answering the question of WHAT a person must do. However, it is often necessary to emphasize HOW and WHY a particular task should be performed in a specific way to draw attention to health, safety, and performance issues.

For example, there are several ways to pick up a box from the floor (Figure 4.4). That is, "picking up a box from the floor" corresponds to the task. But to avoid back and knee problems, it is crucial to reinforce the correct activity for picking up the box, which involves bending the legs and keeping the back straight.

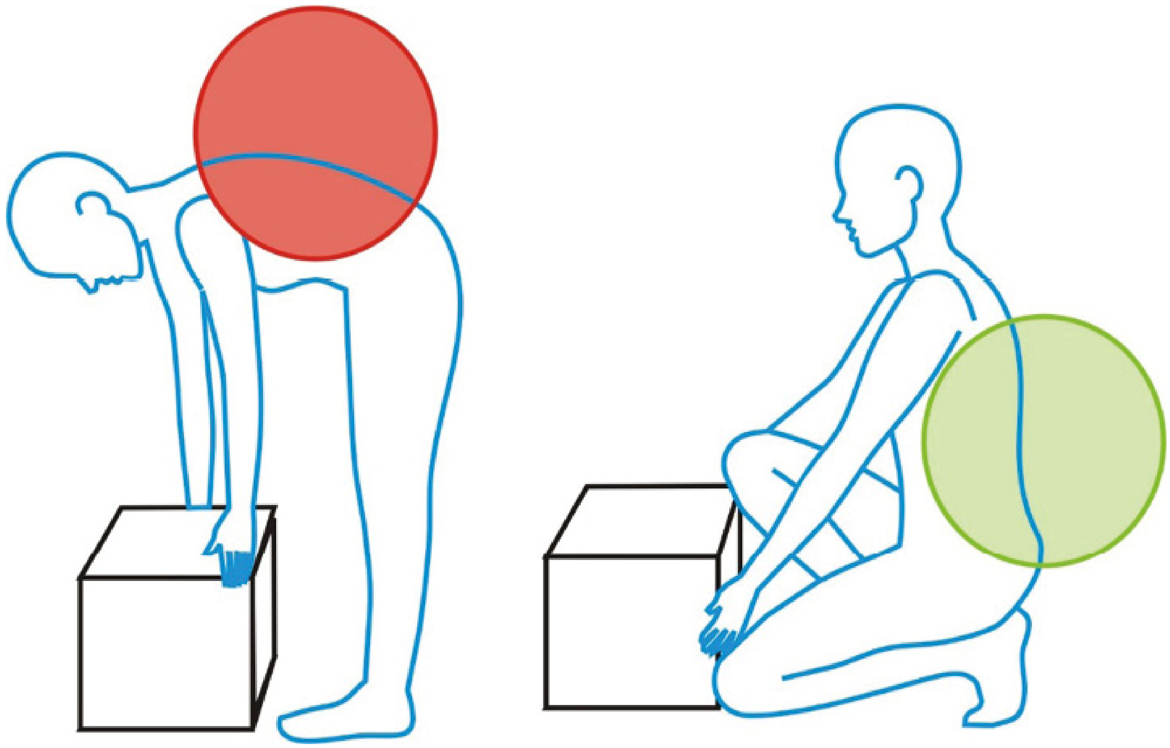

Figure 4.4 – Different ways of performing the task "picking a box from the floor"

4.1.4 Stress and strain

Another two concepts that must be distinguished are "stress" and "strain." Figure 4.5 illustrates the relationship between these concepts.

Stress includes factors that have a direct impact on the activity, such as:

- External context (culture, socioeconomic context, laws, regulations).
- Institutional environment (work shifts, flow, work division, collective relations, values, organizational climate).
- Technical environment (machines, personal protective equipment, tools, workplace, operational procedures).
- Physical environment (temperature, lighting, loads, angles, distances, repetition).

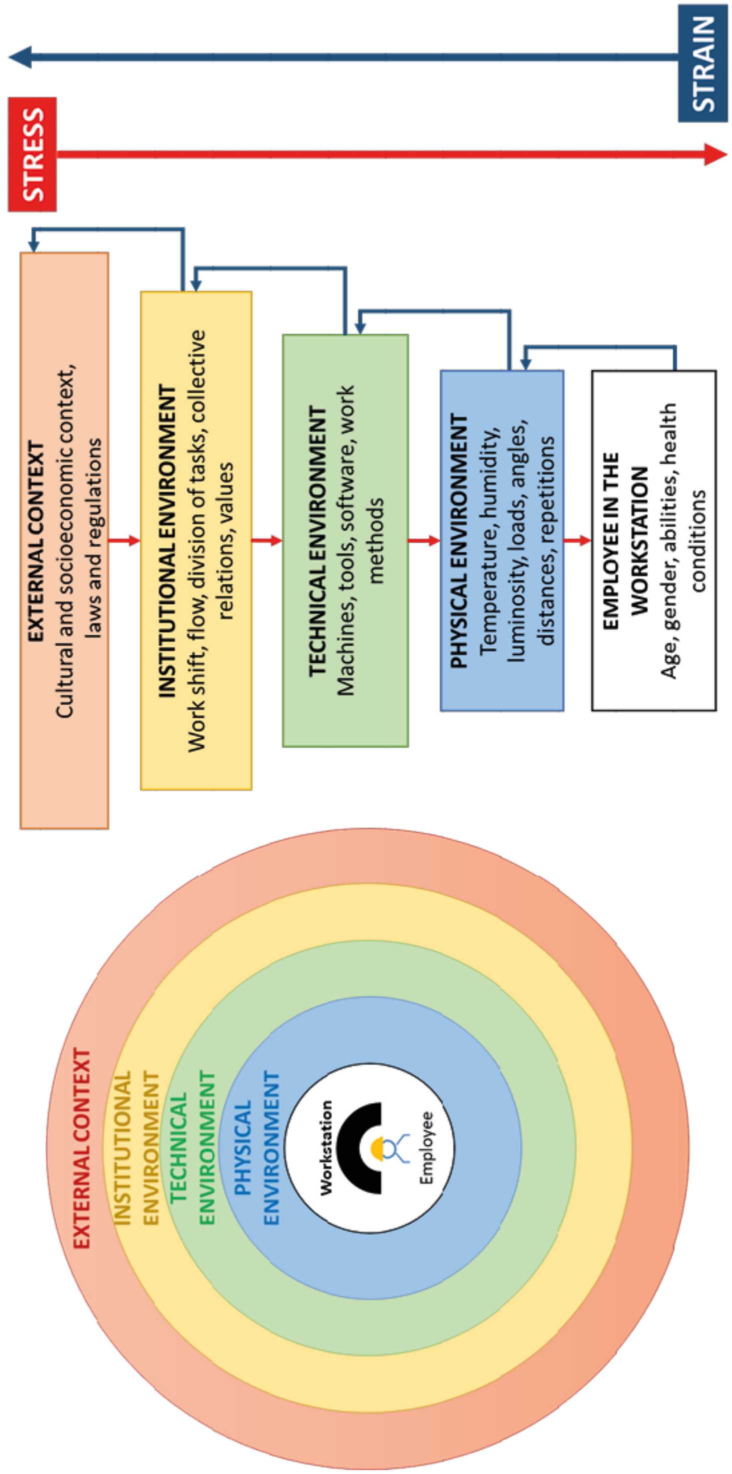

Figure 4.5 – Relationship between the concepts of stress and strain

Thus, stress refers to the influence of the environment on the body. It is, therefore, a set of biological and psychological disturbances caused by aggression to the individual's organism.

Tension, in turn, manifests in the body as a consequence of the stress to which one is subjected. In other words, it is the body's reaction to the environment. Tension, therefore, encompasses all effects on our organism resulting from attempts to adapt to new stressors: pain, discomfort, fatigue, reduced sensitivity thresholds, and even functional impairment.

The red arrow in Figure 4.5 represents the influence of stress, which flows from the macro to the micro level. For example, the external context shapes the institutional environment, which, in turn, influences the technical environment. This affects the physical environment, which in turn affects the worker's workstation. Stress is thus transmitted all the way to the workstation, and, depending on the worker's physical and psychological characteristics, it will be perceived and internalized in unique ways within the activity being performed. In response to stress, tension arises. The blue arrow, therefore, represents the tension generated in response to stress. In contrast to stress, tension flows from the micro to the macro level. It is the worker's conscious and unconscious reaction to all those stress-inducing factors.

4.1.5 Symptom and root cause

Just as in engineering, we must distinguish between the symptoms and the root cause of problems; this distinction is also essential in health.

It may seem straightforward, but unfortunately, few people apply this in practice. To illustrate the difficulty and confusion between these two concepts, consider the following examples:

If you visit a health clinic or a hospital emergency room and present symptoms such as fever or diarrhea, it is common for physicians to treat only the symptoms. If you have a fever, they might prescribe antipyretics; if you have diarrhea, they might prescribe intravenous fluids to rehydrate you. Without investing time in a thorough clinical analysis and conducting additional tests, such as blood, urine, or stool tests, or imaging, it is challenging for a physician to diagnose many illnesses accurately. Of course, in the case of a common cold, this may not cause major issues, but it can pose significant risks in more serious diseases.

Our body is our best ally. It often gives us several signs that things are not going well. Initially, these may be mild signals, such as occasional headaches, insomnia, and bruxism.

However, people often only treat the symptoms themselves, using analgesics or anxiolytics, which becomes problematic if the root cause is not simultaneously addressed, as the symptoms may evolve into more severe illnesses over time.

Figure 4.6 illustrates the differences between these two concepts: symptoms versus root causes.

Accordingly, illness, pain, or discomfort is not just something bad to be muffled and ignored. Obviously, symptoms should always be treated, but just as important as treating them is understanding that they are warning us that things are not going well. Therefore, it is worth reflecting on the root causes of these symptoms, which often require a deep investigation. In addition, treatment commonly demands time and a revision of daily habits related to our work routine. That’s why many people prefer to treat the symptoms and “go with the flow”. After all, it’s more comfortable, isn’t it?

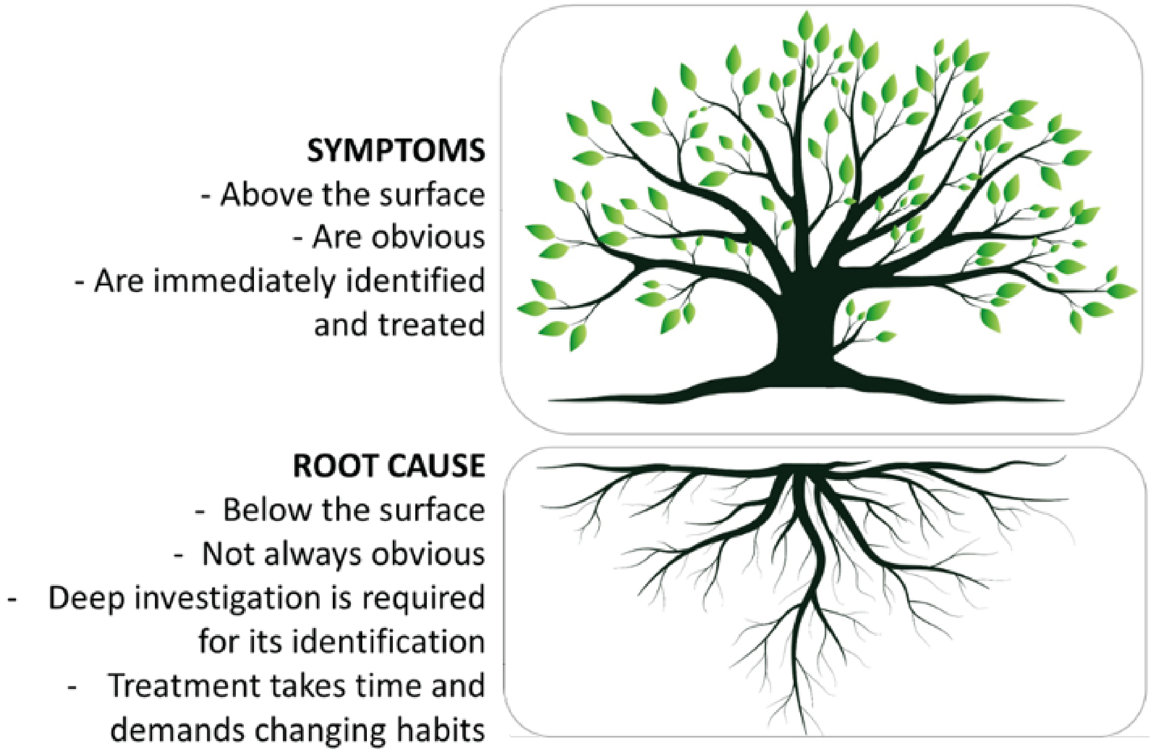

Figure 4.6 – Symptoms versus root causes

4.2 Work pathologies

This section will present physical and mental disorders related to work. Despite being invisible, the latter has experienced significant growth over the past few decades.

4.2.1 Musculoskeletal disorders

Musculoskeletal disorders (MSDs) affect the muscles, nerves, tendons, joints, cartilages, and spinal discs. Regardless of the economic sector or type of occupation, MSDs tend to arise in similar contexts, which generally involve:

- Excessive force exerted during routine movements.
- High repetition rates of the same movement.
- Awkward or extreme joint movements.
- Lack of regular breaks and stretching for bodily recovery.

Therefore, to prevent these disorders, it is essential to improve the workplace and tools, as well as to incorporate regular breaks and stretching sessions to mitigate risk factors.

Examples of MSDs include back pain (dorsalgia), herniated discs, and carpal tunnel syndrome.

Dorsalgia is used generically to refer to what is popularly known as back pain. It is essential to distinguish it from low back pain (lumbalgia) and neck pain (cervicalgia). The former refers specifically to pain in the lumbar spine, while the latter refers to pain in the cervical spine. Figure 4.7 illustrates the division of the vertebral column into cervical, thoracic, and lumbar vertebrae.

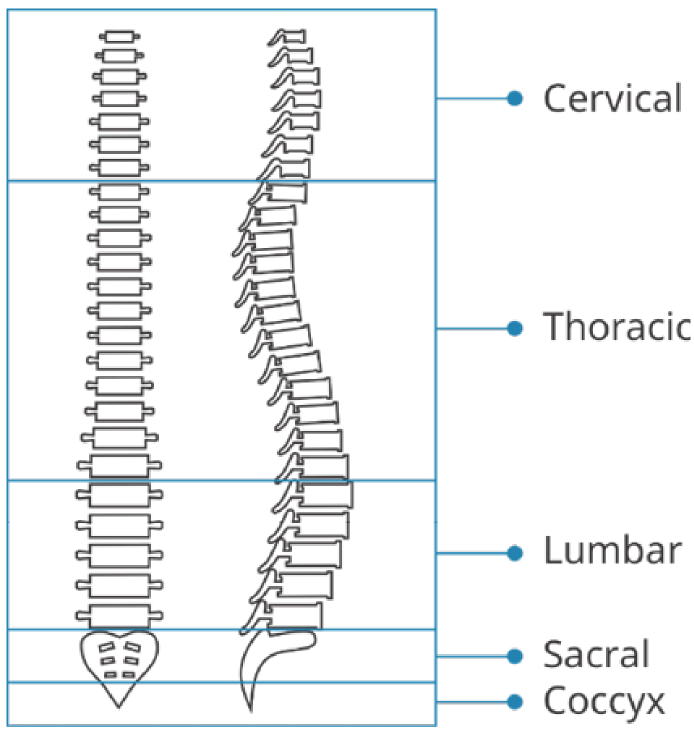

Figure 4.7 – Vertebral Column

A herniated disc is an injury that most frequently occurs in the lumbar region. In these cases, intervertebral discs—ring-shaped structures located between the vertebrae—move out of their normal position and compress nerve roots (Figure 4.8), resulting in intense pain.

It is important to note that, due to the widespread use of cell phones, tablets, and other modern habits, cases of cervical disc herniation have become increasingly common.

Another example of an MSD is carpal tunnel syndrome, which results from compression of the median nerve as it passes through the carpal tunnel in the wrist (Figure 4.9). This condition may arise when:

- Hands are kept in a fixed position for prolonged periods.
- Repetitive efforts are made with a flexed wrist, either with too much or too little force.
- Continuous pressure is applied to the base of the palm.
- There is prolonged vibration in contact with the base of the hands.

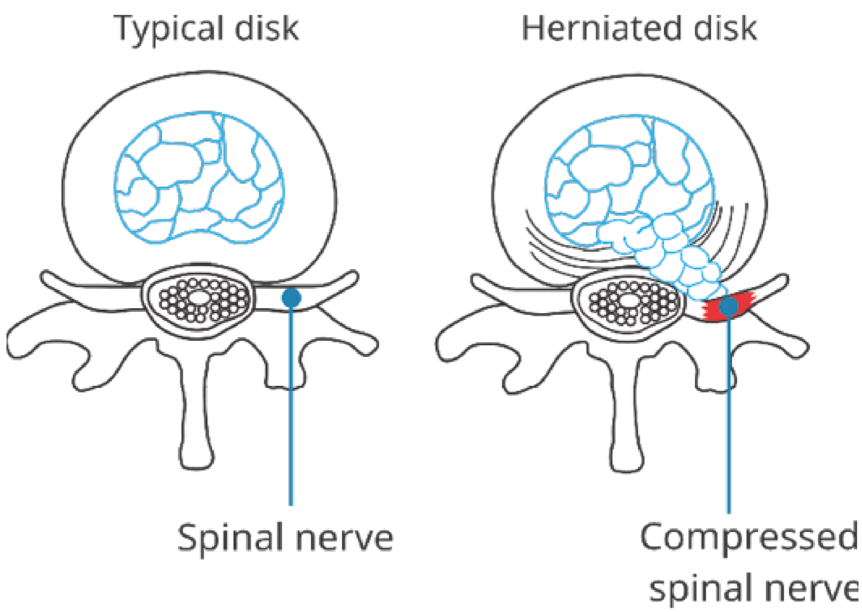

Figure 4.8 – Herniated disk

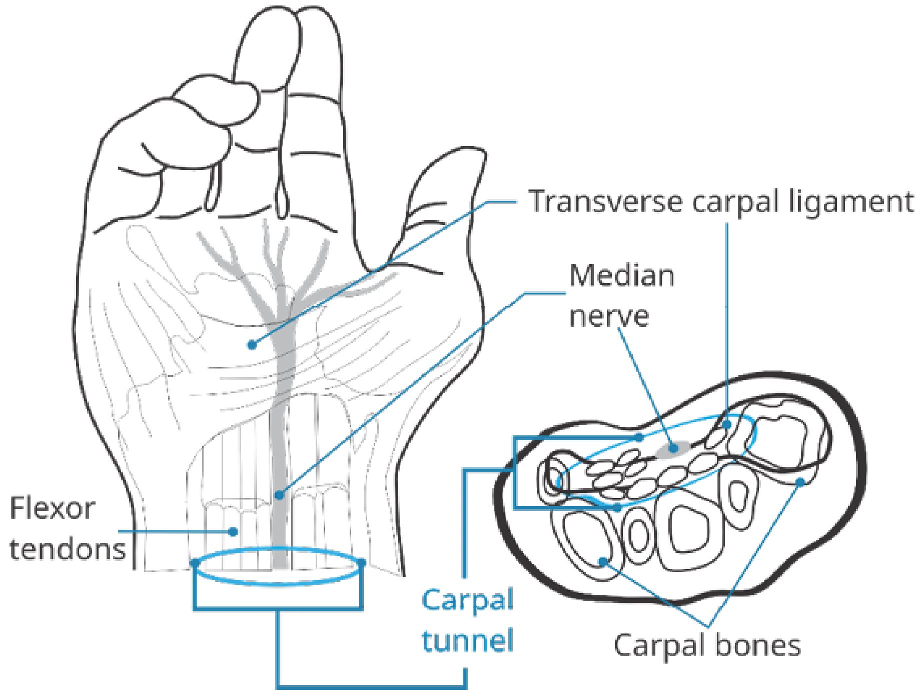

Figure 4.9 – Carpal tunnel syndrome

It is a common disorder associated with prolonged keyboard and mouse use, typical in office work and occupations involving intensive computer and laptop usage.

In conclusion, it is crucial to study the aforementioned MSDs, which result from repeated improper movements at work. All of them cause pain and negatively affect the professional and personal lives of affected workers.

4.2.2 Mental disorders

Figure 4.10 illustrates the percentage growth in granting work-related sick leave benefits under the category "Mental and Behavioral Disorders" in Brazil from 2006 to 2017. It is important to highlight these disorders in this context, as the data refer to benefits granted for accidents or illnesses resulting from workplace conditions. In 2006, only 0.4% of work-related sick leave benefits were due to mental and behavioral disorders. By 2017, this figure had risen to approximately 4.8%—an increase of over 1,100%. This reinforces the importance of addressing mental pathologies in this chapter, as these conditions, although often silent, can be highly detrimental.

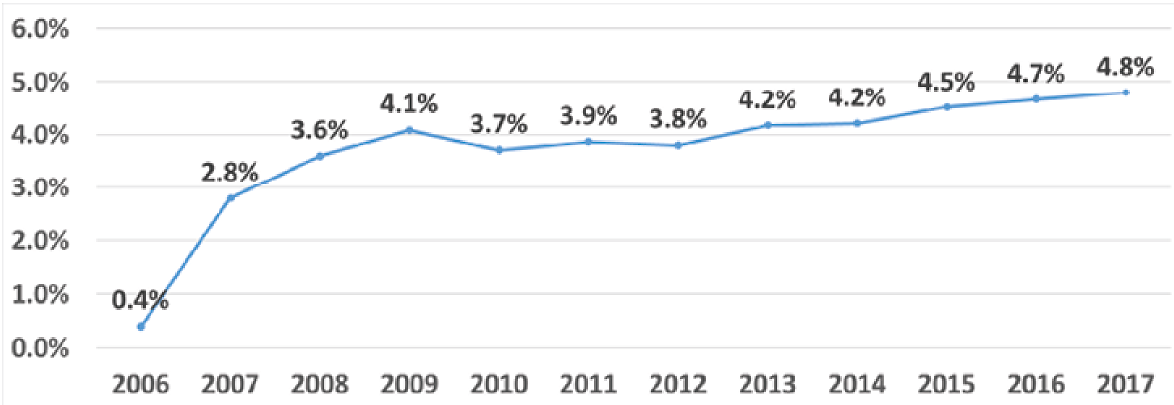

Figure 4.10 – Mental disorders evolution in Brazil

Additionally, an analysis of the subcategories of mental and behavioral disorders that led to the granting of social security sick leave benefits in 2017 in Brazil shows that "depressive episodes" accounted for 43.3 thousand cases, ranking as the tenth leading cause of ill leave both in 2017 and 2016. The second most frequent mental disorder was classified as "other anxiety disorders," which ranked fifteenth in 2017, with 28.9 thousand reported cases.

According to the World Health Organization (WHO), in 2019, one in every eight people, or 970 million people around the world, were living with a mental disorder. In 2020, the number of people living with these disorders rose significantly due to the COVID-19 pandemic, by 26% and 28%, respectively, for anxiety and major depressive disorders in just one year.

4.3 Controlling stress and tension

This chapter does not delve into advanced ergonomics concepts; instead, it focuses on fundamental principles. The following sections present ergonomics and ergomotricity recommendations to reduce stress and limit physical strain. Additionally, tools for analyzing work situations from ergonomic and ergomotricity perspectives are discussed.

Ultimately, motion and time analysts must provide employees with adequate, safe, and comfortable working conditions. In general, workplaces meeting these standards achieve better productivity outcomes while reducing absenteeism and staff turnover.

4.3.1 Ergonomics' recommendations

In terms of ergonomics, during a motion and time study, it is essential to develop a work environment that:

1. Allows the spine to remain upright in static positions (noting that the neck is part of the spine).
2. Enables feet to rest on the floor or on another support.
3. Provides arm support.
4. Includes scheduled breaks for movement, exercise, and stretching.
5. Encourages individuals to listen to their bodies—productivity is a result, not a cause. The body is our best ally and will always provide feedback if the work environment is inadequate.

4.3.2 Ergomotricity's recommendations

Once an ergonomic environment has been established, the next question should be: What are the best gestures and postures to perform a given task? While ergonomics focuses on the broader workspace and routine, ergomotricity focuses on executing dynamic movements, such as lifting objects.

Some key aspects of ergomotricity that should be carefully evaluated when performing tasks include:

1. Bringing the center of gravity closer to the object being moved: The human body's center of mass is located near the navel. Aligning and moving this center closer to the object allows the body to adopt a more comfortable posture. One can observe this behavior in babies who, despite their limited balance and strength, intuitively use this

strategy to carry objects (Figure 4.11).

2. Spine in straight line: Maintaining the spine in a straight line during dynamic movements helps keep the intervertebral discs in place and prevents future issues such as herniated discs.
3. Using muscle groups that favor the movement: For instance, the leg, abdominal, and back muscles can support lifting a box from the floor (see recommendations 2 and 3 in Figure 4.4).
4. Respecting the body's biodynamics: Adjusting body angles and distances facilitates movement. Joints such as the knees, shoulders, and wrists have comfortable angles that allow for safer and more efficient motion, even during repetitive tasks.
5. Supports: Using supports helps stabilize the body and prevent premature fatigue. For example, when reaching for a distant object on a table, each support point helps distribute the load, making the task easier.

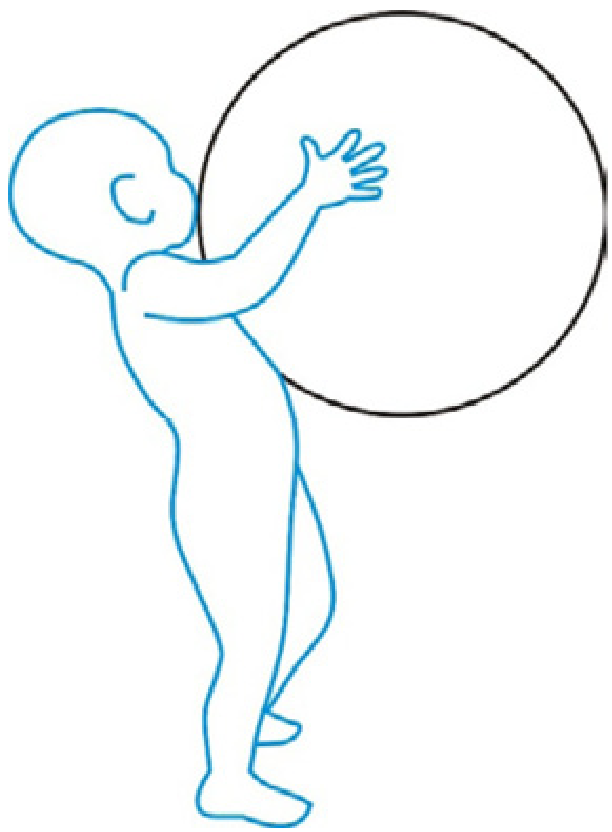

Figure 4.11 – Child carrying a big object

4.3.3 Ergonomics and ergomotricity's tools

Several ergonomic tools assist in the analysis of work situations, including:

- NIOSH Equation – from the National Institute for Occupational Safety and Health: A formula for calculating the recommended weight limits for repetitive static lifting tasks.
- JSI – Job Strain Index (Moore and Garg Index): A method for assessing the risk of developing musculoskeletal disorders in the upper extremities due to repetitive movements.
- OWAS – Ovako Working Posture Analysing System: A practical tool developed by the Finnish company Ovako for evaluating working postures.
- REBA – Rapid Entire Body Assessment: A method based on RULA, OWAS, and NIOSH, designed to assess unpredictable work postures.
- RULA – Rapid Upper Limb Assessment: A quick assessment tool for identifying musculoskeletal risk, emphasizing the upper limbs.

Moreover, the University of Michigan developed the software 3D Static Strength Prediction Program (3DSSPP) (Figure 4.12). A 14-day trial version is available for download, and training videos are available on the official website. The 3DSSPP predicts the static strength required for lifting, pulling, and pushing tasks. It simulates work scenarios by incorporating posture data, force parameters, and anthropometric differences between men and women. The output includes the percentage of individuals who are physically capable of performing the task, spinal compression forces, and comparisons with NIOSH guidelines. The tool also allows users to analyze torso twists and bends, manually input complex forces, and generate automatic postures with 3D human illustrations.

The references section at the end of this chapter lists web links to the software tools mentioned in this book, including the 3DSSPP.

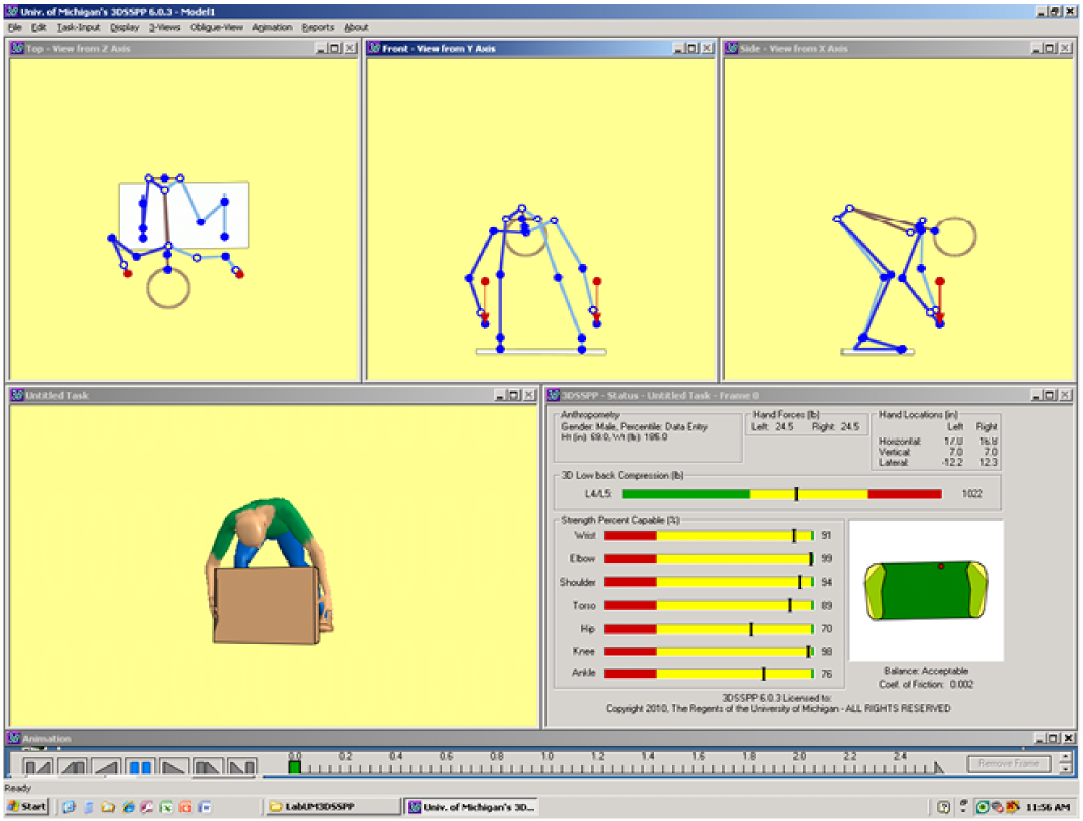

Figure 4.12 – Workstation simulation using the 3DSSPP software

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Softwares

3D Static Strength Prediction Program (3DSSPP), desenvolvido pela Universidade de Michigan – https://c4e.engin.umich.edu/tools-services/3dsspp-software/

Websites

NIOSH Homepage – https://www.cdc.gov/niosh/index.htm
NIOSH Ergonomic Guidelines – https://www.cdc.gov/niosh/docs/2007-131/pdfs/2007-131.pdf

UNIT 2

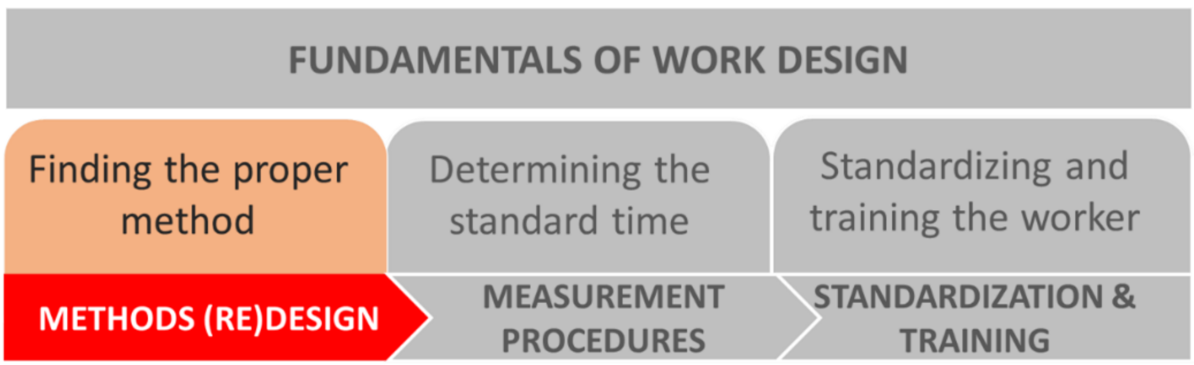
METHODS DESIGN AND REDESIGN

- Principles of waste elimination
- Process analysis (Flow process chart, flow diagram, and value stream map)
- Operation analysis (Activity chart and worker-machine chart)
- Line balancing

UNIT 2:
METHODS DESIGN AND REDESIGN

Before conducting a time study, the proper method for performing the operation must be established. Unit 2 covers principles, tools, and techniques for finding the best method. Among these methods are the flow process chart, flow diagram, value stream map, activity chart, and worker-machine chart.

This unit is divided into four chapters as shown below.



- **Chapter 5:** Principles of waste elimination
- **Chapter 6:** Process analysis (Flow process chart, flow diagram, and value stream mapping)
- **Chapter 7:** Operation analysis (Activity chart and worker-machine chart)
- **Chapter 8:** Line balancing

Chapter 5 deals with the principles of waste economy, which help us learn to "see" inefficiencies in a particular operation. Consequently, we can break our paradigms and rethink our methods of work. The principles of motion economy can be divided into three categories: the use of the human body, the workplace, and the design of tools and equipment. These principles will serve as the basis for the content presented in subsequent chapters.

Chapter 6 introduces techniques for studying and improving flow, such as the process flow chart, the flow process chart, the flow diagram, and the value stream map. These methodologies can be used to study an organization at the macro level by analyzing processes, and at the micro level by focusing exclusively on a job or operation. In any case, before defining the scope of the work, the problem analysis should be conducted from the macro to the micro level. In this way, improvement opportunities for flow efficiency will be prioritized over those for resource efficiency, since the latter compromises the former's results.

Chapter 7 introduces techniques for studying operations, such as activity charts and worker-machine charts. These tools plot the breakdown of operations over time and, accordingly, focus on minor issues, unlike the tools discussed in the sixth chapter. We can use these charts, for example, to calculate the number of workers required or to reduce changeover and cycle times. Therefore, the tools presented in chapters 6 and 7 are highly complementary.

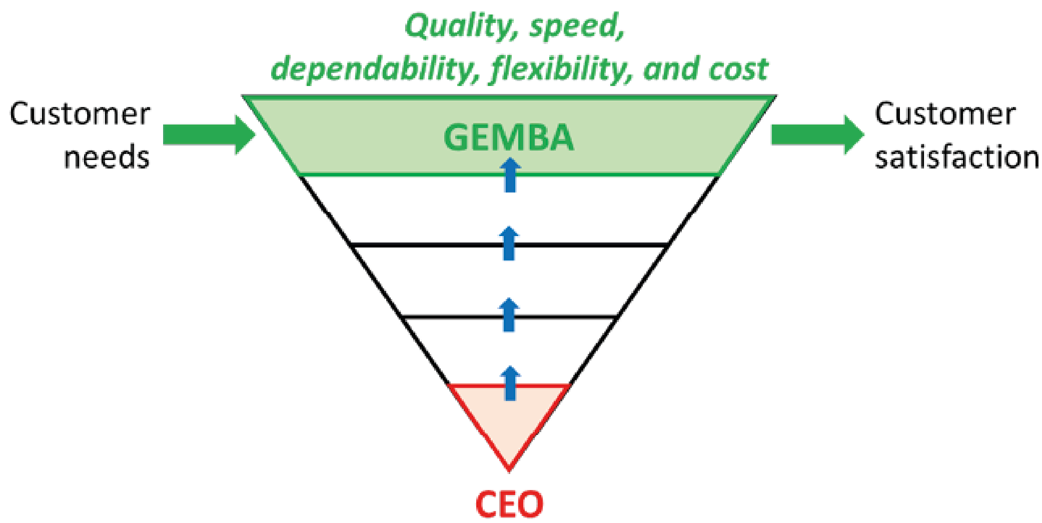
Finally, chapter 8 also dialogues with the previous one. It is interesting to use the techniques described in Chapter 7 when workstation workloads are unbalanced or when there is waste in an operation that can be eliminated, such as waiting time. The eighth chapter presents steps to follow during line balancing that improve workload balance among employees and synchrony among workstations.

Last but not least, it is important to reinforce that sustaining results and continuously improving its work methods require an organization to have constancy of purpose!

This means that an organization ought to maintain its objectives and priorities over time. In a traditional hierarchical organization, as shown in the previous figure, employees are often more concerned with satisfying their superiors' demands than their own customers'. After all, when they please the "bosses", they increase their probability of recognition and promotion.

This traditional thinking can compromise not only an organization's flow efficiency but also its ability to achieve long-term goals. When we do not prioritize customer needs, the natural turnover of managers undermines organizations' consistency of purpose and prevents them from maintaining their results. In other words, organizations that want everything for "yesterday" but lack a clear direction end up forcing their resources (machines, materials, and human resources) to improve resource efficiency rather than flow efficiency. In the end, their employees become less productive and less healthy, and the company's competitiveness does not improve. Therefore, we must be "turtles" who invest more energy in the project and strategic planning to ensure we are on the right track to improve work methods and organizational results.

Note also that the lower part of the traditional hierarchical pyramid is presented as "Gemba", a Japanese term meaning "the actual place" or "place where things happen". This term is usually used to designate the production area or any place where work takes place, and activities add value to the product or service. Accordingly, ideally, "Gemba" must be the priority, since quality, safety, product costs, and dependability are direct results of it.



Ideally, therefore, the upper hierarchical levels should support the lower levels in their work and add real value to the organization. This is the purpose of the inverted leadership pyramid shown in the previous figure.

After all, clients' needs must stand out relative to the priorities of hierarchical leaders. Consequently, the organization's constancy of purpose will be a priority, enabling it to achieve the desired results.

CHAPTER 5: PRINCIPLES OF WASTE ELIMINATION

This chapter presents concepts and principles to follow when improving an operation. It serves, accordingly, as the basis for other chapters of the unit.

First, the different types of waste will be conceptualized. Next, since the book focuses on motion and time studies, the principles of motion economy related to the use of the human body, the workplace, and the design of tools and equipment will be discussed. At the end, the 5S philosophy will be presented, a Japanese methodology for reducing waste and optimizing productivity.

The purpose of the chapter is to help readers use the methods and techniques described in subsequent chapters to analyze the flow and operations, thereby enhancing their ability to identify waste and opportunities for improvement.

5.1 Wastes of Lean Manufacturing

Waste is generated by activities that consume time, resources, or space but do not necessarily satisfy customer needs.

There are three types of activities that generate waste, according to lean (Figure 5.1):

1. Muda: Japanese word that can be translated as “waste” or “useless”.
2. Muri: Japanese word that can be translated as “overburdened”.
3. Mura: Japanese word that can be translated as “unevenness”, “fluctuation”, or “variation”.

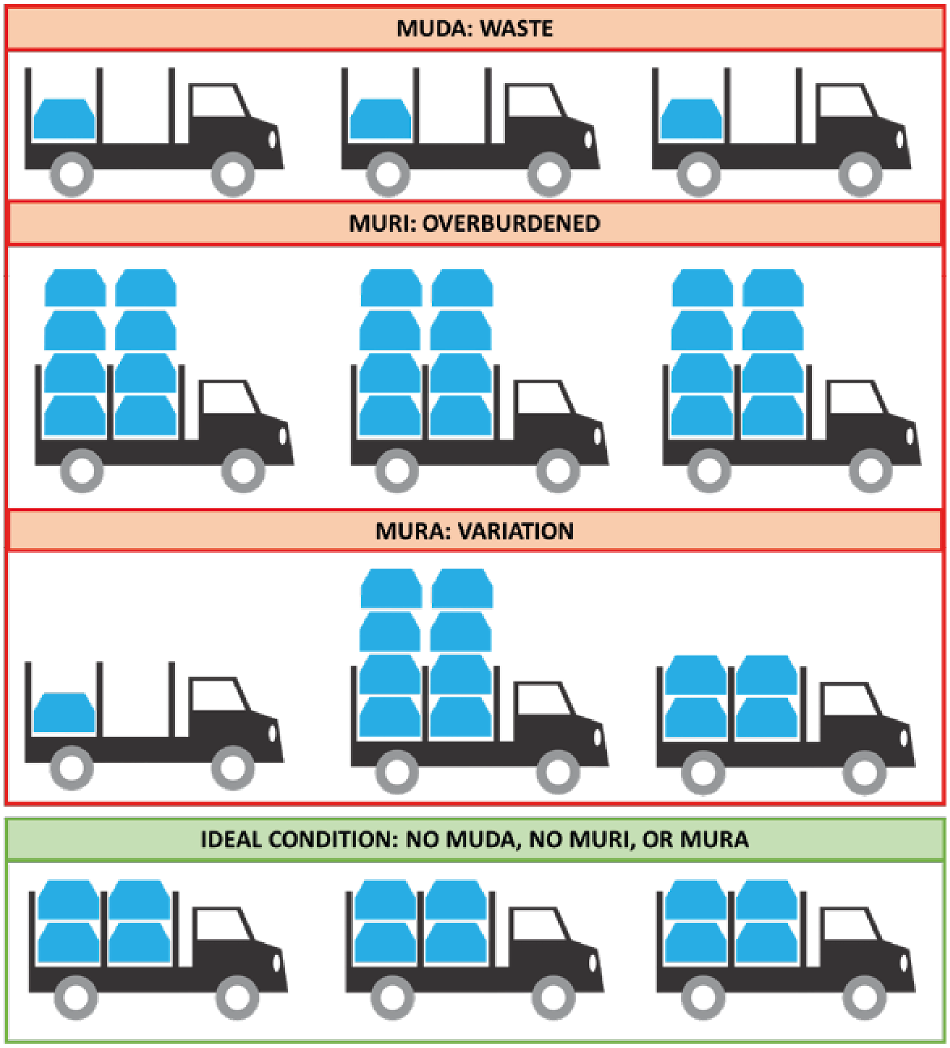


Figure 5.1 – Muda, Muri, and Mura

Muda, Muri, and Mura are also known as the "3Ms" because all three words start with the letter "M". Ideally, processes should have no Muda, Muri, or Mura. After all, processes with no overloads, no waste, and as little variability as possible optimize costs and reduce quality and safety issues.

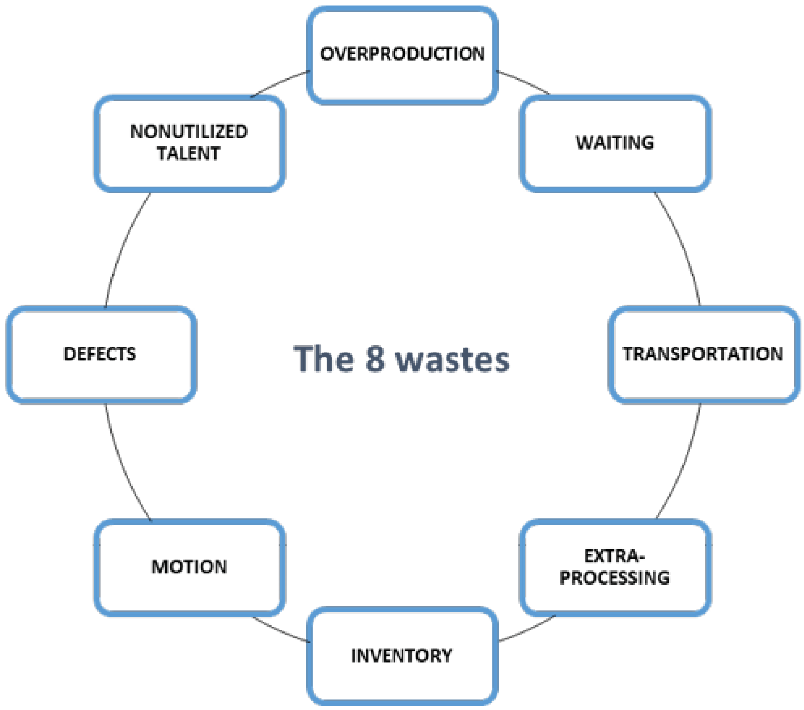


Figure 5.2 – The 8 wastes

There are eight waste categories, according to Taiichi Ohno (Figure 5.2):

1. Overproduction: This waste occurs when a company produces more than it needs to serve its customers. It is considered the worst type of waste, the mother of all others, since when produced in excess, it generates high inventories, unnecessary movements, and wasted resources, consuming productive capacity that could be used to meet customer needs. The cause of overproduction is the lack of predictability of internal processes and external relationships with customers and suppliers. For this reason, variability control should always be a goal.
2. Waiting: The more continuous the production flow, the greater the efficiency and speed with which we can deliver an order to a customer. Thus, delays relate to people, machines, or information "waiting."
3. Inventory: Inventory is problematic because it hides problems,

making it difficult, for example, to detect defects. In addition, it represents immobilized capital, that is, money invested in inputs whose returns will occur only when the customer receives and pays for the purchased product or service. Therefore, one must define the necessary inventory level to buffer potential process variability without incurring high costs.

4. Transportation: This is a waste related to unnecessary transportation. It can result from truncated flows, intermediate inventories far from production lines, and inefficient supply strategies.
5. Motion: Unnecessary handling wastes time, like searching for materials or information. Consequently, workstations, layouts, and inventories must be planned to optimize the movements employees must make. Unnecessary motion is not limited to physical resources; information stored on computers and in other databases must be organized to optimize the company's knowledge management and enable its employees to access it quickly.
6. Unnecessary processing: Refers to performing operations that, if eliminated, would make no difference to the customer. For example, excessive quality inspections can eventually cost more than they benefit. In this sense, unnecessary information processing is also a waste, and many companies and individuals do not know how to handle it. Accordingly, engineers earn high salaries and spend most of their time reading and responding to emails, preparing and watching presentations, updating indicators, filling out reports, and participating in meetings. These activities are necessary but should not consume more than 30% of a person's work time. The truth is that, for example, engineers today spend up to 90% of their time on activities that often do not add value. On the contrary, they should spend most of their time seeing and investigating problems in loco at the Gemba. This Japanese term means "real place" or "place

where things happen," generally used for the production area of an industry or any place where work adds value to a product, a person, or information.

7. Defects: The ideal is always to perform "first time right." This waste concerns, therefore, the commitment of financial, human, and time resources to redo, correct, or rework what was done incorrectly.
8. Nonutilized talent: This eighth waste was not described by Ohno, but should not be neglected for that reason. It is about the intellectual waste of failing to leverage employees' potential within a company. The idea is not to think of employees as machines that must be assigned as many projects and activities as possible. This can be "genius" in the short term, but in the medium and long term, it can be suicide. If the employee is reasonable and proactive, they will probably go to another company, or if they don't leave, they may have physical and mental health problems that could compromise their employability. For example, a challenge nowadays is the recent technological evolution that has enabled most people to work with computers, the internet, and mobile phones. However, excessive information can also become a source of waste, and many companies and individuals do not know how to manage it effectively. As a result, engineers are often highly paid to spend most of their time reading and replying to emails, preparing and attending presentations, updating performance indicators, completing reports, and participating in meetings. While these activities are undoubtedly necessary, they should not occupy more than 30% of a professional's time. In reality, engineers today often spend up to 90% of their time on tasks that are usually non-value-adding. Ideally, engineers should spend most of their time within the production process itself, observing and investigating problems directly at the source. Thus, companies must hire and manage their human resources intelligently, fostering a work environment that

enables employees to fully develop and apply their capabilities and skills as human beings.

5.2 Principles of motion economy

The principles of motion economy are not a recent development. As previously mentioned in the first chapter of this book, the Gilbreths formulated rules for efficiency and economy of motion. Subsequently, other researchers in the same field contributed to and expanded this list.

These principles can be grouped into three categories, according to their focus of application:

- The study of human body movements.
- Workplace design.
- Tool and machinery design.

The principles of motion economy assist in designing the workplace, positioning tools and machinery, and defining the necessary movements to perform a given operation. The main goal is to avoid unnecessary and fatiguing movements whenever possible.

5.2.1 Related to the human body movements

Human movements should be executed harmoniously, following the ergonomic and ergomotricity principles presented in Chapter 4. Such harmony is achieved when movements are performed symmetrically, simultaneously, with synchrony and fluidity (see Figure 5.3).

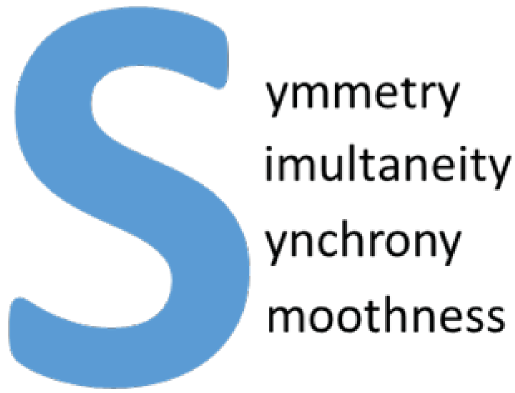


Figure 5.3 – The 4S principles for efficient human movement

To ensure movements are performed harmoniously, the following recommendations should be observed:

- Both hands should begin and end their movements simultaneously.
- Both hands should not remain idle simultaneously, except during rest periods.
- Arm movements should be carried out in opposite and symmetrical directions and executed simultaneously (see Figure 5.4). When this is not feasible, an alternative is to move the arms simultaneously in perpendicular directions (see Figure 5.5).
- Manual movements should be as short as possible.
- The number of motions used to assist the operator should be limited to what is strictly necessary and minimized when muscular effort is required.
- Straight-line movements involving abrupt changes in direction should be replaced with smooth, curved, and continuous hand movements.
- Constrained or "controlled" movements should be replaced by parabolic movements, which are faster, easier, and more accurate.
- The task layout should, whenever possible, allow for a natural and smooth work rhythm.

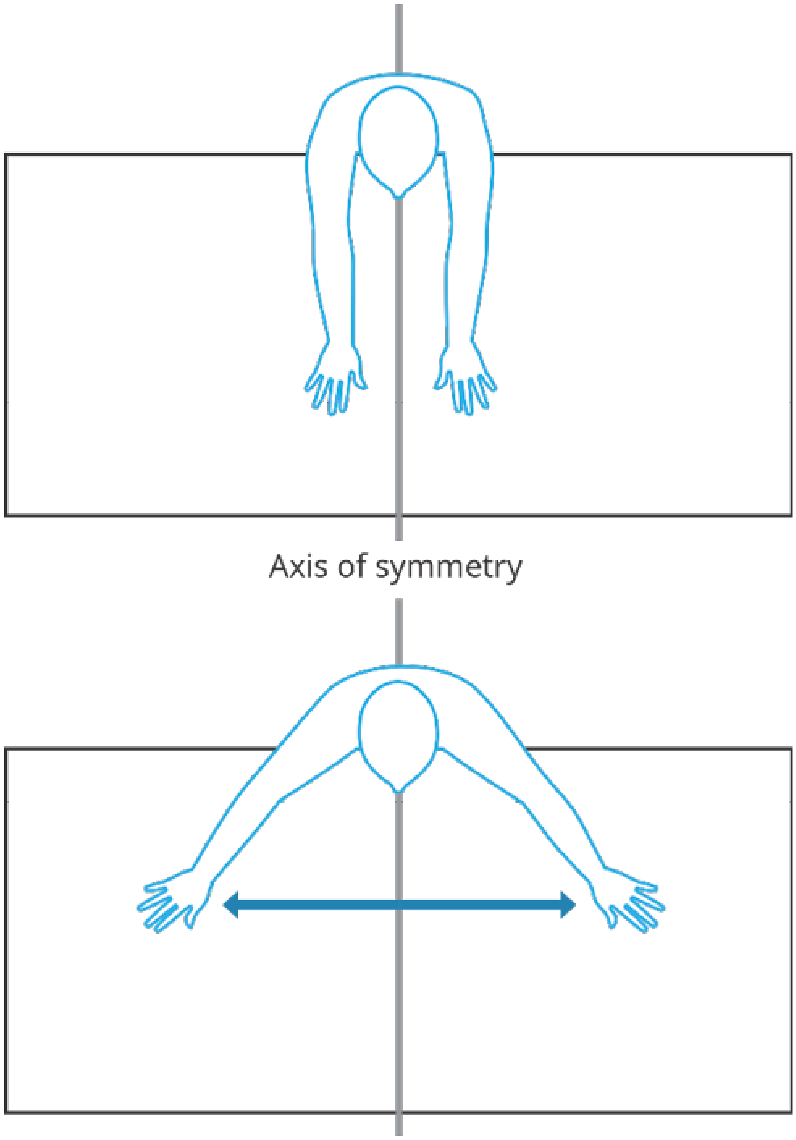


Figure 5.4 – Simultaneous motions of the arms in opposite and symmetrical directions

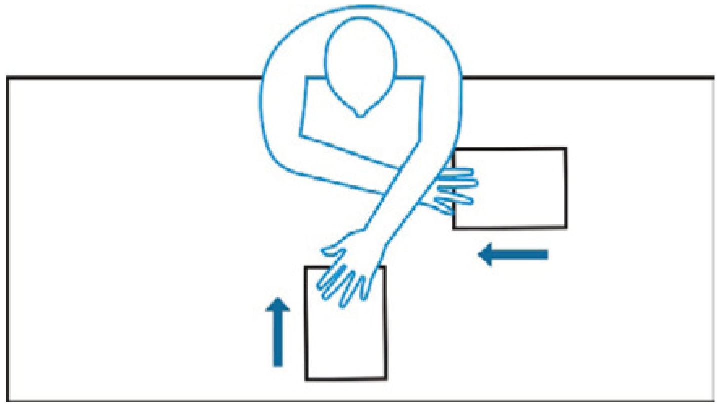


Figure 5.5 – Simultaneous motions of the arms perpendicular to each other

5.2.2 Related to the workplace

Materials, tools, and machinery used in the workplace should be arranged in predefined, fixed locations near the point of use. This arrangement enables the execution of the most appropriate movement sequence and helps avoid unnecessary motion. Whenever possible, tools and materials should be prepositioned. Prepositioning means placing an object in a predetermined location so it can be grasped in the most convenient position for use when needed again.

The layout of materials should be based on ergonomic concepts of normal and maximum working areas, which apply to both the horizontal and vertical planes (see Figures 5.6 and 5.7).

The normal working area is the space within reach of the hands when the elbows are kept close to the body. This area represents where tasks can be performed with normal energy expenditure.

In contrast, the maximum working area is the space the hands reach when the shoulders serve as the reference point. This area should be reserved for occasional tasks, as it requires greater physical effort and increases fatigue compared to the normal working area. It is also important to note that the overlap between both hands can lead to excessive fatigue and should be used sparingly.

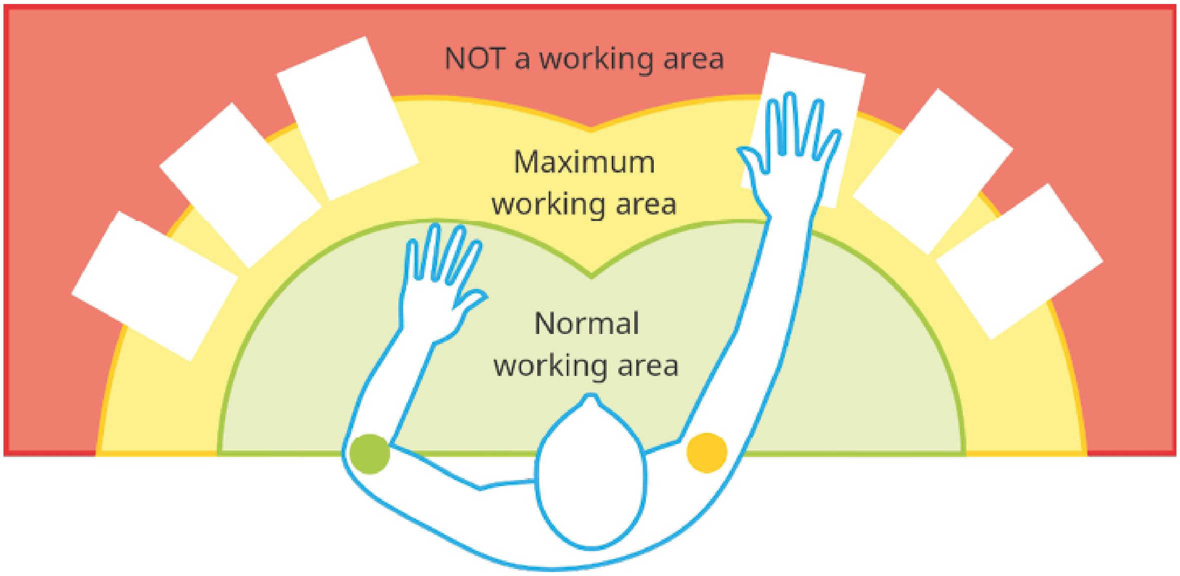


Figure 5.6 – Working spaces in the horizontal plane

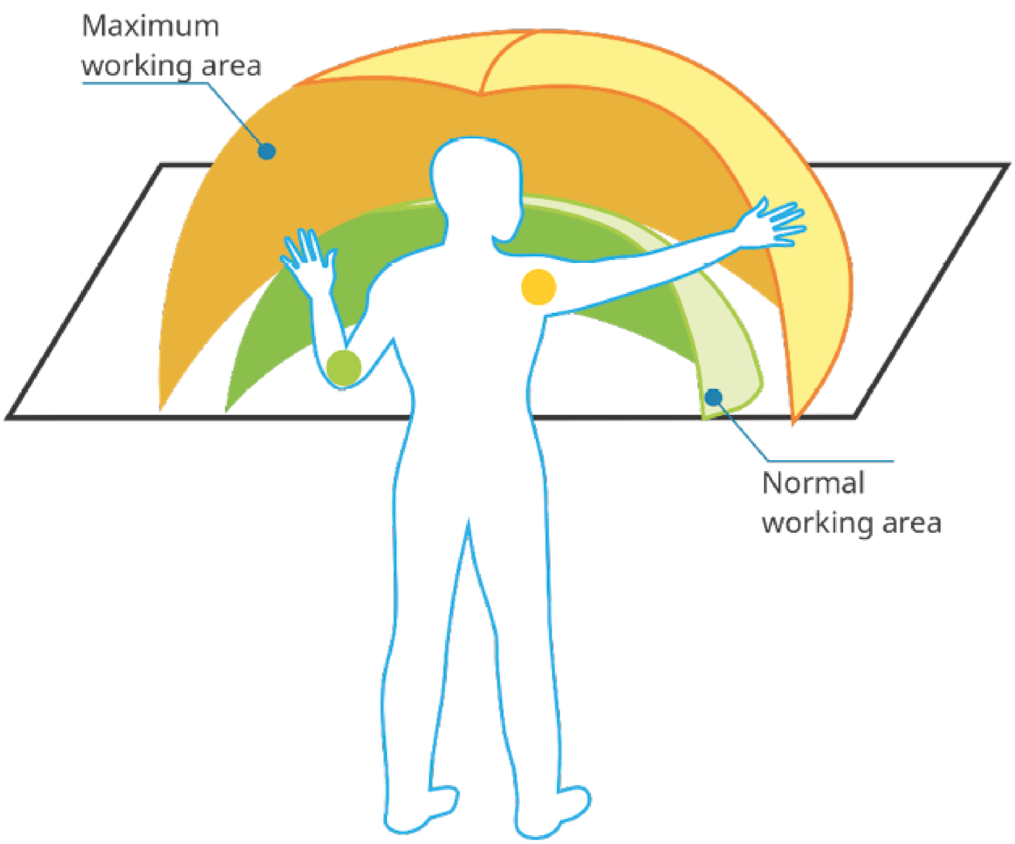


Figure 5.7 – Working areas in three dimensions

Another critical aspect of workplace design is leveraging gravity to assist the operator: whenever possible, gravity-fed containers and discharge systems should be used to distribute materials near their point of use and to transfer processed parts to the subsequent step in the production process.

Environmental conditions—such as lighting, noise, and seating—must also be carefully planned:

- Lighting should be designed to provide adequate visual perception for the task at hand. Both excessive and insufficient lighting can be detrimental to performance and health.
- Noise levels must be controlled to prevent hindrance to task execution or long-term health risks.
- The workspace's layout should allow the employee to alternate between standing and sitting positions during work activities.
- The type and height of the chair should be selected to promote proper posture and ergonomic alignment for the worker.

For instance, Figure 5.8 illustrates how an office workspace should be ergonomically arranged.

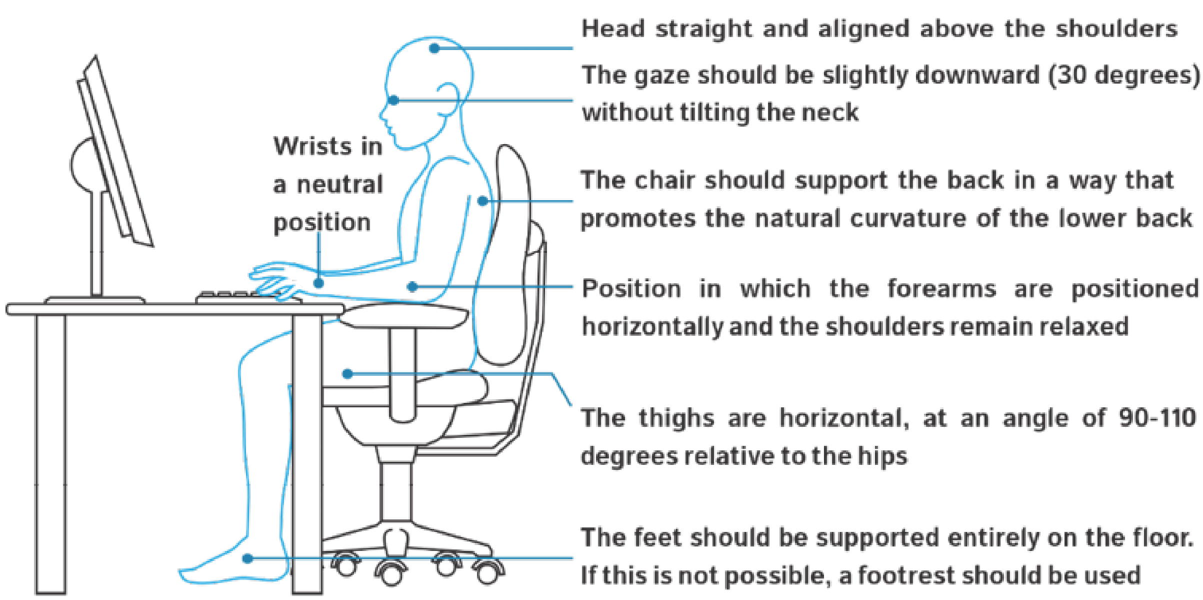


Figure 5.8 – Ergonomic workspace

5.2.3 Related to the design of tools and equipment

The design and development of tools and machinery offer significant opportunities to minimize unnecessary or fatiguing movements for workers. The following aspects should be considered:

Tools

Two or more functions should be combined into a single tool whenever possible. For example, a hammer often incorporates dual functionality: driving nails and removing them (Figure 5.9).

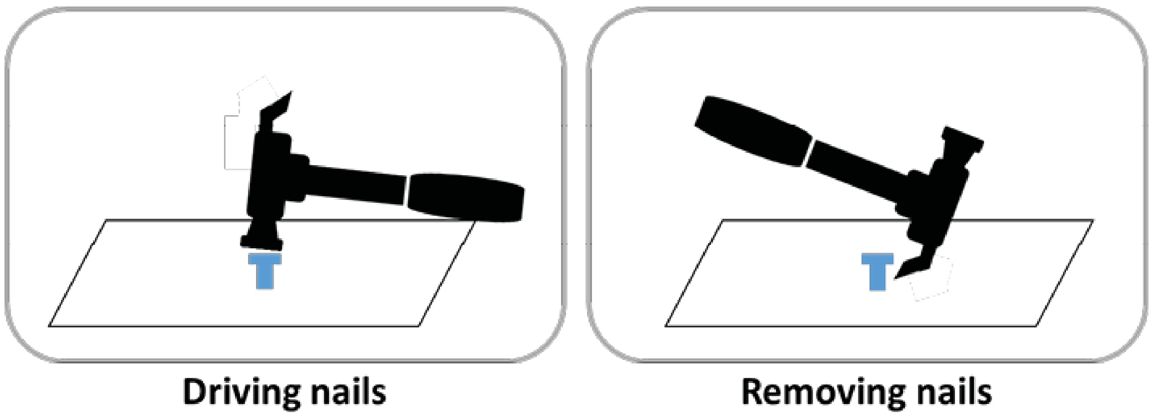


Figure 5.9 – Hammer: Dual-function tool for driving and removing nails

Jigs, pedals, and other devices

Devices such as jigs or foot pedals should be employed to relieve the hands from performing specific tasks. These tools can enhance productivity by freeing the operator’s hands for more critical or precise activities.

Levers, crossbars, and handwheels

Levers, crossbars, and handwheels should be positioned so the operator can engage them with minimal bodily repositioning and maximum mechanical advantage. This facilitates efficiency and reduces operator fatigue.

Keyboards and other input devices

As the thumb, index, and middle fingers are typically the most frequently used digits in manual tasks, input devices—such as keyboards—should be designed to prioritize ease of use and accessibility for these fingers, promoting comfort and performance during prolonged use.

Devices that require finger action should be designed so that all fingers are used evenly. Furthermore, it is vital that the load is distributed according to each finger's intrinsic capabilities.

5.3 5S: Japanese philosophy of eliminating waste

5S is a Japanese philosophy of eliminating waste from the workplace. 5S is related to five Japanese words that begin with the letter "S" (Figure 5.10): Seiri, Seiton, Seiso, Seiketsu, and Shitsuke.

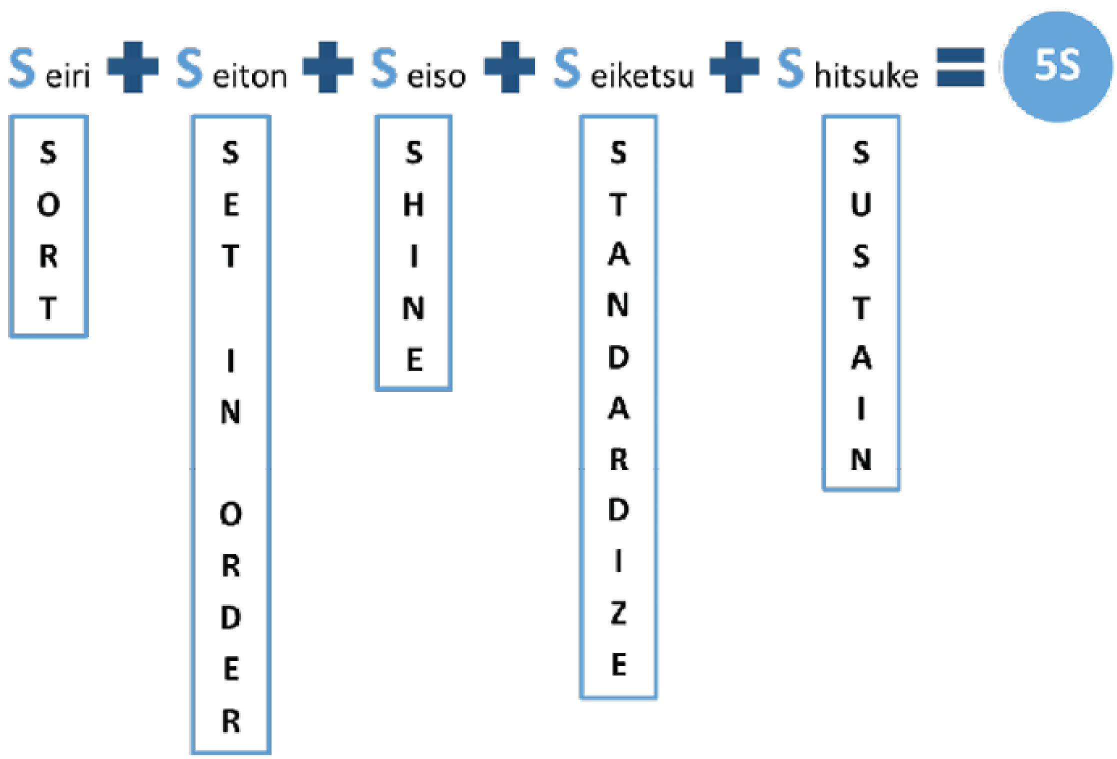


Figure 5.10 – The 5S

First S (Seiri): Sorting

The first sense of Seiri means to sort. That is, you must remove everything that is not useful from the workplace.

The sort sense involves the following actions:

- To analyze everything (tools, furniture, materials, equipment) in the workplace to determine what needs to be present and what can be removed.
- To check the usefulness of each item by asking: “Will this item be used by me or someone else?” The goal is to identify things that aren’t being used or that don’t work.
- Gather all unnecessary materials in one place.
- Whenever possible, these materials should be reused or sold as scrap; otherwise, they should be discarded.
- In the end, only strictly necessary materials should remain in the workplace.

Second S (Seiton): Set in order

Organization (Seiton) means keeping materials readily available, so there is no need to search for them. The basic idea behind this sense is to create a logic for organizing and arranging materials, making their location predictable.

To promote the sense of organization, the following actions can be taken, for example:

- Designing the workplace layout.
- Demarcating circulation areas.
- Defining the location for each material.
- Storing similar objects together based on frequency and point of use.
- Identifying materials with standardized labels and tags.
- Enabling visibility through visual management (e.g., color-coded identification).
- Defining the quantity of materials in each designated location.

- Raising awareness about the importance of maintaining a tidy workspace.

Third S (Seiso): Shine (Cleanliness)

The goal of Seiso is to keep the work environment and equipment clean.

Key actions include:

- Identifying sources of dirt.
- Assigning people responsible for cleaning.
- Defining what must be cleaned and how often.
- Encouraging employees to clean up their mess.
- Reusing and recycling materials where possible.
- Always tidying up after completing tasks.
- Avoiding waste production.
- Promoting collective responsibility for cleanliness.

The final point is key to cleanliness: the cleanest environment is not necessarily the one that is cleaned the most, but the one that becomes the least dirty. In Japan, for example, students clean their own schools—an approach that fosters awareness and responsibility. Intuitively, a child would think twice before discarding a candy wrapper on the floor when they know they will be responsible for cleaning it later that day.

Fourth S (Seiketsu): Health

In Japan, the concept of Seiketsu is more closely related to physical health. However, health has acquired a broader meaning in Brazil, encompassing both physical and mental health.

Below are some actions aimed at promoting physical health:

- Raising awareness about the importance of personal hygiene.
- Continuously improving and cleaning sanitary facilities (bathrooms, locker rooms, and cafeteria sinks).
- Encouraging physical exercise and workplace fitness practices for

employees, both in and out of the workplace.

- Promoting countermeasures against occupational risks like dust, noise, heavy labor, and extreme conditions like heat.
- Designing and improving workstations based on ergonomic and ergonomic-motor principles.
- Creating rest facilities to aid in fatigue recovery.

Moreover, nowadays, mental health is as important as physical health. New technologies have extended work hours through emails and messaging applications. As a result, anxiety and mental stress have become chronic problems in our society. Therefore, actions should also be taken to improve people's mental health:

- Making everyday work a pleasant experience.
- Raising awareness about how people should use new technologies at work and outside.
- Establishing limits on the use of these new technologies.
- In jobs that involve constant computer use, employees should be encouraged to take intermittent breaks to rest, stretch, or engage in other physical activities to counterbalance the mental workload (Figure 5.11).
- Creating a work environment where people can communicate clearly about their problems and dissatisfaction.
- Building facilities for leisure activities.

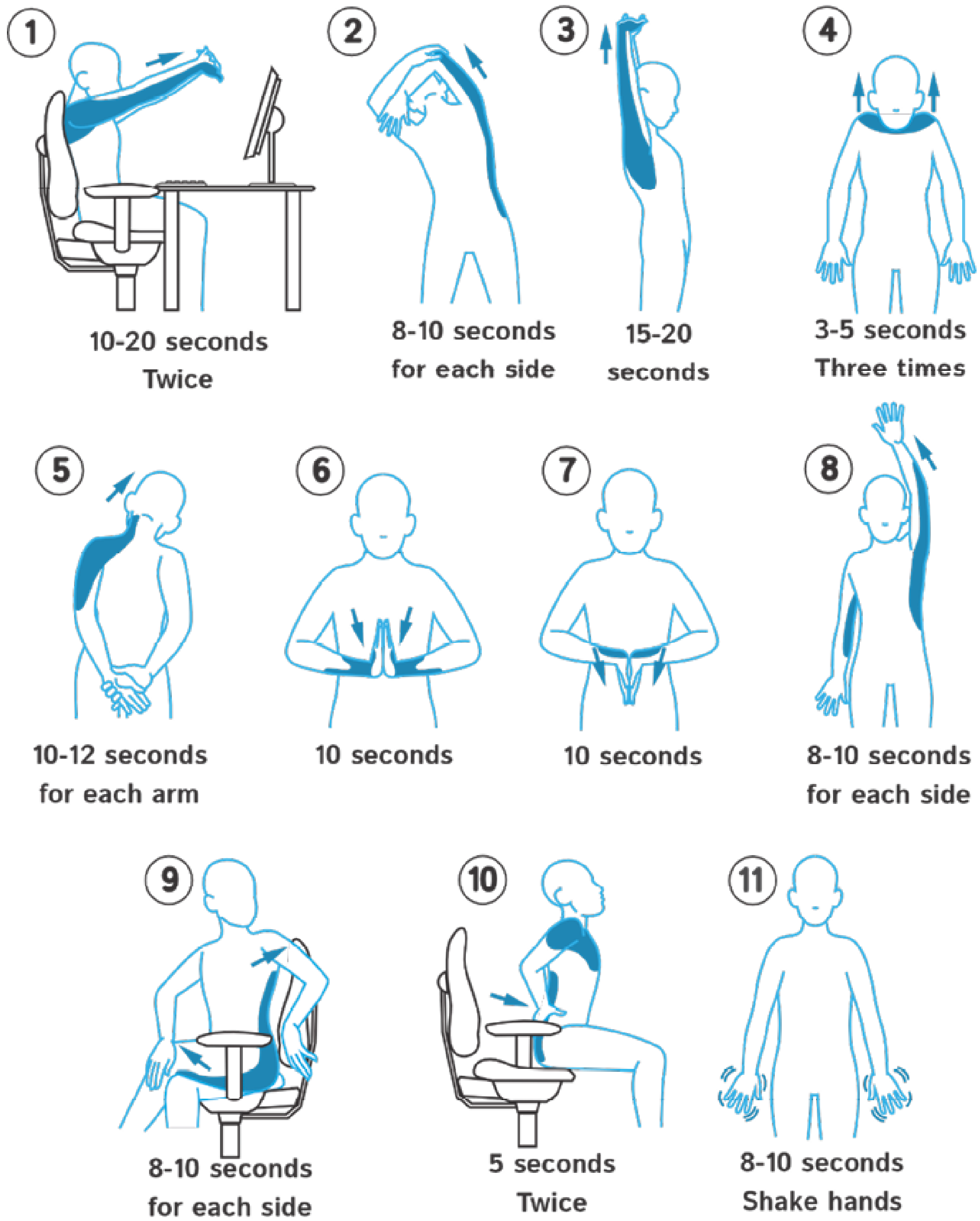


Figure 5.11 – Exercises to be performed by employees who use computers for a long time

Fifth S (Shitsuke): Sustain (Self-Discipline)

Shitsuke can be translated as the creation of good habits. Thus, it involves developing a culture of continuous improvement among all involved. The other four senses must already be fully established to achieve this higher level of self-discipline. In other words, this is the most difficult sense to achieve, but it is crucial for turning a one-time

5S implementation effort into sustainable improvement.

Some actions that help in the development of self-discipline include:

- Complying with regulations and standards.
- Developing checklists to assess the workplace based on the 5S principles.
- Creating an audit calendar.
- Defining responsible individuals for conducting audits.
- Conducting periodic training sessions.

A critical point in conducting audits involves the limits of responsibility. It is not uncommon for problems to be “hidden” between these boundaries to avoid penalties. Therefore, if dirt is found between two sectors — for example, between the painting and machining sectors — it is recommended that both sectors be penalized. Improvement should naturally be carried out by everyone over time and should not be restricted by spatial delimitations. We are responsible for keeping our workplace clean and organized, but we also face an even greater challenge: passing this work to the next sector in an organized and proper manner. Many problems at the boundaries of responsibility stem from thoughts such as “I did my part, now it’s your responsibility,” much like in a swimming relay race. However, since we are all responsible for the results we achieve, we should work as if we were in a relay race, paying twice as much care and attention to the baton exchange zones between sectors (Figure 5.12). Consequently, collective thoughts and attitudes should be valued over individual and disaggregating ones.

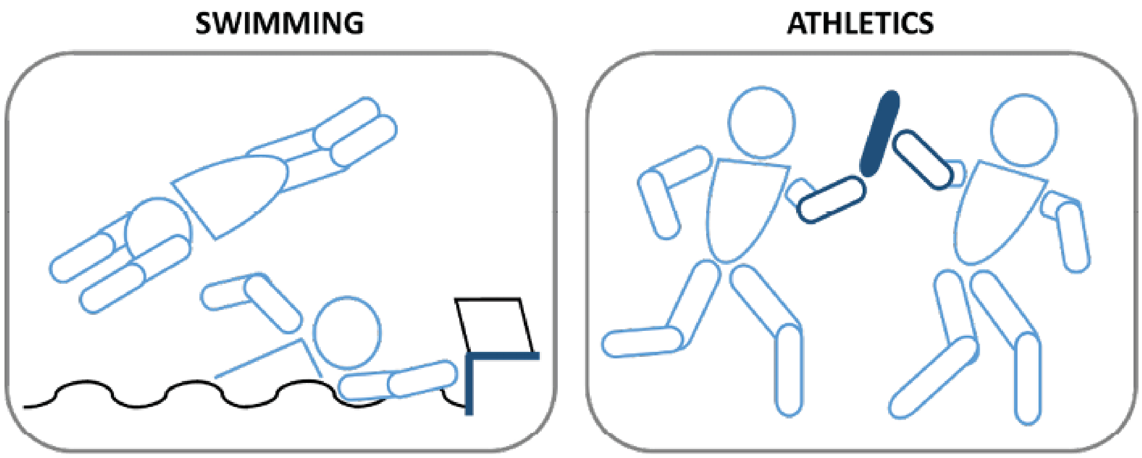


Figure 5.12 – Relays in swimming *versus* athletics

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CHAPTER 6: PROCESS ANALYSIS (FLOW PROCESS CHART, FLOW DIAGRAM, AND VALUE STREAM MAP)

It is recommended to study the process GLOBALLY BEFORE conducting a detailed investigation of a SPECIFIC operation within that process.

This chapter addresses three methodologies to study the flow:

- Flow process chart.
- Flow diagram.
- Value stream map.

These techniques represent the whole process aimed at enhancing understanding and, consequently, facilitating the identification of potential improvements.

Moreover, at the end of this chapter, the combined application of these flow analysis methodologies is presented.

6.1 Flow process chart

The flow process chart represents its activities using sequential symbols (Figure 6.1).

These symbols can be combined when activities co-occur in the same place (space) or at the same time (time). For example, an operator can perform the inspection and operate a part simultaneously (Figure 6.2). Care should be taken with the symbol in Figure 6.2, as some authors also use it to represent necessary operations that do not add value.

Figure 6.3 presents a form for drawing a flow process chart, which is also available separately in Appendix 4. The idea is that each line of the form must contain information about a single activity: operation, inspection, transportation, storage, or delay. It is important to gather additional information, such as the time spent on each operation or the distance traveled.

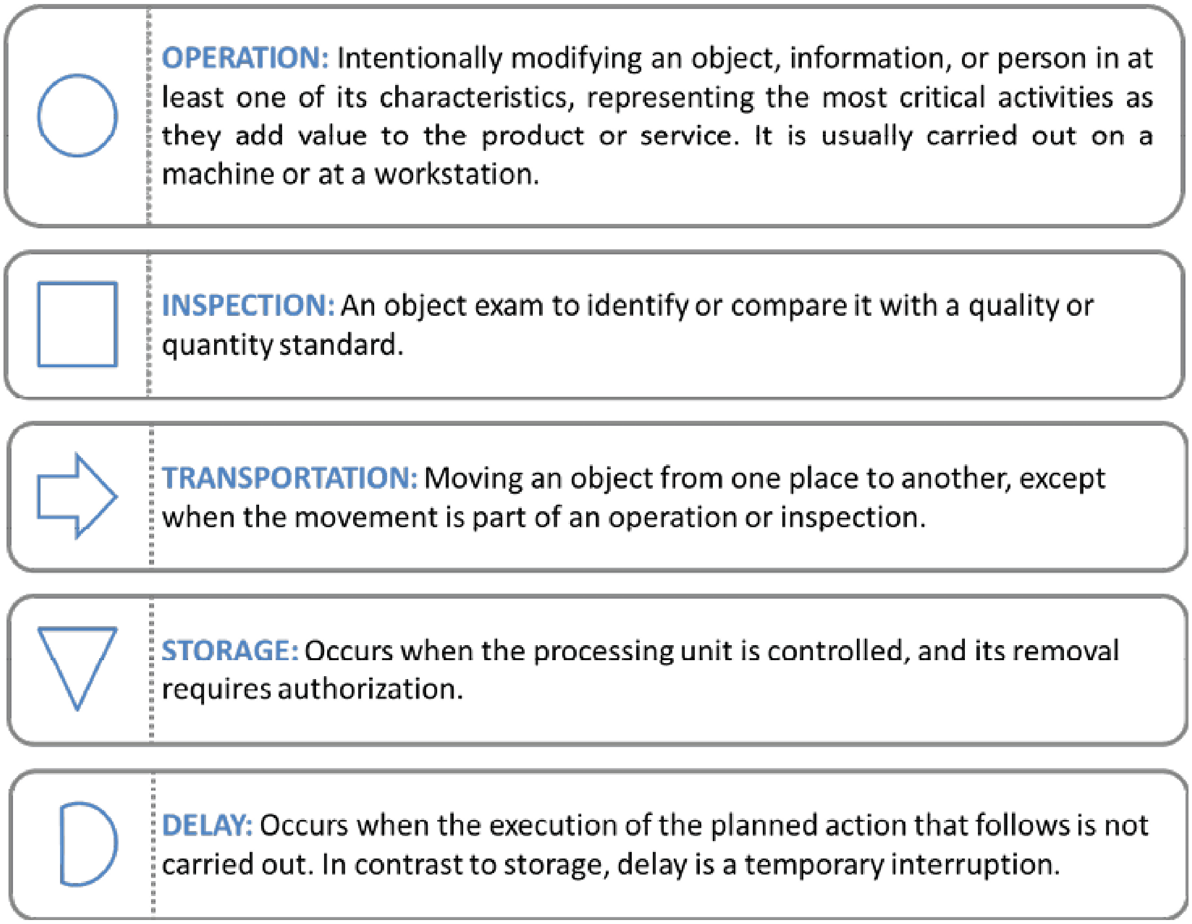

Figure 6.1 – Symbols of the flow process chart

Figure 6.2 – Example of symbol combination

Figure 6.4 illustrates a flow process chart for sandwich assembly. Note that the transport symbols are always interspersed with the others (operation, delay, inspection, and storage) and that the total time per sandwich is given by:

$$\frac{360}{10} + 4 + 27 + 10 + \frac{30}{10} + 8 + 120 + 2 = 210\ seconds$$

FLOW PROCESS CHART

Current method ☐ **New method** ☐

Activity:

Date:

SYMBOLS

○ **Operation** □ **Inspection** ⇨ **Transportation** ▽ **Storage** D **Delay**

DISTANCE	TIME	SYMBOLS	EVENT DESCRIPTION
		○ □ ⇨ ▽ D	
		○ □ ⇨ ▽ D	
		○ □ ⇨ ▽ D	
		○ □ ⇨ ▽ D	
		○ □ ⇨ ▽ D	
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		○ □ ⇨ ▽ D	
		○ □ ⇨ ▽ D	
		○ □ ⇨ ▽ D	
		TOTAL	

Figure 6.3 – Form for flow process chart and flow diagram

FLOW PROCESS CHART

Current method ☒ **New method** ☐

Activity: Sandwich assembly

Date: XX/XX/XXXX

SYMBOLS

○ **Operation** □ **Inspection** ⇨ **Transportation** ▽ **Storage** D **Delay**

DISTANCE	TIME	SYMBOLS	EVENT DESCRIPTION
-	360 per batch of 10 sandwiches	● □ ⇨ ▽ D	Preparation: open the loaf of bread package and prepare other containers (open packages, cut ingredients)
0.3	4	○ □ ➡ ▽ D	Pick two slices of bread and place them on the assembly table
-	27	● □ ⇨ ▽ D	Sandwich assembly: add fillings and close the sandwich
0.2	0	○ □ ➡ ▽ D	Transport to the inspection area
-	10	○ ■ ⇨ ▽ D	Final inspection
0.5	0	○ □ ➡ ▽ D	Moving to the finalization area
-	30 per batch of 10 sandwiches	● □ ⇨ ▽ D	Finalization: close containers, throw away trash, and clean the table
1	8	○ □ ➡ ▽ D	Transport to finished product storage
-	120	○ □ ⇨ ▼ D	Finished product storage
0.5	2	○ □ ➡ ▽ D	Delivery to customer
2.5	210	**TOTAL PER SANDWICH**	

Figure 6.4 – Flow process chart form: Sandwich assembly

6.2 Flow diagram

Sometimes, to better visualize a process, the flow lines are represented on a layout or illustrative diagram of the area where the process takes place. A spaghetti diagram visually represents the flow of the flow unit through the processes. Figure 6.5 presents a spaghetti diagram for the sandwich assembly example, developed to identify wasted movements and unnecessary transport activities.

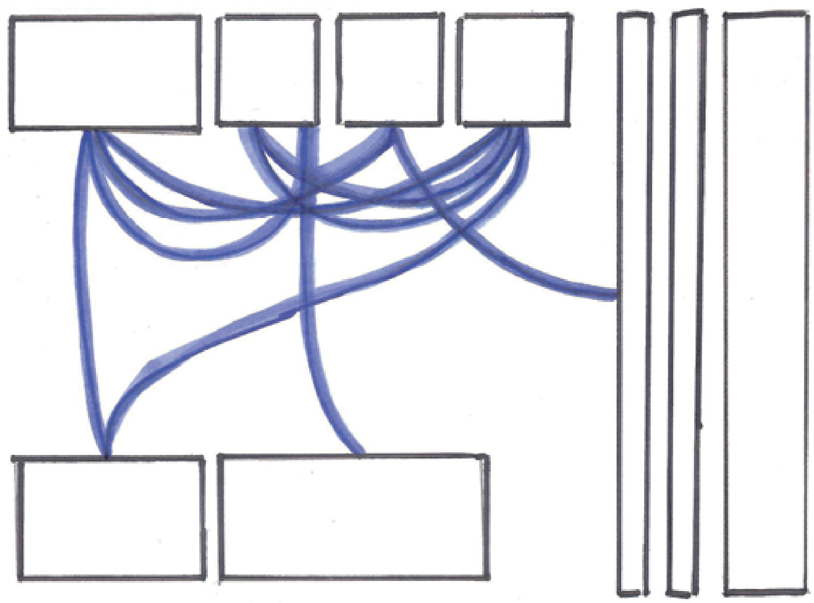

Figure 6.5 – Spaghetti Diagram

A flow diagram, in turn, combines a flow process chart with a spaghetti diagram and can be represented in two or three dimensions.

Below are the steps to follow in developing a flow diagram. This example will continue the sandwich assembly process after improvements have been made based on the spaghetti diagram in Figure 6.5.

Step 1 (Figure 6.6) – Develop a scaled diagram or obtain the layout of the area to be studied.

The work must begin with the layout of the area to be studied or, if it is not possible to obtain it, with a diagram or freehand representation of this space.

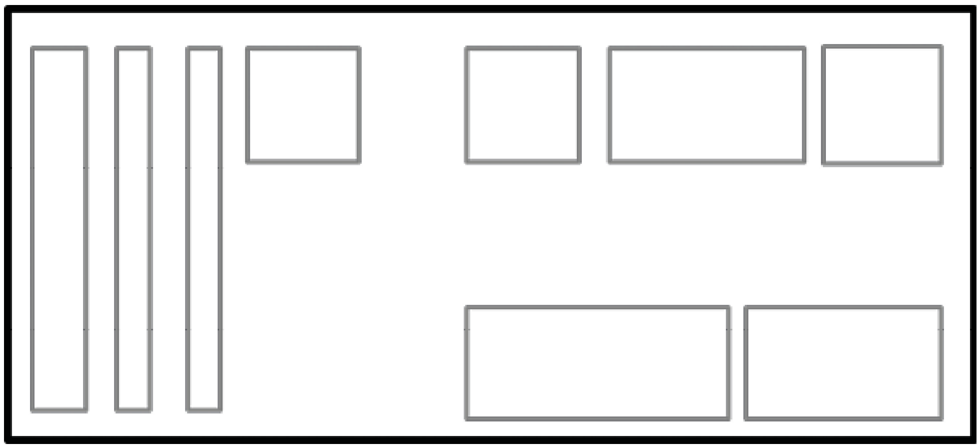

Figure 6.6 – Flow Diagram (Step 1)

Step 2 (Figure 6.7) – Highlight the areas of interest where the work will be focused

The areas of interest, defined in relation to the project objectives, must be highlighted.

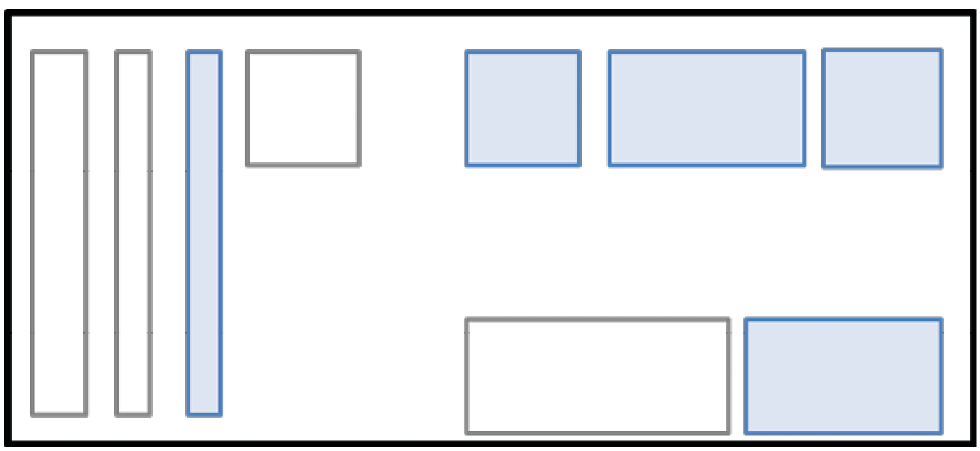

Figure 6.7 – Flow Diagram (Step 2)

Step 3 (Figure 6.8) – Follow the process as if you were the flow unit under analysis

At this stage, the data needed to construct the flow diagram will be collected. For this purpose, the form shown in Figure 6.3 should be used; it is also available in Appendix 4.

The process must be followed from the outgoing finished-goods inventory to the incoming raw-material inventory. Lean methodology recommends following this reverse flow, since the idea is to start from the customer's need and understand the requirements that preceding activities must meet.

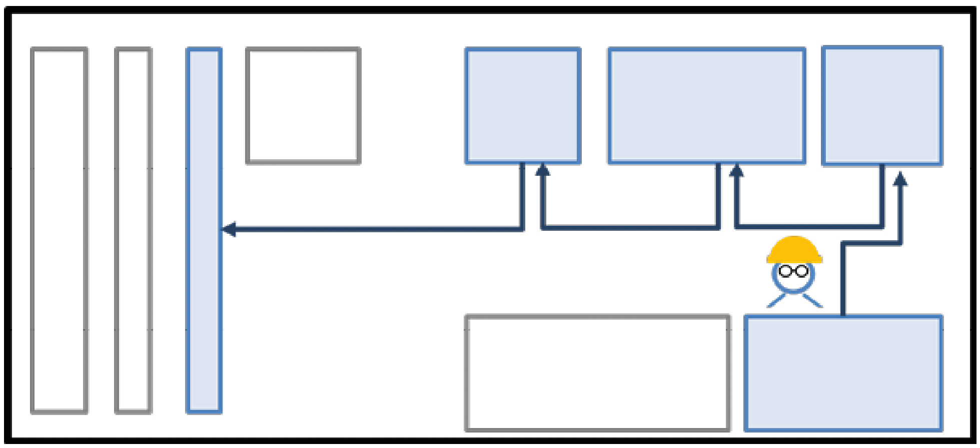

Figure 6.8 – Flow Diagram (Step 3)

Whenever possible, times and distances should be recorded. If this is not feasible, an alternative is to plot the movements using software such as AutoCAD and estimate the distance traveled. Additionally, different colors should be used to represent distinct paths or types of information.

Step 4 (Figure 6.9) – Construct the flow diagram

Using the collected data, the flow diagram can be constructed on a printed layout using post-its or in software such as Microsoft Excel or AutoCAD. Note that the same symbols from the process flowchart are used.

Figure 6.10 illustrates a flow diagram plotted on a factory layout. In this case, the combined square-and-circle symbol was used to represent unnecessary operations that do not add value. Blue dots were used to describe the operators involved in the process. In other words, other symbols can be created or adapted to meet the project's specific needs.

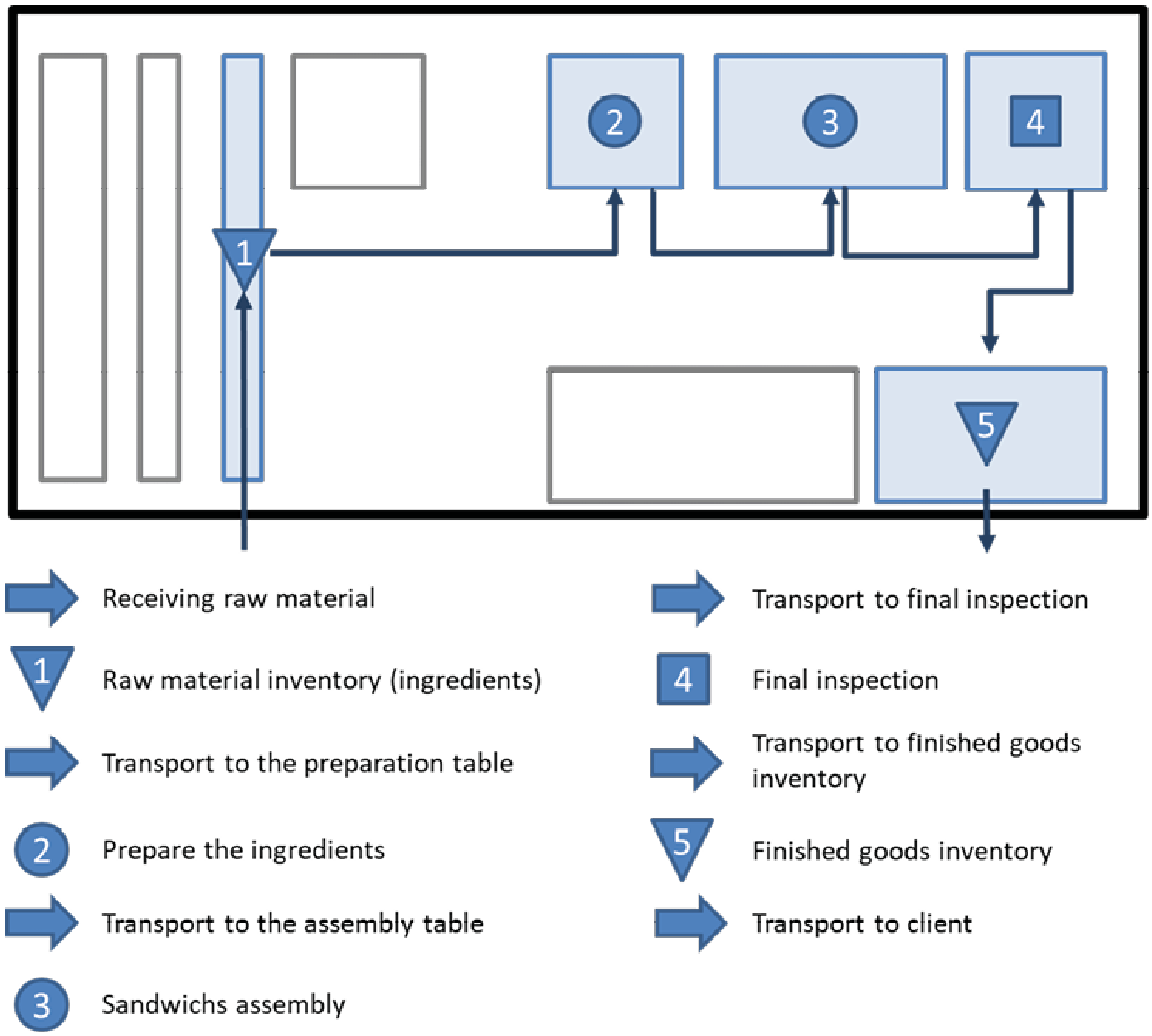

Figure 6.9 – Flow Diagram (Step 4)

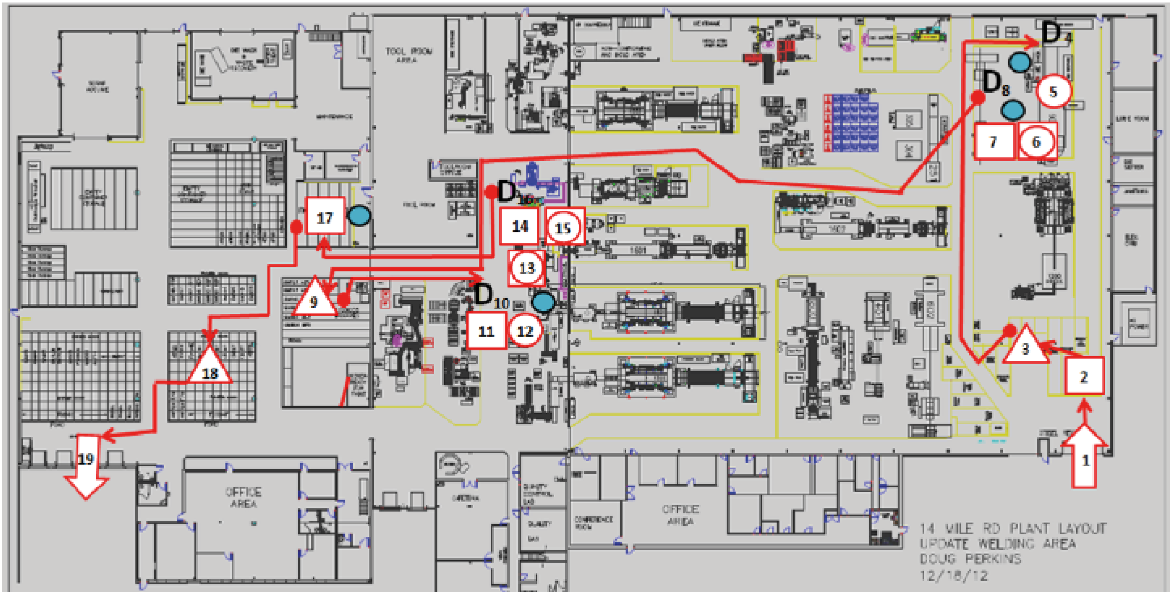

Figure 6.10 – Industry Flow Diagram

6.3 Value Stream Map

A value stream refers to all actions, whether value-adding or non-value-adding, that are necessary for transforming a product or service from raw materials to the customer. Therefore, value stream maps focus on the flow of the entire system, rather than on individual processes or operations. This tool is intrinsically linked to the concepts discussed in Chapter 2.

Thus, it is essential first to establish key concepts, such as value-adding activity, lead time, and takt time. Next, a step-by-step procedure for developing a value stream map will be presented.

6.3.1 Basic concepts

Value-adding activity

A value-adding activity meets the following criteria:

- It satisfies the customer in terms of both tangible and intangible aspects of the product or service. In other words, it delivers to the customer something they are willing to pay for.
- It “transforms” the flow unit, adding value.

Lead Time

Lead time refers to the total time required to complete a process from start to finish. This concept can be applied in various contexts:

- Industrial production: The time between the customer's order placement and the product's shipment.
- Service delivery: The time from when the customer requests the service until the service is executed.
- Product development: The time from the conception of a new product to its actual availability in the consumer market.

The term "lead time" may appear under different names, depending on the context. For example, in the healthcare sector, a widely monitored indicator is Length of Stay (LOS), which refers to the time a patient spends from admission to discharge in a healthcare facility (e.g., a hospital).

Regardless of the context, in most processes, non-value-adding activities account for 90% or more of the total lead time (Figure 6.11).

Accordingly, it is generally more advantageous to reduce non-value-adding activities than to optimize value-adding operations.

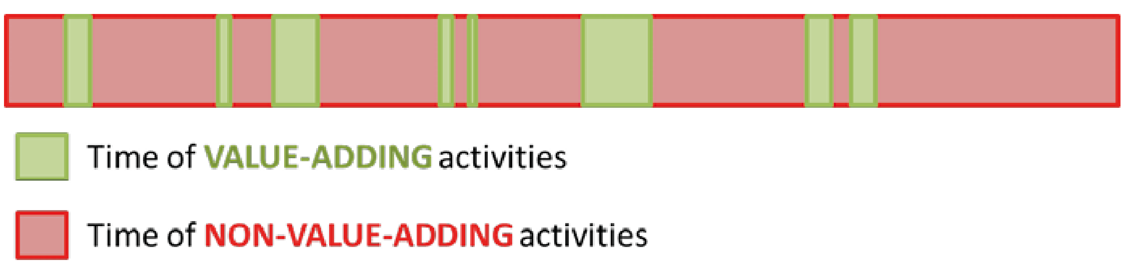

Figure 6.11 – Lead time subdivided into value-adding and non-value-adding activities

Takt Time

The German word "takt" can be translated as beat. Just as musicians follow the rhythm of a piece with a metronome, takt time sets the pace production should follow to meet customer demand. This measure provides an organization with the required production time per unit to respond effectively to customer needs. Accordingly, it can be concluded that:

- If the time required to produce a product exceeds the takt time, the customer will receive the product with a delay.
- If the time required to produce a product is significantly shorter than the takt time, production costs can likely be optimized.

Takt time can be calculated using the following formula:

$$Takt\ time = \frac{Available\ production\ time}{Demand}$$

6.3.2 Step-by-step procedure for developing a Value Stream Map

Step 1 – Definition of the product or product family to be analyzed

The selection should be based on the problem to be addressed. At this stage, it is crucial to examine the problem and define the study's scope. Since it is impossible to analyze all products and services simultaneously, it is necessary to delineate a specific product, service, or product family for which the value stream map will be developed.

Step 2 – Data collection in the office

Before beginning map development, it is essential to gather information from various departments and companies.

Supplier information:

- Names of the companies that supply the inputs required for the production of the product or service.
- Number of raw material deliveries within a given time (day, week, or month).
- Number of pieces or weight per delivery.
- Cost of raw materials.
- The quantity of raw material required to produce a product or

provide a service.

Customer information:

- Names of the companies to which the product or service is delivered.
- Demand for the product under analysis from each of these companies.
- Number of finished product deliveries within a given time (day, week, or month).
- Number of pieces or weight per delivery.

Process information:

- Inventory of raw materials, intermediate inventory (WIP – Work in Progress), and finished goods inventory.
- Number of pieces considered per batch to plan the production schedule.
- For each machine involved in the manufacturing process:
    - Number of operators per machine.
    - Number of shifts per working day.
    - Number of operating days per month.
    - Percentage of Overall Equipment Effectiveness (OEE): OEE represents, in percentage terms, the time during which the equipment actually produced relative to the available time (Figure 2.7). This already excludes planned downtime (preventive maintenance, testing, and equipment modifications). In other words, this indicator highlights losses related to availability (breakdowns, setups, pauses, breaks, meetings), performance (reduced speed and empty cycles), and quality (defects).
    - Average machine downtime (in hours per week or as a percentage).
    - Average losses due to lack of quality (number of parts

scrapped or as a percentage).
    - Machine hourly standard.
- Weekly releases for the job being analyzed.
- Costs of processed parts throughout the production process.
- Costs associated with parts scrapped due to quality problems.

Step 3 – Data collection in the production area

In this stage, the process should be followed as if one were the flow unit under analysis, starting from the finished-goods inventory (downstream processes) and moving backward to the initial raw-material inventory (upstream processes). The concepts of downstream and upstream processes are illustrated in Figure 6.12. As these terms are commonly used to describe reference points along a river's course, the idea is to apply them to represent the flow of a product or service within an organization. Thus, downstream refers to the direction of the river's mouth, which, in industrial terms, corresponds to the final processes closer to the customer. In contrast, upstream refers to the river's source and, in the industrial context, to the initial stages of product or service transformation.

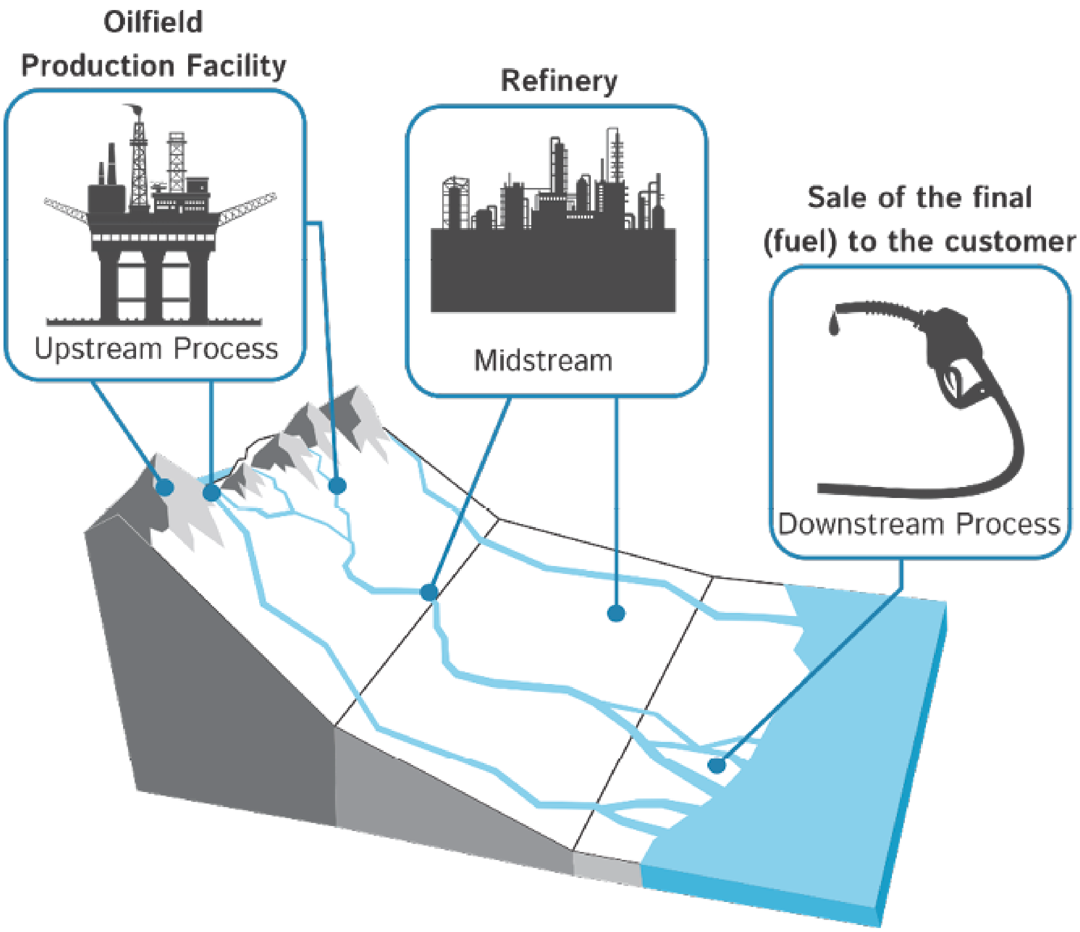

Figure 6.12 – Downstream and upstream processes

The data needed to construct the value stream map will then be collected. For this purpose, the form presented in Figure 6.13, also available in Appendix 4, may be used.

When developing a value stream map, the objective is not to document how the process should function, but rather how it occurs. It is akin to taking a snapshot of what is observed. Problems must therefore be made explicit, not concealed. Hence, instead of building the value stream map solely on secondary data, it is essential to observe the process and validate any secondary data directly.

VALUE STREAM MAPPING FORM

Activity:

Date:

SYMBOLS

○ **Operation** □ **Inspection** ⇨ **Transportation** ▽ **Storage** D **Delay**

○ Time	□ Time	⇨ Distance	▽ Quantity	D Time	EVENT DESCRIPTION

Figure 6.13 – Value stream mapping form

VALUE STREAM MAPPING FORM: TRUSS ASSEMBLY STUDY

Activity: Truss assembly

Date: XX/XX/XXXX

SYMBOLS

○ **Operation** □ **Inspection** ⇨ **Transportation** ▽ **Storage** D **Delay**

○ Time	□ Time	⇨ Distance	▽ Quantity	D Time	EVENT DESCRIPTION
		10 meters			A forklift delivers eucalyptus parts from the external storage area
35 minutes					Operator #1 cuts six pieces to the appropriate size
		5 meters			Transport to the workstation of Assembler #1
25 minutes					Assembler #1 takes three small pieces and assembles a small triangle
		5 meters			Transport to the workstation of Assembler #2
20 minutes					Assembler #2 takes three long pieces and assembles a large triangle
		5 meters			Transport to the workstation of Assembler #3
25 minutes					Assembler #3 takes each of the triangles assembled in steps 3 and 4 and assembles the truss
		5 meters			Transport to the inspection
	5 minutes				The supervisor inspects the completed truss
		10 meters			Forklift transports trusses to final storage
			100 truss		Trusses await delivery in final storage

Figure 6.14 – Value stream mapping form: Truss assembly study

An example is presented in Figure 6.14, based on a study of the steps involved in assembling a wooden truss (a small triangle composed of three small pieces within a larger triangle composed of three larger pieces).

Step 4 – Developing the Value Stream Map

The value stream map can be constructed using post-it notes or through software such as Microsoft Excel or Microsoft Visio, following the sub-steps described below.

Sub-step 4.1 – Calculation of Takt Time (Figure 6.15)

The first step is to calculate the takt time using the previously presented formula. It is the maximum time per unit allowed to produce a product to meet demand.

$$Takt\ time = \frac{Available\ production\ time}{Demand} =$$

$$\frac{6\ days/week \times 3\ shifts/day \times 8\ hours/shift}{12{,}500\ pieces/week} =$$

$$0.01152 \frac{hours}{piece} \times 3{,}600 \frac{seconds}{hour} \cong$$

$$41.5\ seconds\ per\ piece$$

Days/week	Shifts/day	Hours/shift	Available Time (in sec per wk)	Weekly demand (in pcs)	Takt Time (in seconds/pç)
6	3	8	518,400	12,500	41.5

Figure 6.15 – Calculation of takt time in a value stream map

Sub-step 4.2 – Adding customer information

Figure 6.16 represents the customer in the value stream map. In fact, the map should begin with the customer, as the customer drives the subsequent processes.

In this section, include information about the customer, such as the company name, takt time, delivery frequency, delivery load, and any other relevant data deemed necessary.

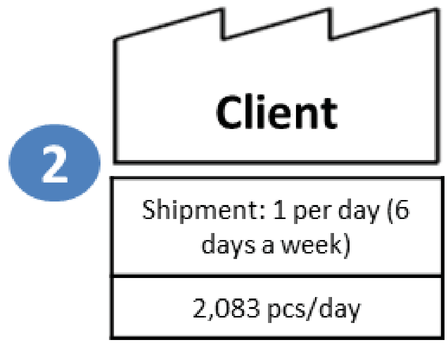

Figure 6.16 – Customer information in a value stream map

Sub-step 4.3 – Adding information about value-adding operations

Operations that add value to the system should be included (Figure 6.17). In the example under analysis, the value-adding operations are stamping, heat treatment, and machining.

For each operation, it is advisable to include data such as:

- Number of operators per machine.
- Number of operating days within a given time period.
- Machine gross cycle time, calculated using the machine's hourly standard.
- Average loss due to non-quality (number of rejected parts or scrap rate) or rework generated.
- Number of shifts per day in which the operation occurs.
- Number of machines.
- Average downtime (in hours per week or as a percentage).
- Overall Equipment Effectiveness (OEE) percentage.
- Number of parts per cycle.
- Machine actual cycle time

$$Machine\ actual\ cycle\ time\ = \frac{Machine\ Gross\ Cycle\ Time}{1 - Scrap\ Rate - Downtime\ Rate}$$
$$= \frac{Machine\ Gross\ Cycle\ Time}{OEE}$$

STAMPING (3)	
2 operators	
Days/week	2.5
Gross cycle time (seconds/pc)	7.2
Scrap/Rework Percent	2.0%
Number of Shifts	2
Number of Machines	1
Downtime Percent	4.2%
Actual C/T (seconds/piece)	7.7
Quantity of Pieces per Cycle	1

Figure 6.17 – Information on value-adding operations

These data will serve as input for calculating the actual time spent per piece during the operation.

Sub-step 4.4 – Adding information about inventory non-value-adding time (Figure 6.18)

Figure 6.18 – Information on inventory in a value stream map

At this stage, it is necessary to include information on the WIP presented between operations, such as the quantity of parts held in stock or their corresponding weights.

Subsequently, the data concerning the number of parts or the weight of materials in inventory should be converted into the average time these materials remain in stock.

This can be determined by multiplying the number of parts by the takt time to obtain the average inventory time, which is similar to Little's Law presented in Chapter 2.

$$Inventory\ time = Inventory\ quantity \times Takt\ Time$$

For example, let us assume there are 10 parts in inventory and the takt time is 5 hours per part. Therefore, we have:

$$Inventory\ time = 10 \times 5 = 50\ hours$$

This formula assumes that the parts are arranged in a queue and follow a "First In, First Out" (FIFO) withdrawal system. Thus, as the customer or the following process pulls one part every five hours, in approximately 50 hours (10 × 5), the entire stock of 10 parts will be consumed.

Sub-step 4.5 – Adding supplier information (Figure 6.19)

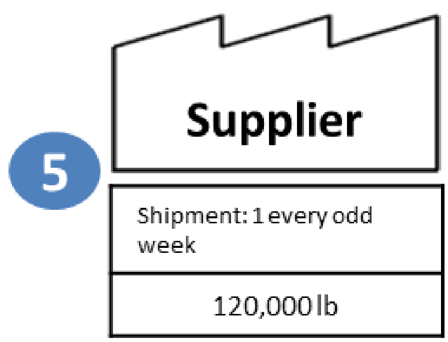

Figure 6.19 – Supplier information in a value stream map

At this sub-step, information about the suppliers should be added, such as the company name, takt time, delivery frequency, delivery load, and any other relevant data deemed valid.

Sub-step 4.6 – Calculation of the value-added percentage (Figure 6.20)

6

TOTAL Lead time	223.6 hours
Value-added time	0.01 hours
Non-value-added time	223.58 hours
% of value-added time	0.005%

Figure 6.20 – Calculation of the value-added percentage in a value stream map

All times associated with operations that add or do not add value to the process (such as inventory time, operation time, waiting periods, transportation, and inspections) should be considered.

$$Lead\ time = \text{Time of value adding activities} + \text{time of non value adding activities}$$

Subsequently, the value-added ratio can be calculated.

$$Value\ added\ ratio = \frac{Value\ added\ time}{Lead\ time}$$

It is worth noting that the percentage of value-added time was previously discussed in Chapter 2.

At this stage, all time measurements must be expressed in the same units to allow accurate calculation of the percentage. The percentage of value-added time is generally low, often below 1%. This is a common occurrence in large-scale production processes, which often rely on high inventory levels to absorb process variability. Consequently, most of the time, the product remains in inventory, while the period during which it effectively adds value and undergoes transformation is negligible.

Sub-step 4.7 – Adding data about the information flow (optional)

Data on information flow may be included when relevant to understand not only material flow but also production planning and control processes.

Sub-step 4.8 – Executive Summary

At the end of the process, it is advisable to present a managerial summary of the expenses involved in both value-adding and non-value-adding operations, such as:

- Analysis of inventory holding costs (Figure 6.21): In this case, it is sufficient to multiply the required production value at each stage of the process by the number of parts or kilograms in stock.

Inventory	Value	Quantity/Weight in Inventory	Inventory Value
Raw Material	$0.51 per lb	33,000 lb	$16,978.50
WIP	$2.87 per piece	13,896 pieces	$39,926.65
Finished Good	$4.65 per piece	2,500 pieces	$11,621.94
TOTAL INVENTORY COST			**$68,527.09**

Figure 6.21 – Analysis of inventory holding costs

- Analysis of costs due to non-quality losses (Figure 6.22): The average cost of non-quality losses can be calculated, for example, by determining the expenses associated with part rejection and rework.

$$Scrap\ loss\ per\ week = Scrap\ rate\ per\ equipment \times Weekly\ demand \times Scrap\ part\ cost$$

For instance, stamping machines have an average rework rate of approximately 2.013%. Moreover, the value of each part through this process is $2.87, and 12,500 parts are produced weekly on this machine. Thus, we have:

$$Srap\ loss\ per\ week = 0.02013 \times 12{,}500 \times \$2.87 = \$729.56$$

Operations	Loss of Scrap per Week
Stamping	$729.56
Heat treatment	$216.30
TOTAL LOSS DUE TO QUALITY PROBLEMS	**$945.86**

Figure 6.22 – Analysis of costs associated with non-quality losses

Sub-step 4.9 – Adding improvement notes (Kaizen Box)

Finally, notes may be added to highlight problems and opportunities for improvement. These notes are commonly referred to as Kaizen boxes.

Figure 6.23 presents the value stream map developed based on this step-by-step procedure.

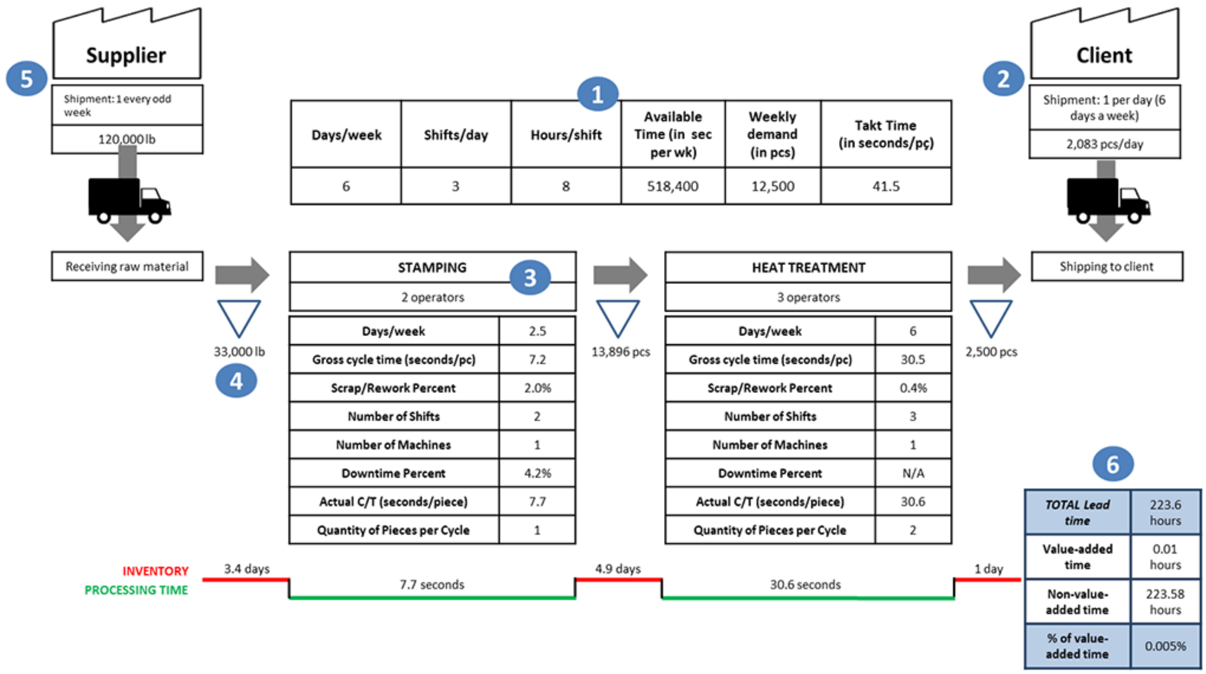

Figure 6.23 – Example of a Value Stream Map

6.4 Hybrid methods

It is essential to note that, in practice, these methodologies can often be applied together. This is illustrated in Figure 6.24, which continues the study on truss assembly, whose data collection form was presented in Figure 6.14.

This figure illustrates a process flow diagram constructed with post-it notes, where, as in the value stream map, information concerning value-adding activities is made evident. Such information is then used to calculate the percentage of process time that effectively adds value.

The complementary use of these flow analysis methodologies consequently enhances the robustness of potential improvement project outcomes. Moreover, visual management with Post-it notes encourages teamwork and a continuous-improvement mindset.

It is essential to highlight that these methodologies are not mutually exclusive. On the contrary, as demonstrated in the previous example, they can be applied in hybrid or complementary ways.

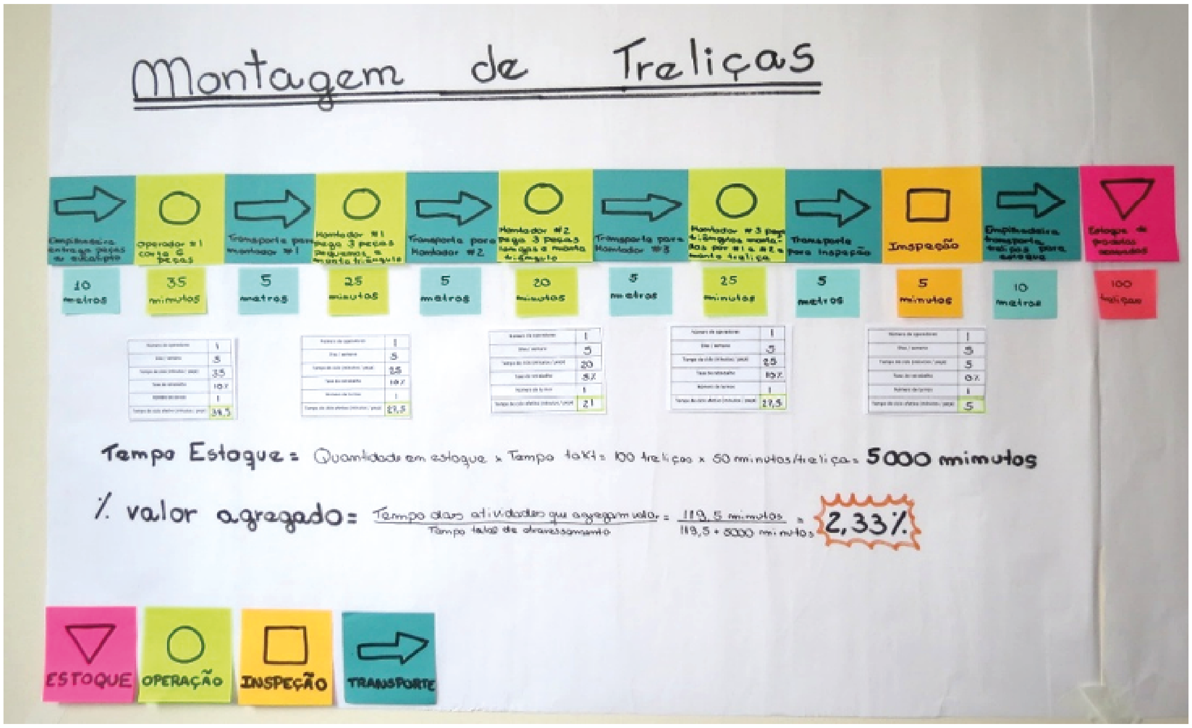

Figure 6.24 – Example of combining a value stream map with a flow process chart

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Softwares

AutoCAD – https://www.autodesk.com.br/products/autocad/free-trial
Microsoft Office – https://www.office.com/
Microsoft Visio – https://www.microsoft.com/pt-br/microsoft-365/visio/flowchart-Software

CHAPTER 7: OPERATION ANALYSIS (ACTIVITY CHART AND WORKER-MACHINE CHART)

This chapter presents the techniques used to analyze operations based on time subdivisions, such as:

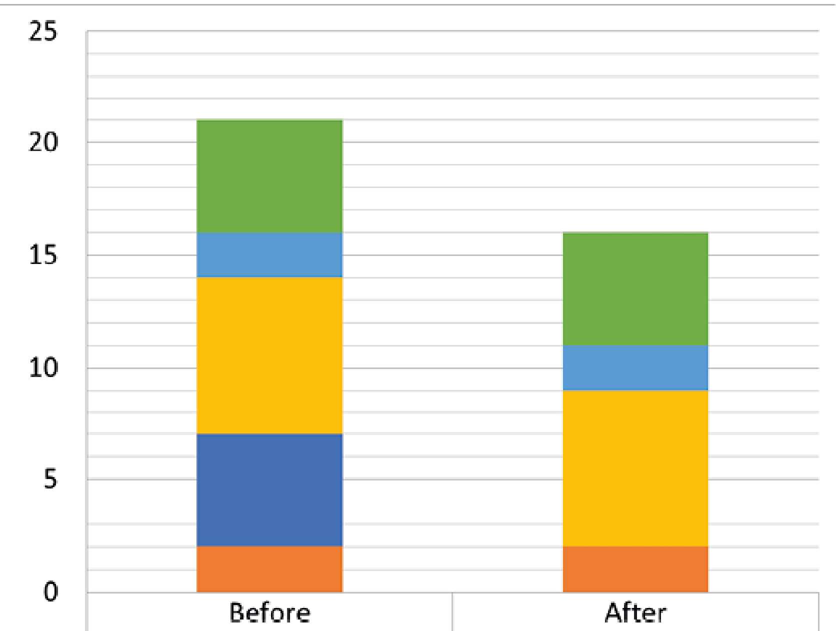
- Activity charts.
- Worker-machine charts.

The section on worker-machine charts will show how this type of chart can be used to balance the number of operators and machines required for a given operation. Furthermore, it will show how to use the chart to optimize changeover time (Single Minute Exchange of Die—SMED) and workstation cycle time (Single Minute Cycle Time—SMCT).

7.1 Activity chart

When the workload is unbalanced among employees or when waiting periods can be reduced, it is useful to have a subdivision of a production process or a series of operations expressed as a function of time. Activity charts show only the activities the operator performed over time.

For example, in a bakery, an activity chart was created to identify potential improvements in the toast-preparation process. At the start of the day, demand for the product was high. However, many customers complained about the long wait for their toast, as they were in a hurry to get to work.



	Before	After
Remove the toasted bread from the toaster	5	5
Place the slice of bread in the toaster	2	2
Spread butter on the bread to be toasted	7	7
Carry the slice to the toaster table	5	0
Take a slice of sandwich bread from the package	2	2

Figure 7.1 – Activity chart comparing toast preparation before and after improvements

During the study, it was found that the sliced bread packages were too far from the toaster. In light of this finding, the stock of sliced bread was relocated to a spot near the toaster – an improvement after which the activity "take slice to toaster table and return" was eliminated, representing a gain of 5 seconds. Figure 7.1 presents the activity charts before and after the implementation of the improvements, showing the activities involved in a work cycle and their respective times. Thus, the employee's working time per toast, previously 21 seconds, was reduced to 16 seconds following the improvements.

7.2 Worker-machine chart

In certain types of work, the operator and the machine work intermittently. Thus, it is helpful to construct a scaled chart to clarify the interrelation between the operator and the machine. This chart serves several purposes, such as identifying opportunities for improvement in the working method.

The chart shows the cycle time considering the worker-machine set.

In general, the cycle time can be divided into three macro-steps:

- Preparation: Loading materials into a machine (idle machine).
- Operation: Machine-cycle time (machine process time).
- Post-processing: Unloading materials from a machine (idle machine).

Based on the previous bakery example, the implemented improvement was insufficient to achieve the desired results, as the worker's idleness was not evident. Thus, a worker-machine chart was constructed to identify other opportunities for improvement in this work method (Figure 7.2). The chart shows that the worker "anticipates" preparing the next toast while the toaster processes the current toast. The cycle time (time spent to complete one work cycle, that is, the time spent per unit produced), considering both the toaster and the worker, is 25 seconds (Figure 7.3). This time is longer than that shown in Figure 7.1, as evidenced by the worker's idle time (9 seconds).

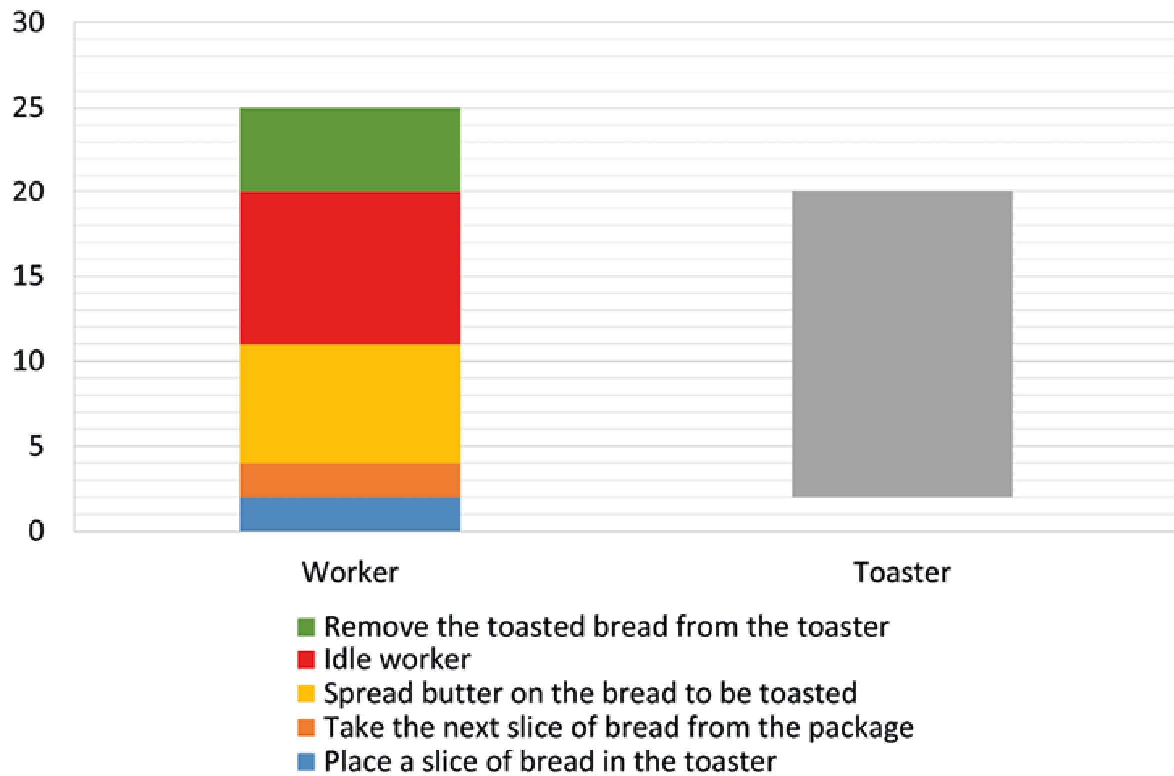


Figure 7.2 – Worker-machine chart for toast preparation activity

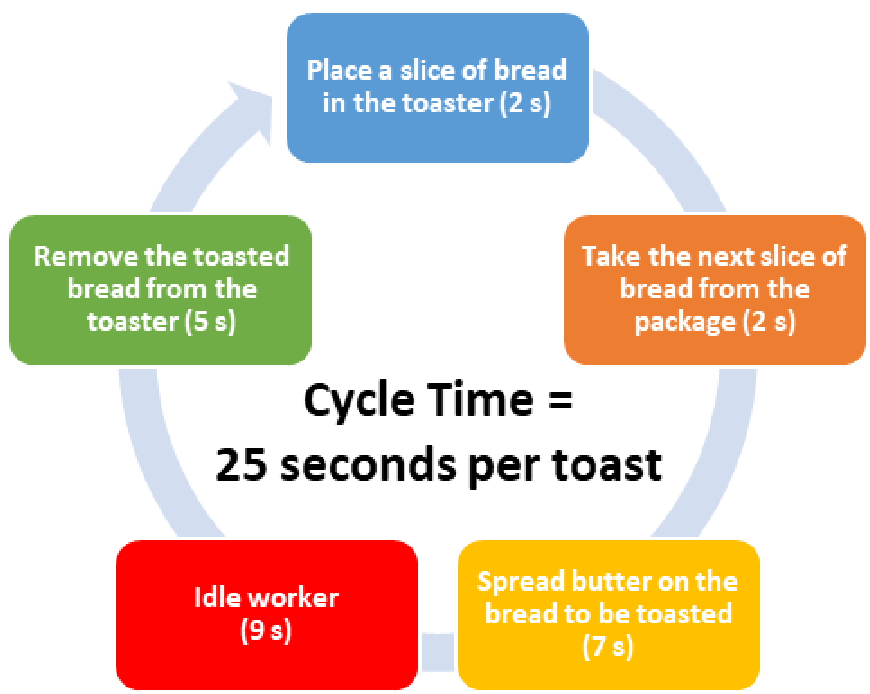


Figure 7.3 – Cycle time for the toast preparation activity

We can also calculate the percentage of utilization of the worker and the toaster using the following formula:

$$Utilization = \frac{Operation\ time}{Cycle\ time}$$

Thus, Table 7.1 compares the worker and the toaster utilization in this example.

	Worker	**Toaster**
Idle time	9 s	7 s
Operation time	16 s	18 s
Cycle time	25 s	25 s
Utilization	64%	72%

Table 7.1 – Comparison of the worker and the toaster utilization

This table revealed that the worker's idle time could be used to anticipate the preparation of another toast. Figure 7.4 presents the revised worker-machine chart based on this improvement opportunity. Note that a more modern toaster was also acquired in this case, which toasts two slices simultaneously, since the old toaster toasted only one.

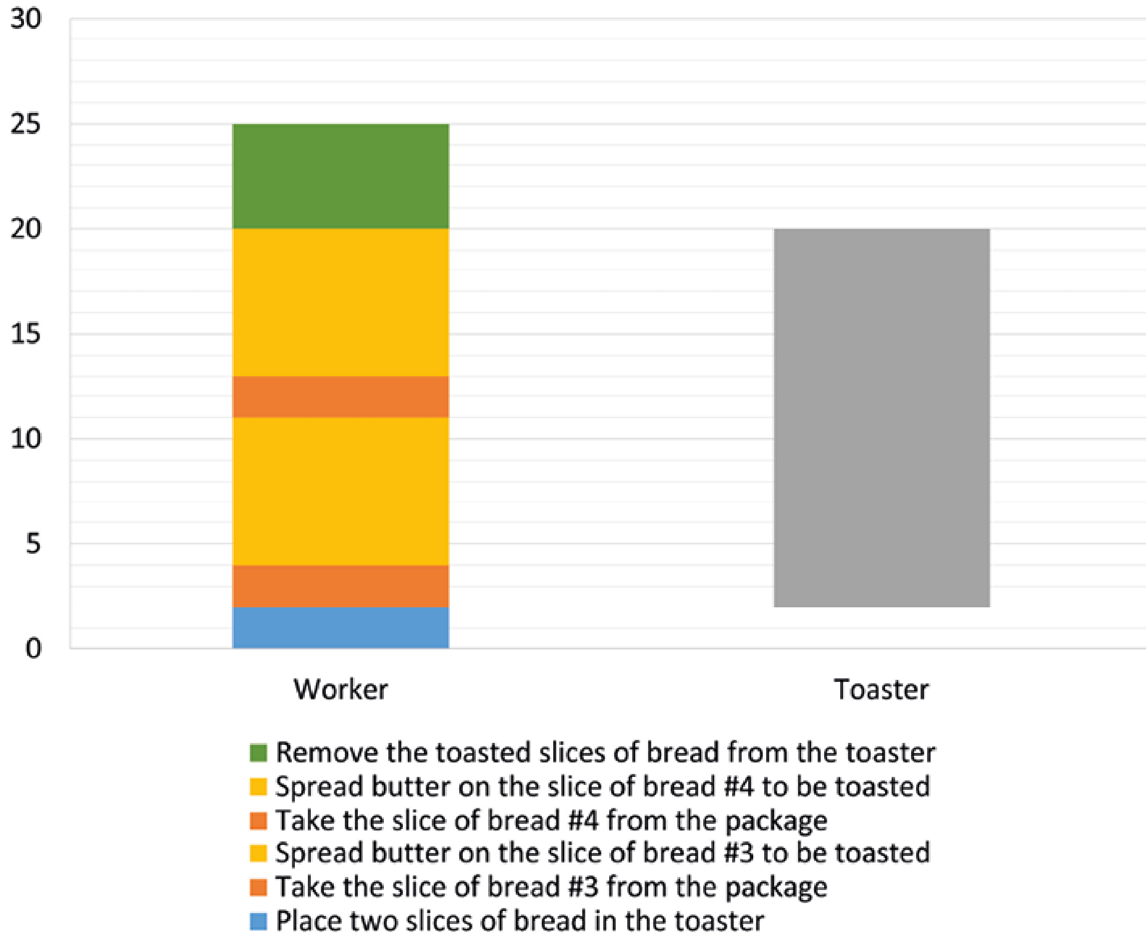


Figure 7.4 – Worker-machine chart with the new toaster

Thus, with the improvements, the worker's utilization increased from 64% to 100% (Table 7.2). The toaster's utilization remained constant at 72%, but it is worth noting that the new equipment now processes two toasts in the same time as the old one. That is, the toaster's cycle time was reduced by half. Previously, the cycle time was 25 seconds per toast; after the improvements, it decreased to 12.5 seconds per toast.

Based on the concepts presented regarding worker-machine charts, the following section demonstrates how these concepts can be applied to balance the number of operators and machines required for an operation, optimize changeover time (SMED), and optimize the workstation cycle time (SMCT).

	Worker	Toaster
Idle time	0 s	7 s
Operation time	25 s	18 s
Cycle time	25 s	12.5 s
Utilization	100%	72%

Table 7.2 – Comparison of the utilization of the worker and the toaster with the new toaster

7.2.1 Calculating the number of workers required

Two approaches can be used to balance the number of machines and operators required. The first is the traditional Industrial Engineering approach, which provides greater analytical accuracy and is therefore recommended, for example, when deciding to purchase equipment for constructing a new factory. The second is the one recommended by lean manufacturing textbooks. Due to its simplicity, the latter should be used only in studies that do not require high precision, such as macro-level mappings.

An important observation is that while the first approach provides the number of machines one operator can control, the second provides the number of workers required. Thus, care must be taken when studying these approaches, as certain subtleties distinguish them.

Traditional approach

To calculate the number of machines that one operator can control, we first need to define some concepts related to the subdivisions of the operator and equipment cycle time:

- External time: Time of external activities, that is, activities performed by the operator while the machine is idle (loading, unloading, and activating the machine).

- Internal time: Time of internal activities, that is, activities performed by the operator while the machine is processing (inspecting, gauging, walking between machines, cleaning, and getting or disposing parts).
- Process time: Machine cycle time.
- Idle time: Time in which either the operator or the machine is waiting for work.

The concepts of internal and external activities can be compared to a sandwich: the external activities would be the “bread” and represent the activities before and after the machine’s cycle time. Meanwhile, the internal activities would be the “filling” and describe the operator’s activities performed in parallel with the machine’s cycle. These concepts are illustrated in Figure 7.5.

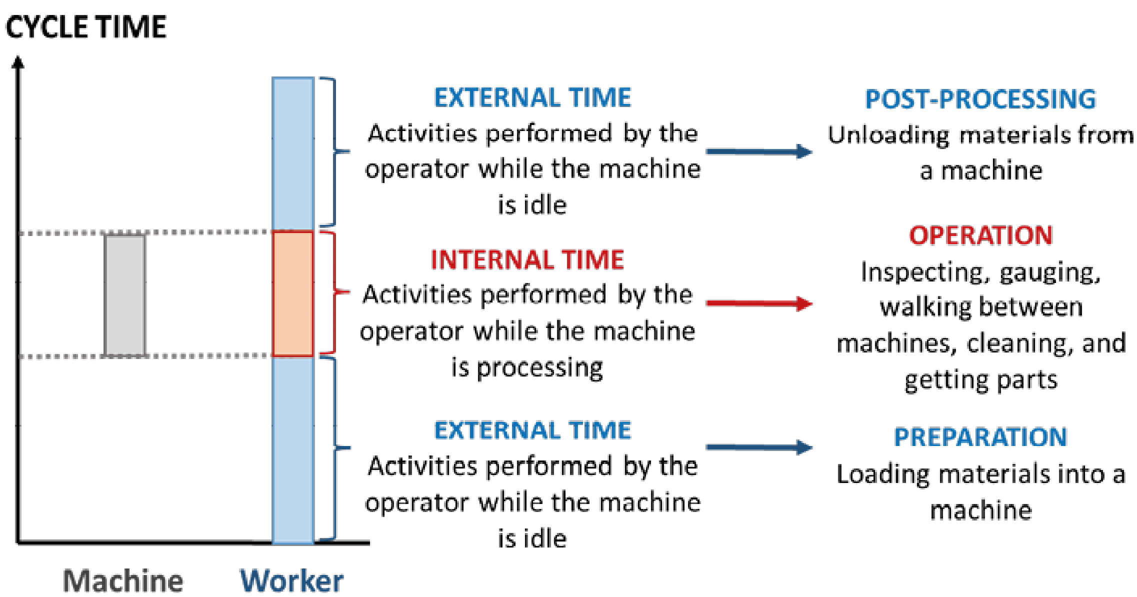


Figure 7.5 – Cycle time: Internal and external activities

Considering the cycle time, INTERNAL ACTIVITIES can be performed while the MACHINE IS PROCESSING. EXTERNAL ACTIVITIES MUST be performed while the MACHINE IS IDLE (Figure 7.5).

Once the terms are defined, we should use the following formula in the calculation:

$$\text{Number of machines per operator} = \frac{\text{Operator external time} + \text{Machine process time}}{\text{Operator external time} + \text{Operator internal time}}$$

Let's illustrate the calculation using the worker-machine chart in Table 7.3. This chart shows what the operator and the machine are doing. The time required (in minutes) for each activity is indicated in parentheses.

WORKER	MACHINE
Unloading part (0.13)	Idle (0.25)
Loading and activating the machine (0.12)	
Cleaning part (0.10)	Processing (1.00)
Inspecting part (0.10)	
Idle (0.80)	

Table 7.3 – Example of worker-machine chart

Thus, in this case, we have:

- External time: 0.13 + 0.12 = 0.25.
- Internal time: 0.10 + 0.10 = 0.20.
- Process time: 1.00.

Therefore,

$$\text{Number of machines per operator} = \frac{0.25 + 1.00}{0.25 + 0.20} = \frac{1.25}{0.45} = 2.78 \text{ machines per operator}$$

Ultimately, the value must be rounded up or down, as appropriate.

Note that if it is rounded up, the machine will remain idle. Otherwise, if it is rounded down, the operator will remain idle.

In the example above, the value will be rounded down. One operator will control two machines, as the managers prefer to keep him idle while improvements are made to enable the operator to control three machines. Considering this factory has four pieces of equipment, two operators will be required.

Lean approach

The lean approach is more straightforward. In this case, the formula to be used is as follows:

$$Number\ of\ workers = \frac{Cycle\ time}{Takt\ time}$$

In the previous example, the cycle time to produce a part was 1.25 minutes. Furthermore, let us consider that, to meet customer demand, one part must be produced every 48 seconds, which is every 0.8 minutes. Thus:

$$Number\ of\ workers = \frac{Cycle\ time}{Takt\ time} = \frac{1.25}{0.80} = 1.56 \rightarrow 2\ workers$$

The rounding logic in this case is the opposite of the traditional approach, which calculates the number of machines per operator. In contrast, the lean approach calculates the number of workers required. Consequently, the resulting value must be rounded up to idle the operator. Otherwise, the takt time will not be met, and there will be a risk of failing to meet customer demand.

Thus, according to this second approach, two operators would be required. In this example, both approaches yielded the same result, but in practice, this is not always the case.

7.2.2 Reducing changeover and cycle times

Worker-machine charts can also be used to optimize both changeover and cycle time.

Changeover time optimization (Single Minute Exchange of Die – SMED)

Changeover time is the time elapsed between the last conforming part in a batch, in terms of quality, and the first conforming part of the next batch, assuming normal production speed. The methodology that uses worker-machine charts to reduce changeover time is SMED (Single Minute Exchange of Dies), a technique for achieving a batch changeover in a "single minute".

The concept will be exemplified in a dairy company. In this company, a changeover must be performed every time strawberry-flavored yogurt production ends and coconut-flavored yogurt production begins. Thus, the equipment must be cleaned, and the production inputs must be changed. Consequently, the more flavors produced in a month, the more changeovers are required and the lower the daily production capacity.

Table 7.4 shows daily production capacity by the number of yogurt flavors produced each month.

NUMBER OF YOGURT FLAVORS TO BE PRODUCED PER MONTH	DAILY PRODUCTION CAPACITY
1 flavor	32,000 kg
2 flavors	27,000 kg
3 flavors	18,000 kg

Table 7.4 – Daily production capacity according to the number of flavors to be produced

Therefore, the company must reduce changeover time to increase its daily yogurt production capacity. This reduction through SMED enables more setups and smaller batch sizes. Consequently, flexibility increases without compromising production efficiency, allowing a smoother production flow (continuous flow); reduction of intermediate inventory (Work In Progress – WIP) and lead time; agility in detecting and reducing losses resulting from quality problems; a more balanced production of products over time (production leveling), which enables optimization of productive resources; and even a reduction in the average cycle time of a piece of equipment.

Below are several time-saving opportunities in SMED:

- Performing tasks in parallel.
- Organization and standardization of tools and other inputs required during the changeover, using visual management and 5S methodologies.
- Reduction of movement and transport times, using tools such as spaghetti diagrams and process flowcharts.
- Development of quick coupling and decoupling devices.
- Leveraging employee synergy through teamwork.
- New studies to reduce the frequency of quality tests and adjustments in the regulation stage, which occurs after setup.

The following are the steps that must be followed when performing an SMED. Before optimizing setup time, the changeover of interest should be recorded on video, from the last good part of the previous batch to the first good part of the next batch. This video will help identify the necessary activities, waste, and opportunities for improvement. Consequently, each activity can be described and its duration documented. This can be done using an Excel spreadsheet or with Post-its.

SMED consists of 5 steps:

Step 1 – Identify internal and external activities

Based on the recorded video, the activities should be identified as internal or external.

In this case, the concepts of internal and external activities differ slightly from their use in the context of cycle time. However, since these are relative concepts, the sandwich metaphor can be used again. In the case of changeover time, external activities would be the "bread," representing activities performed in parallel with the machine cycle. In contrast, internal activities would be the "filling," representing tasks performed by the operator while the machine is idle.

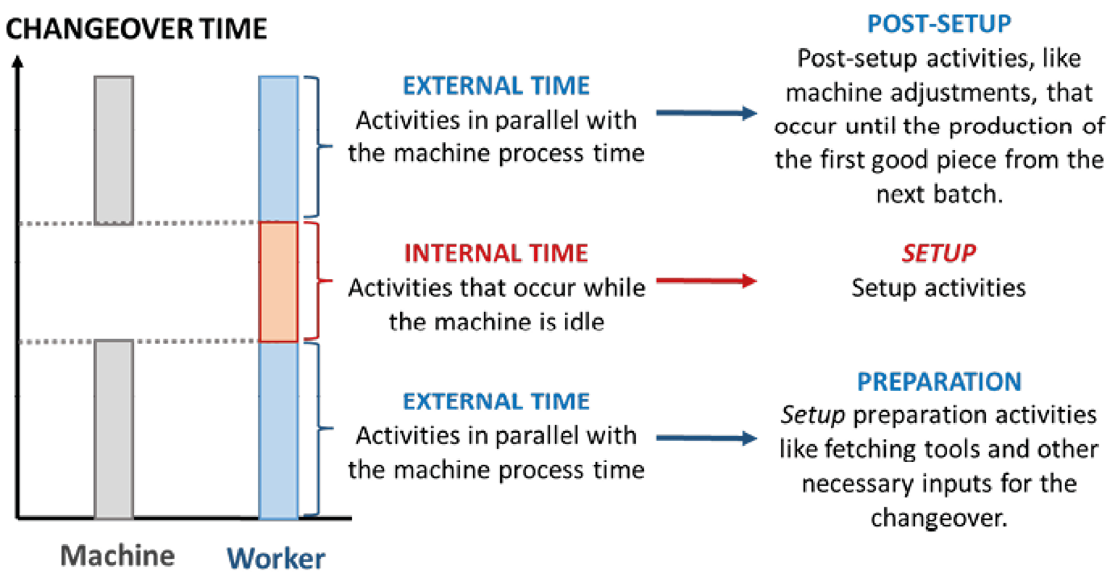


Figure 7.6 – Changeover time: Internal and external activities

Therefore, considering the changeover time, INTERNAL ACTIVITIES are those that MUST be carried out while the MACHINE IS IDLE, and EXTERNAL ACTIVITIES are the activities that CAN be carried out while the MACHINE IS RUNNING (Figure 7.6).

Thus, external activities include preparation tasks that precede the changeover and can be performed in parallel with the machine cycle, such as fetching tools and other necessary inputs. In addition, external activities after setup, such as machine adjustments, may lead to quality losses. For this reason, changeover time should be analyzed through the production of the first good piece in the next batch.

Step 2 – Separate external from internal activities

After identifying internal and external activities, they should be grouped accordingly. Internal activities will be grouped when the machine is idle, and external activities will be grouped before the machine is stopped or after it is restarted. That is, if there are tasks that occurred while the machine was idle but could have been "anticipated" and carried out in parallel with the equipment's operation, they should be reallocated to this more favorable moment.

Step 3 – Convert internal into external activities

The third step essentially consists of transforming internal activities into external ones. This can be achieved by organizing tool changes, preparation, resource supply, and the procurement of spare materials.

This crucial step represents a great time-saving opportunity during the changeover. Its estimated gains can exceed 30% in reduction of changeover time.

For example, the SMED technique was applied in a project to reduce the lead time for executing preventive maintenance for agricultural machines. One of the actions that led to the most significant gains in reducing this time was the acquisition of additional filters. This allowed the previously performed filter-cleaning operation during preventive maintenance (an internal activity) to be converted into an external activity. Thus, the spare filter remains clean, and during preventive maintenance, it is sufficient to replace the dirty one with the clean spare. At an appropriate moment after this maintenance, the dirty filter will be washed and kept in reserve for the next maintenance, so that it can replace another dirty filter.

Step 4 – Reduce the internal time

The next opportunity lies in reducing the time spent on internal activities, particularly those that must be performed while the machine is idle. It is advisable to investigate reports that may indicate causes of delays in previous changeovers, as they can provide clues about potential improvement opportunities.

Step 5 – Reduce the external time

This step focuses on reducing the time required for activities that can be performed in parallel with the machine cycle.

The five steps of SMED are represented in Figure 7.7.

After performing SMED, it is recommended to carry out the changeover with the actions already implemented and measure the new time achieved. As in any improvement project, standards should be reviewed, training conducted based on these updates, and the results monitored. Visual standards should be used whenever possible, and periodic audits should be conducted against these standards to ensure results are sustained.

Cycle time optimization at a workstation (Single Minute Cycle Time – SMCT)

The same SMED logic can be applied to reduce cycle time at a workstation. The only caution is to note that, in this case, the distinction between internal and external activities is slightly different, since internal activities occur in parallel with the machine cycle, as shown in Figure 7.5. In SMED changeovers, internal activities occur while the machine is idle.

Therefore, to optimize a workstation's cycle time, we will also follow five steps, as presented in Figure 7.8.

Step 1 – Identify internal and external activities

In this case, the concept is slightly different. INTERNAL ACTIVITIES are those that CAN be performed while the MACHINE IS PROCESSING. In contrast, external activities refer to activities that MUST be carried out while the MACHINE IS IDLE, such as during machine loading and part removal (Figure 7.5).

Step 2 – Separate internal from external activities

After identifying internal and external activities, they should be grouped in the second step of SMED. In this case, internal activities will be grouped in parallel with the machine's process time, while external activities will be grouped during idle periods. That is, if tasks occur while the machine is idle but could be "anticipated" and performed in parallel with the equipment's operation, they should be relocated to this more favorable moment.

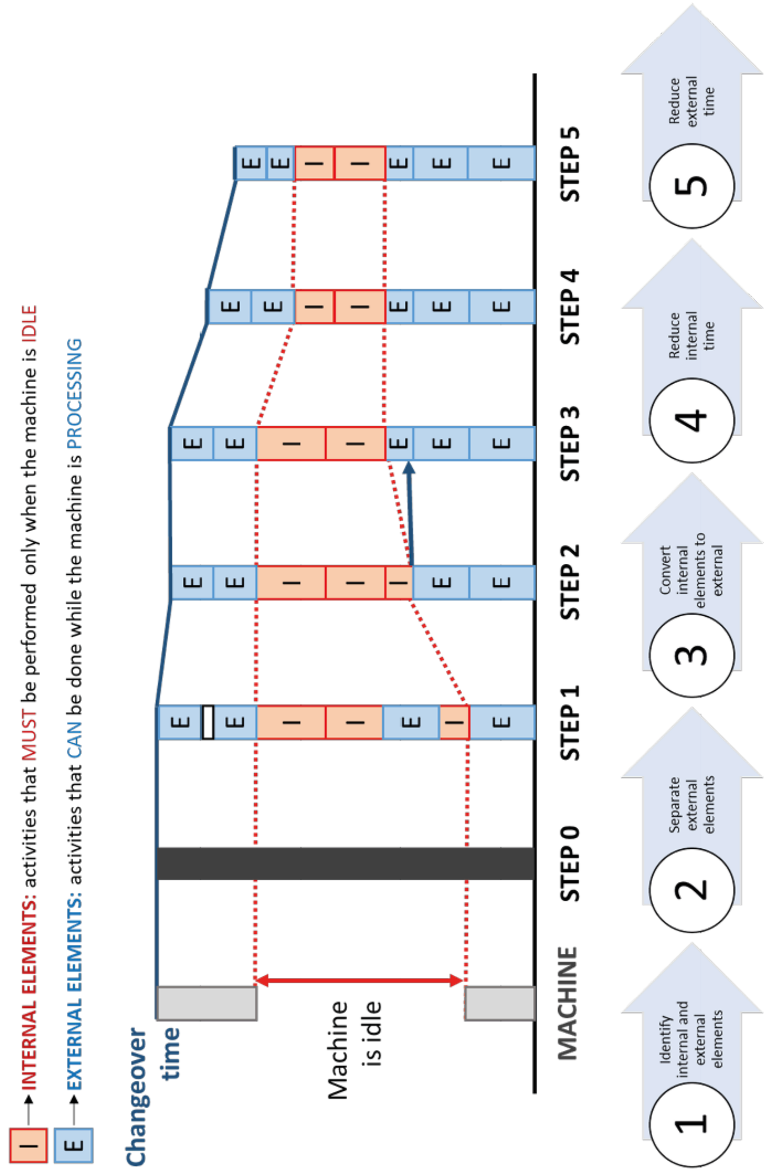


Figure 7.7 – Single Minute Exchange of Die (SMED) steps

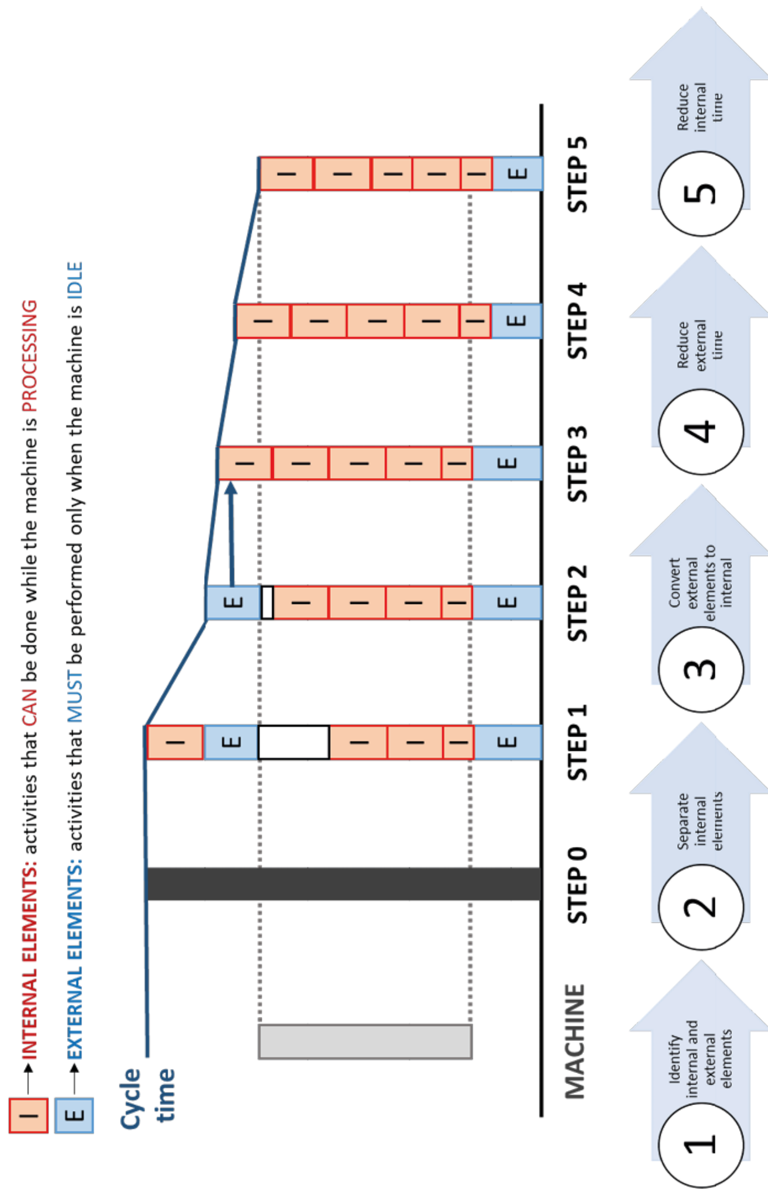


Figure 7.8 – Single Minute Cycle Time (SMCT) steps

Step 3 – Convert external into internal activities

This step is somewhat different from SMED. During a changeover or cycle, one should continuously optimize activities while the machine is running to keep the changeover or cycle time as short as possible. That is why internal activities are converted into external ones in the third step of SMED. However, in the case of cycle time reduction, external activities should be converted into internal ones. Notice that in both cases, the goal is to make the operator work as much as possible in parallel with the machine, and to minimize the machine idle time, whether during a changeover or during the cycle time.

Step 4 – Reduce the external time

When the goal is to optimize cycle time, external activities must be reduced before internal activities, for the same reason presented in the previous step. Priority should be given to reducing the time spent on activities that occur while the machine is idle.

Step 5 – Reduce the internal time

Finally, one should reduce activity times in parallel with the machine cycle.

TIP: USE POST-ITS

Whenever a project involves many people, it is advisable to use visual tools such as Post-its to construct activity charts and worker-machine charts (Figure 7.9). While performing the analyses in isolation on a computer may be practical and convenient, it does not foster a spirit of teamwork and continuous improvement.

Thus, one can use a wall to build a worker-machine chart, for example, during a project to reduce setup time (SMED). In this way, all team members will participate in the assembly and, consequently, will feel "owners" of the project. Furthermore, Post-Its facilitate any necessary rework. If required, you can relocate a

Post-it to the correct position.

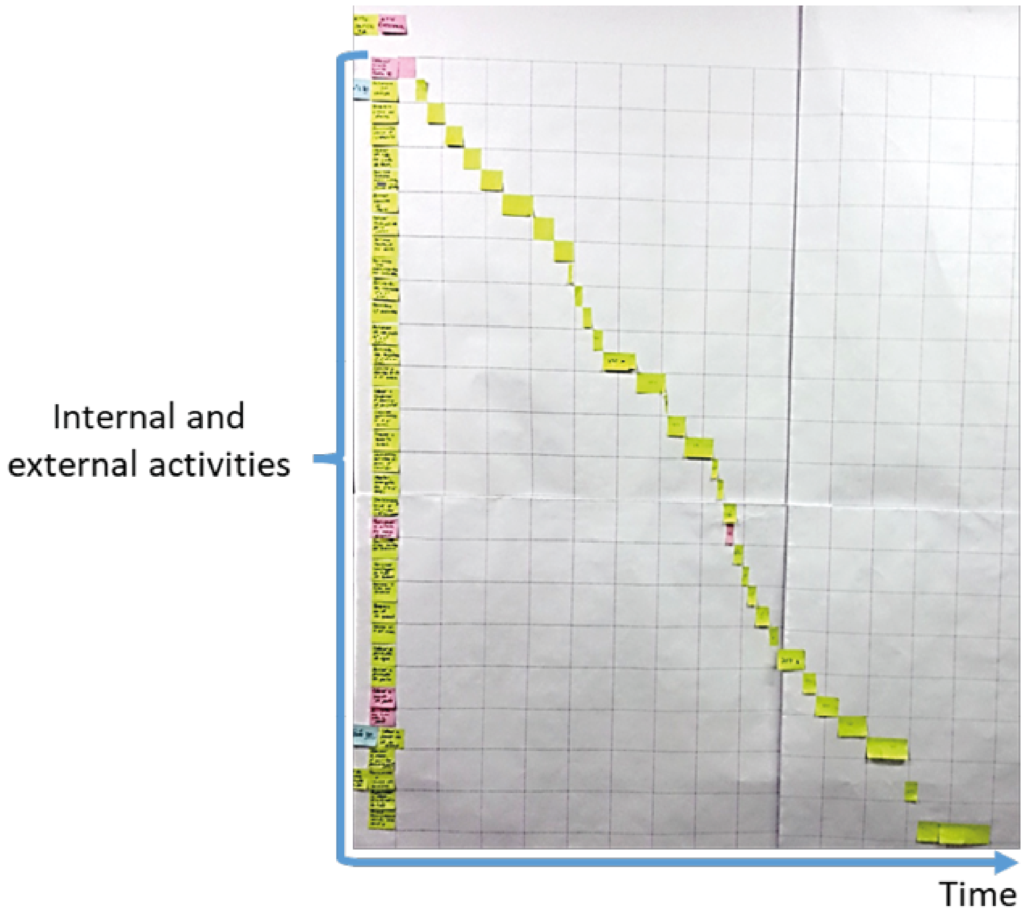


Figure 7.9 – SMED using Post-its

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CHAPTER 8: LINE BALANCING

Before the development of the assembly line, Ford built its cars (Model T, S, among others) at the Piquette plant in Detroit (Figure 8.1). There, the vehicles remained stationary while the workers carried out the manufacturing. In the past, it would not have been surprising for a single person to assemble a car.

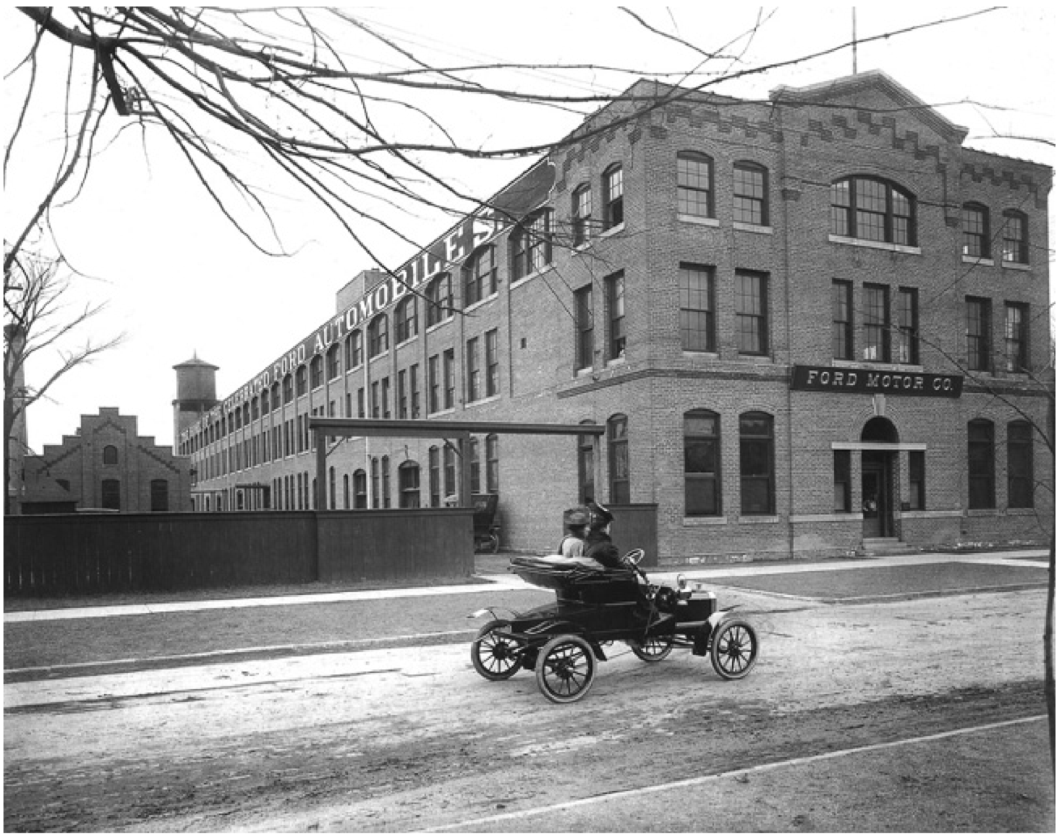

Figure 8.1 – Ford's Piquette Plant in Detroit.

From this perspective, hypothetically considering that an experienced operator, for example, worked 8 hours a day, 22 days a month, and spent 44 hours assembling a car, how many operators would be needed to meet a demand of 80 cars per month?

From the data provided, one operator would be able to assemble four cars per month:

$$Number\ of\ cars\ assembled\ per\ operator =$$

$$\frac{Planned\ production\ time}{Time\ to\ assemble\ a\ car\ per\ operator} =$$

$$\frac{8\,\frac{hours}{day} \times 22\,\frac{days}{month}}{44\,\frac{hours}{car}} =$$

$$4\ cars/operator.month$$

Therefore, to meet the demand of 80 cars per month, twenty operators would be necessary:

$$Value\ added\ ratio = \frac{Value\ added\ time}{Lead\ time}$$

In today's world, in which most automotive companies have a high demand for cars, this strategy does not prove to be very interesting, since it requires high investment in equipment, a high need for physical space, long training time for an operator to learn how to assemble a car alone, and even the difficulty of finding people with such a specific profile.

The solution to the problem was the specialization of labor, dividing work among multiple operators, and the advent of the automotive assembly line. Accordingly, the workload of building a car was divided among the operators in a balanced manner. In this way, overload and idleness among the operators were avoided, and all could work simultaneously, preventing bottlenecks and optimizing the process's value-added percentage.

Sharing tasks among operators often results in idle time, creating an unbalanced line. Figure 8.2 shows an unbalanced line in which the times at each station differ significantly. In this case, the production pace will be dictated by the slowest operator (the bottleneck), that is, the workstation with the highest cycle time, which in this figure is operator 3.

Line balancing aims to achieve a better balance of workload between workers and equipment. Consequently, it introduces a more uniform production flow.

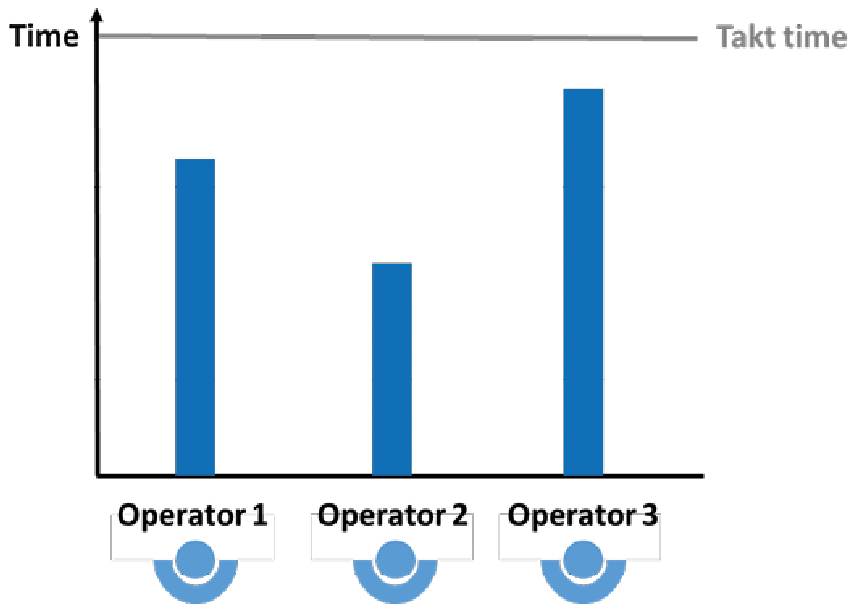

Figure 8.2 – Unbalanced line

A balanced production line is represented in Figure 8.3. This figure shows that the time spent at any workstation is nearly equal to that at the others. In other words, the activity time is better balanced across these stations to meet the required production rate, calculated using the takt time (as presented in Chapter 6). On the other hand, the production rate determines the optimal number of workers to assign to a workstation.

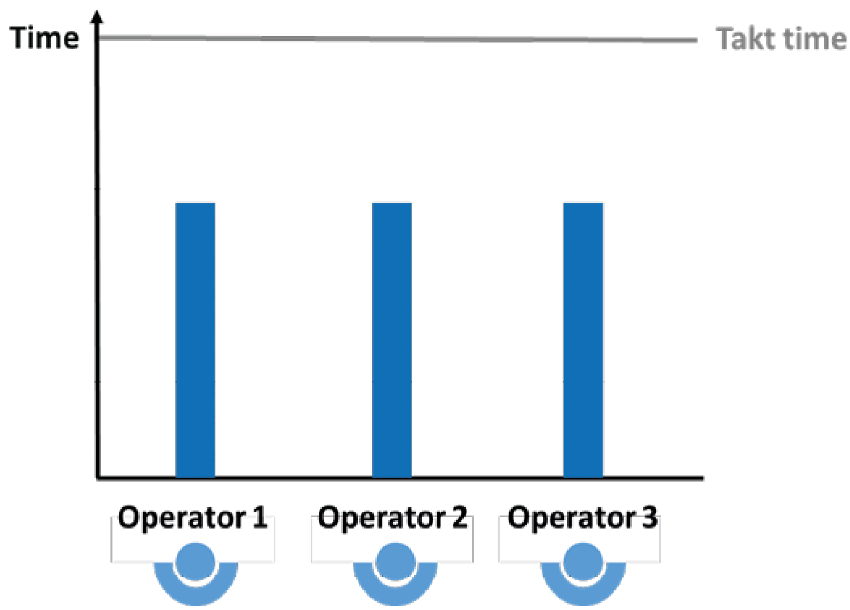

Figure 8.3 – Balanced line

Thus, line balancing involves determining the ideal number of workers to assign to a production line or workstation and allocating tasks or work elements to each operator to achieve the highest possible operational efficiency. This is the subject of the present chapter.

In addition to adjusting the number of operators and defining the task allocation for each of them, line balancing can also be carried out through:

- Acquisition of additional machines for the slowest jobs.
- Stockpiling of materials.
- Increasing feeds and speed.
- Method improvements.
- Adjustment of line speed.
- Subcontracting and outsourcing.

Some considerations must be made when performing line balancing through the adjustment of the number of operators:

- Tasks or element times are indivisible.
- The takt time of the line is the maximum possible time for a work

element to meet customer demand.

- The work method is fixed.
- Element times can be achieved even by slower operators.
- The learning curve—mathematical representations used to verify workers' performance when subjected to repetitive tasks—is disregarded.
- The sum of the element times is the total cycle time of a workstation.
- Precedence rules must be maintained.

In other words, line balancing should be performed when the process is in its ideal state. One should not complete line balancing until task times are improved or their precedence rules are changed. If such opportunities are identified, improvements should be made before line balancing.

Once the process is properly standardized and free of special causes that affect its variability, line balancing can be carried out using the step-by-step procedure described below.

8.1 Step-by-step of line balancing

Figure 8.4 briefly presents this step-by-step process, which is detailed below.

Step 1 – Organization of required information

At this stage, the necessary information for the subsequent steps of the balancing process will be collected and organized, such as:

- Descriptions and times of work elements (tasks).
- Precedence diagram.
- Shipping volume (demand).
- Total available production time (overall department efficiency, equipment availability, number of working days, work shifts, and hours per shift).

Step 2 – Calculation of takt time

Depending on the data available, takt time can be calculated in two ways:

Option 1: Calculation of takt time through the desired line speed

The first option is to use the line speed to calculate takt time. Line speed can be calculated using the following formula:

$$Line\ speed = \frac{Shipping\ volume}{Efficiency}$$

For example, if a pizzeria must produce five pizzas per hour and its efficiency is 83%, the line speed will be:

$$Line\ speed = \frac{5\ pizzas}{0.83} \rightarrow 6\ pizzas\ per\ hour$$

That is, it will be necessary to produce more pizzas than customer demand, since inefficiencies, such as quality losses, require some units to be discarded.

Figure 8.4 – Step-by-step procedure for line balancing

Next, the takt time is calculated:

$$Takt\ time = \frac{1}{Line\ speed} = \frac{1}{6\ pizzas\ per\ hour}$$

$$= 0.167\ hour\ per\ pizza$$

By converting the obtained value to minutes per pizza, we have:

$$0.167 \frac{hour}{pizza} x\ 60 \frac{minutes}{hour} = 10\ minutes\ per\ pizza$$

Thus, the takt time is 10 minutes per pizza. In other words, one pizza should be completed every 10 minutes.

Option 2: Direct calculation using takt time

In the second approach, it is not necessary to calculate the line speed, and the takt time can be determined directly using the formula presented in Chapter 6.

$$0.167 \frac{hour}{pizza} x\ 60 \frac{minutes}{hour} = 10\ minutes\ per\ pizza$$

For example, if the monthly demand is 10,000 pizzas and the establishment operates 100,000 minutes per month, the takt time will be:

$$Takt\ time = \frac{100{,}000\ minutes\ per\ month}{10{,}000\ pizzas\ per\ month} = 10\ minutes\ per\ pizza$$

Step 3 – Determine the optimum number of operators

The optimal number of operators will be the larger value between the following two calculations:

- Calculation:

$$Value\ added\ ratio = \frac{Value\ added\ time}{Lead\ time}$$

- Calculation 2: Counting the number of elements whose element time is greater than half of the takt time.

Considering, for example, 10 element times (in minutes): 1, 2, 3, 4, 5, 6, 7, 8, 9, and 10. Therefore, the Minutes. Given this information and a Takt Time of 10 minutes, we will proceed with two calculations to determine which is greater. Thus, we have:

- Calculation 1:

$$Optimum\ number\ of\ operators = \frac{\sum Element\ Times}{Takt\ Time} =$$

$$\frac{55}{10} = 5.5 \rightarrow 6\ operators$$

Since we cannot divide an operator in half, this value is rounded up. Calculation 1 thus yields six operators.

- Calculation 2:

Five elements have a time greater than half of the Takt Time (5 minutes). The task elements that exceed 5 minutes are: 6, 7, 8, 9, 10.

Next, we must choose the greater value obtained from calculations 1 and 2:

- **Calculation 1 = 6 people**
- Calculation 2 = 5 people

Therefore, the final number of operators to be allocated is six.

Step 4 – Calculation of the Gross Potential Efficiency (GPE)

The Gross Potential Efficiency (GPE) can be calculated using the following formula:

$$Gross\ Potential\ Efficiency = \frac{\sum Element\ Times}{(Takt\ Time) \times (Optimum\ number\ of\ operators)}$$

For the example presented in step 3, we have:

$$0.167 \frac{hour}{pizza} x\ 60 \frac{minutes}{hour} = 10\ minutes\ per\ pizza$$

Step 5 – Line Balancing

At this stage, based on the task times shown in the precedence diagram, tasks must be grouped and assigned to each workstation. During the grouping process, two guidelines must be followed:

- The number of groups must equal the optimum number of operators calculated in Step 3. After all, each group corresponds to the tasks assigned to each operator. If the number of groups is lower than the value calculated in Step 4, the balance efficiency will be compromised.
- The sum of the assigned task times for each workstation must not exceed the takt time calculated in Step 2. Otherwise, the customer demand will not be met.

It is important to note that both mathematical models (such as operations research and simulation) and heuristic models can be used for line balancing.

Table 8.1 presents the type of model to use based on the problem's complexity and randomness level.

PROBLEM COMPLEXITY	**High**	Heuristic and Metaheuristic Models	Simulation Models
	Low	Linear Programming Models	Stochastic Models
		Low	**High**
		RANDOMNESS LEVEL	

Table 8.1 – Models to be used according to problem complexity and randomness

Although they do not provide "optimal solutions," heuristic methods yield satisfactory results with acceptable computational times.

Several heuristics can be used to allocate tasks to each workstation. The decision rule for choosing the sequence of tasks to be grouped can be based on the following:

- Longest Operation Time: Prioritizes the candidate task with the longest operation time. The objective is to allocate the most demanding tasks first, with shorter-duration tasks receiving secondary priority.
- Shortest Operation Time: The opposite of the longest operation time rule, giving preference to allocating workstations that include the shortest tasks.
- Most Following Tasks (Most Followers): Selects first the candidate with the highest number of subsequent tasks according to the precedence diagram. For example, in Figure 8.5, item G has only one following task (H), while item D has four following tasks (E, F, G, and H). This rule aims to maintain flexibility, ensuring that good options remain available for allocating the last workstations.
- Fewest Following Tasks (Fewest Followers): The opposite strategy to the most following tasks, where the candidate with the fewest subsequent tasks is chosen first.
- Ranked Positional Weight: The positional weight of an operation is determined by its position in the precedence diagram, calculated as the sum of the times of all subsequent operations. Given a takt time, the elements are assigned to stations in descending order of their positional weight.

These heuristics are discussed in detail in books by Gaither and Frazier, as well as by Krajewski, Ritzman, and Malhotra.

There are software tools, such as QM for Windows, that automatically generate results for all these heuristics. However, it is worth emphasizing that the goal of this book is to actively engage students in line balancing and to develop their critical thinking, regardless of the strategy they choose, rather than passively receive results from software.

This is a key skill for future engineers, since even minor improvements in the production line can lead to a more efficient balance.

Step 6 – Calculation of Actual Efficiency (AE)

Based on the actual number of operators resulting from the line balancing performed in Step 5, we can calculate the Actual Efficiency (AE):

$$Actual\ Efficiency = \frac{\sum Element\ Times}{(Takt\ Time) \times (Actual\ Number\ of\ Operators)}$$

By comparing the Actual Efficiency (AE) with the Gross Potential Efficiency (GPE) calculated in Step 5, we can draw the following conclusions:

- If Actual Efficiency (AE) = Gross Potential Efficiency (GPE): The best possible balance has been achieved for a given line speed.
- If Actual Efficiency (AE) < Gross Potential Efficiency (GPE): Further analysis is needed to improve the balance.

If AE < GPE, there are potential solutions:

- Task reallocation: Check whether tasks can be reassigned to other workstations to achieve a better balance.
- Improvement of work methods: For example, by eliminating waste and acquiring more reliable equipment.
- Use of standardized buffers with a small number of parts between workstations.
- Adjustment of line speed: If it is possible to reduce line speed without affecting production volume, a better cost per piece can be achieved with a more balanced line.
- Task sharing between workstations.

- Allocation of multiple workstations: This strategy is helpful for bottlenecks or tasks with high cycle times.
- Break down tasks that appear to be indivisible.
- Allocation of additional shifts or overtime: Utilizing workers outside their regular hours to produce parts to meet demand.

8.2 Example (adapted from ENADE 2017 – Industrial Engineering)

The step-by-step process described will be illustrated through a question from the 2017 Brazilian National Student Performance Exam (Exame Nacional de Desempenho dos Estudantes-ENADE) for the Industrial Engineering program.

A company produces integrated electronic circuits on a single eight-hour work shift per day. This company needs to produce 1,200 units per month within 25 business days. Each unit produced (electronic circuit) undergoes eight tasks during its assembly line, as shown in Table 8.2. The same table also presents the task durations (in minutes) and precedence relationships.

TASK	DESCRIPTION	TIME	Predecessors
A	To receive the products and release the cables	6	-
B	To position the cables and fasteners contiguously	4	A
C	To insert the fasteners into the	3	B

	differentiation terminals		
D	To apply a coating to the component fastener	5	C
E	To assemble the base and to position the components	4	D
F	To secure the protective grounding conductors	5	D
G	To sand the base and apply adhesives	2	E, F
H	To secure components to the base and to remove burrs	1	G

Table 8.2 – Assembly Line Balancing Example

Step 1 – Organization of required information

Construction of the Task Precedence Diagram (Figure 8.5):

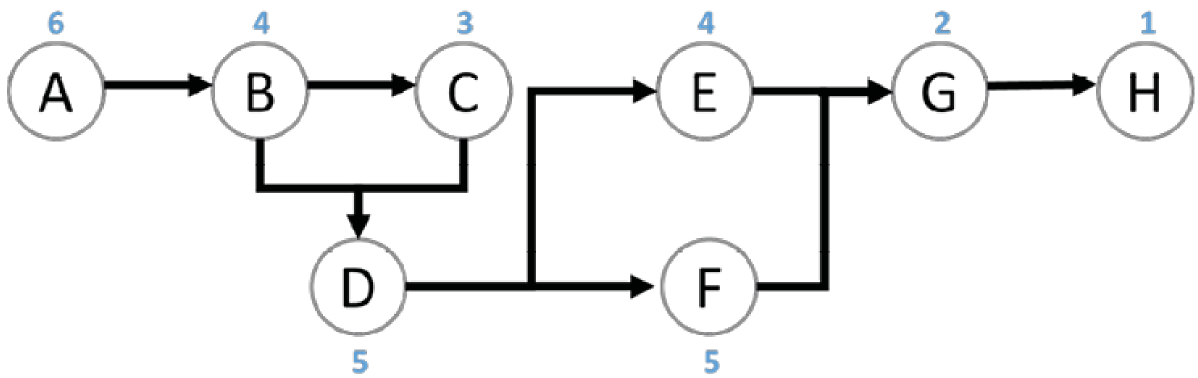

Figure 8.5 – Task precedence diagram

Variables provided in the problem:

- Monthly demand: 1,200 units.
- Number of working days: 25 working days per month.
- Number of work shifts: 1 shift per day.
- Number of hours per shift: 8 hours per shift.
- Sum of element times: 6 + 4 + 3 + 5 + 4 + 5 + 2 + 1 = 30 minutes.

Step 2 – Calculation of takt time (in minutes per unit produced):

$$Takt\ time = \frac{Available\ production\ time\ per\ month}{Monthly\ demand} =$$

$$\frac{\#\ of\ working\ days/month \times \#\ of\ shifts/day \times \#\ of\ hours/shift}{Monthly\ demand} =$$

$$\frac{25\ days/month \times 1\ shift/day \times 8\ hours/shift}{1{,}200\ pieces/month} =$$

$$Takt\ time = 10\ minutes\ per\ piece$$

The problem provides the necessary data to calculate the takt time. This means the company must spend at most 10 minutes producing each piece.

Step 3 – Determine optimum number of operators

- Calculation 1:

$$Optimum\ number\ of\ operators = \frac{\sum Element\ Times}{Takt\ Time} =$$

$$\frac{30}{10} = 3\ operators$$

- Calculation 2:

Just task A has a time greater than half of the Takt Time of 5 minutes (Figure 8.5).

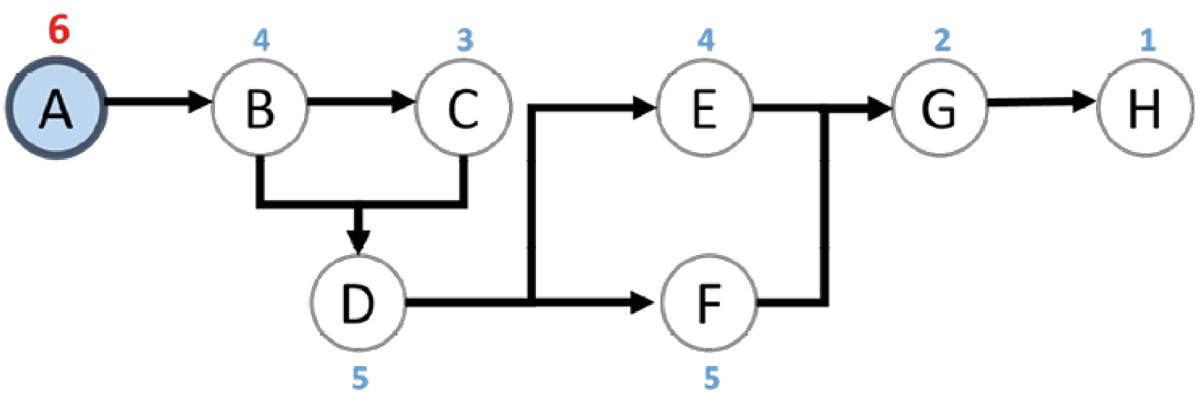

Figure 8.6 – Tasks with processing time greater than 5 minutes

Next, the highest value obtained from calculations 1 and 2 must be selected:

Next, we must choose the greater value obtained from calculations 1 and 2:

- **Calculation 1 = 3 operators.**
- Calculation 2 = 1 operator.

Therefore, the final number of operators to be allocated is three.

Step 4 – Calculation of the Gross Potential Efficiency (GPE)

The Gross Potential Efficiency (GPE) can be calculated using the following formula:

$$Gross\ Potential\ Efficiency = \frac{\sum Element\ Times}{(Takt\ Time) \times (Optimum\ number\ of\ operators)} =$$

$$Gross\ Potential\ Efficiency = \frac{30}{10 \times 3} = 1 \rightarrow 100\%$$

Step 5 – Line Balancing

In Step 4, we concluded that the optimal number of operators is three. Therefore, the tasks should be grouped into three sets, each assigned to one of the three operators (Figure 8.7). Furthermore, the total time of the grouped tasks must not exceed the calculated takt time of 10 minutes.

It should be noted that this "optimal" balancing assumes that non-sequential tasks can be grouped. However, when constraints require tasks to be allocated sequentially to operators, these assumptions must be taken into account during the balancing process. As a result, the actual efficiency will be lower than the total potential efficiency until improvements are implemented to enable the system to reach its full potential efficiency.

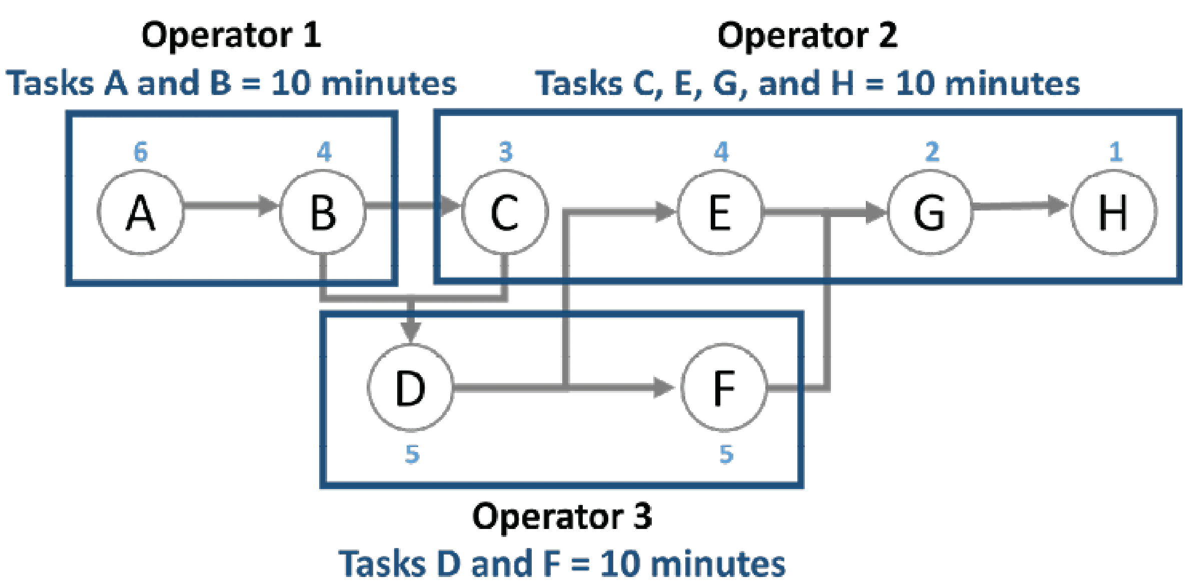

Figure 8.7 – Line Balancing

At this point, you might wonder: how would it be possible to allocate these tasks in a non-sequential manner? In such cases, a simple solution would be to work with standardized intermediate inventories (WIP) of a single piece between specific workstations (Figure 8.8 and Table 8.3). This improvement allows non-sequential tasks to be handled sequentially and synchronizes those stations.

Another critical point is that we assume task times to be fixed. However, it is essential to emphasize that, in practice, these times exhibit some randomness and can be modeled by probability distributions. If high variability in task times is observed, Six Sigma or lean projects can be initiated to mitigate this variability.

However, suppose such variability cannot be reduced to an acceptable level, thereby preventing balancing in accordance with the heuristics suggested in this book. In that case, it is recommended to use simulation models to balance the process. These models can be developed using software such as Arena or Promodel.

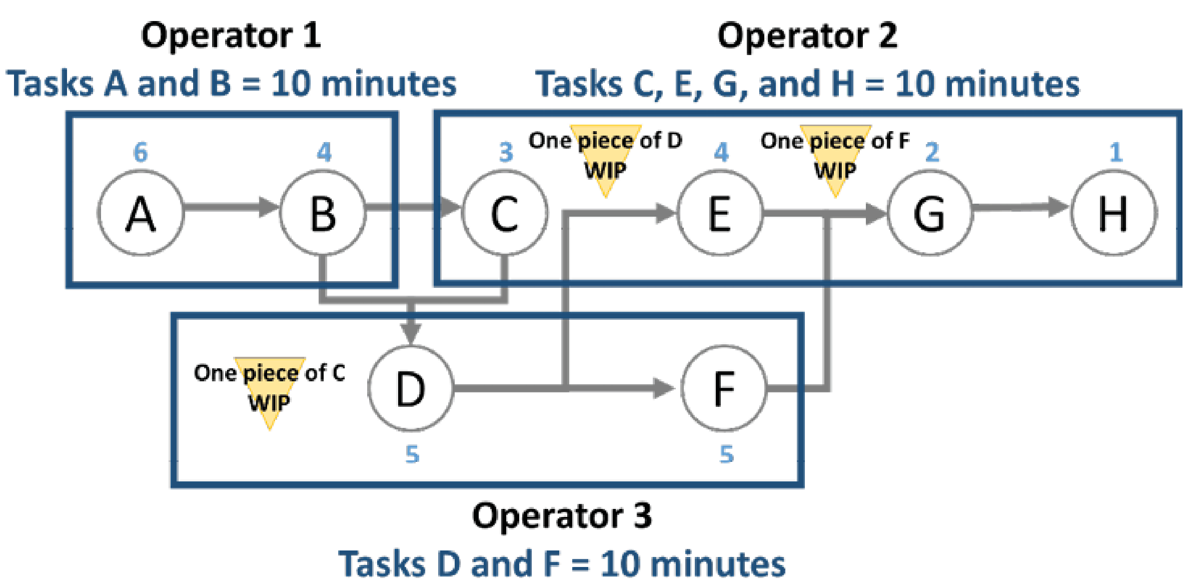

Figure 8.8 – WIP to enable the balancing of non-sequential task lines

TIME (IN	TASK BEING EXECUTED			DESCRIPTIO

MIN)	Op1	Op2	Op3	N
0	A	C	D	Operator 1 (Op1) begins task A Operator 2 (Op2) begins task C Operator 3 (Op3) begins task D
3	A	E	D	Op2 ends task C and begins E
5	A	E	F	Op3 ends task D and begins F
6	B	E	F	Op1 ends task A and begins B
7	B	G	F	Op2 ends task E and begins G
9	B	H	F	Op2 ends task G and begins H
10	The end	The end	The end	Op1 ends

				task B Op2 ends task H Op3 ends task F

Table 8.3 – Chronological description of task execution by operators within a work cycle

Step 6 – Calculation of Actual Efficiency (AE)

$$Actual\ Efficiency = \frac{\sum Element\ Times}{(Takt\ Time) \times (Actual\ Number\ of\ Operators)}$$

$$Actual\ Efficiency = \frac{30}{10 \times 3} = 1 \rightarrow 100\% = GPE$$

Since AE = GPE, the best balance was achieved. It is worth noting, however, that other solutions to this same example would also allow the formation of three task groupings of 10 minutes each. The solution presented was chosen for didactic purposes.

8.3 Yamazumi

Figure 8.9 – Yamazumi built with Post-its

Whenever possible, tools that facilitate visual representation of line balancing, such as yamazumi boards, may also be used. Yamazumi is the Japanese term for "stack" or "pile." Essentially, a yamazumi chart is a stacked bar chart (Figure 8.9). It can be constructed using differently colored Post-it notes to facilitate the identification of wastes that represent improvement opportunities at a given workstation. In line balancing, Post-its are particularly useful because they encourage teamwork and facilitate the creation of alternative scenarios by transferring tasks among operators.

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Softwares

Arena – https://www.arenasimulation.com/
Promodel – http://www.belge.com.br/promodel.php
QM for Windows – Free Software

UNIT 3

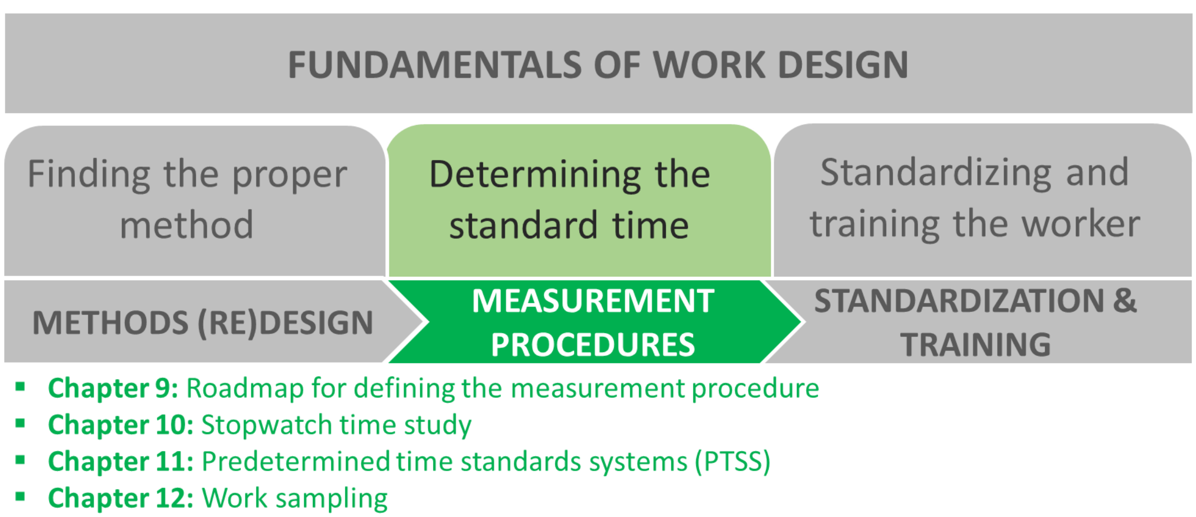
WORK MEASUREMENT PROCEDURES

- Roadmap for defining the measurement procedure
- Stopwatch time study
- Predetermined time standards systems (PTSS)
- Work sampling

UNIT 3: WORK MEASUREMENT PROCEDURES

After defining the proper method, the next step is to determine the standard time. In this unit, the work measurement procedures will be presented, divided into four chapters:

- Chapter 9: Roadmap for defining the measurement procedure – presents the guidelines to define the best work measurement procedure to use for a given problem.
- Chapter 10: Stopwatch time study – uses a stopwatch and statistical techniques to determine the standard time of an operation.
- Chapter 11: Predetermined time standards systems (PTSS) – uses predetermined time systems to predict standard times based on movement patterns.
- Chapter 12: Work sampling – a method for analyzing work using a checklist of activities that constitute a job and taking many observations at random times.



CHAPTER 9: ROADMAP FOR DEFINING THE MEASUREMENT PROCEDURE

This chapter aims to provide guidelines for selecting the appropriate work measurement procedure: stopwatch time study, predetermined time standards systems (PTSS), or work sampling.

In this regard, it is important to emphasize that whenever a motion and time study is conducted, a systematic problem-solving methodology, such as PDCA or DMAIC, should be followed. Planning, in particular, is a key phase, as it determines the most appropriate time-measurement procedure for the specific problem at hand.

The selection of the measurement procedure should therefore be understood as a natural consequence of the problem to be addressed. Thus, one must first understand the cost-benefit relationship inherent to the issue (Figure 9.1).

Figure 9.1 – Cost-benefit relationship in work measurement

Regarding the expected benefits of the study, the following questions should be considered:

- What level of accuracy is required for the data to be collected? What level of precision can this motion and time study realistically achieve, given our constraints?

- What is the intended impact? Is the objective a localized improvement or a broader organizational change? Are the expected outcomes significant enough to justify the investment?
- How sustainable are the results we aim to achieve? Will the results be maintained over time, or will they require constant reassessment?

Conversely, the costs of solving the problem must also be assessed, as it is not always feasible to allocate all the resources required to conduct a study. Regarding these costs, we must ask ourselves:

We must also consider the following guiding questions:

- How many people can we allocate to carry out this project? → Human resource cost
- What is the time horizon for achieving our objective—short, medium, or long term? How much time is available to conduct the study? → Time cost
- How many workstations and product families will need to be analyzed? → Scope of the study
- How much funding can we invest in this project? → Financial costs

It is important to emphasize that, in many cases, there is a directly proportional relationship between the costs incurred and the benefits obtained. In other words, if the goal is to achieve highly precise, sustainable results that encompass multiple processes across the organization, the associated costs will likely be high. We will need a larger team, the project will have a longer duration, and, consequently, it will require greater financial investment.

Thus, in the end, the decision should aim to achieve the most favorable cost-benefit balance given the organization's reality.

Given the specific problem's cost-benefit relationship, the time measurement procedure should be selected based on its intrinsic characteristics, as outlined in Table 9.1. It is worth noting that these characteristics are presented for the three main procedures.

	STOPWATCH TIME STUDY	PTSS	WORK SAMPLING
Precision	**High** It uses statistical tools to determine standard times.	**High** It relies on standard tables containing predetermined times for various types of movements/operations.	**Moderate** As data are collected through sampling, precision is lower than in other methods, given the risk of not properly following the statistical assumptions or of not collecting the recommended sample size.
Costs	**Higher costs involved** A higher demand for data collection time may consequently	**Lower costs involved** As it relies on video recording, it is not necessary to collect many	**Lower costs involved** Since it involves sampling, data can be collected more quickly and inexpensively.

	require more human and financial resources for the project.	cycles. Therefore, the project can be carried out in less time, with fewer personnel, and consequently, at a lower cost.	
Critical phase for success	**Planning and data collection**	**Learning to consult the SPDT table to convert movements into standard times**	**Planning (definition of the sample and collection frequency)**
Cycle Time	**Preferably for short (greater than 4 seconds), medium, and long cycle times (attention to cost trade-offs)** Should not be used for cycle times shorter than 4 seconds, as the reaction time to operate the stopwatch may increase	**PTSS can be applied to short, medium, and long cycle times; the consulted table will vary accordingly** This is the most suitable method for very short cycle times, as the necessary movements are converted into standard times.	**Recommended for medium and extended cycle times** If the cycle time is short, it is advisable to use a more precise measurement method, such as time study or a predetermined time system.

	variability in the collected data. It can also be used for long cycle times, though data collection and analysis will be more labor-intensive.		
Training	**Requires prior training, primarily in data collection** When multiple individuals are involved in data collection, it is crucial to conduct several training sessions and ensure that data collection instruments are well standardized to avoid biased data.	**Requires prior training, mainly in learning the PTSS table** The highest cost of this procedure is the time required to learn to use the tool. Initially, users will take longer to apply it, but with experience, the process becomes increasingly faster.	**Requires less training, which is also faster** As it is a more straightforward procedure, there is a reduced need for training, and sessions can be shorter and more efficient.

Table 9.1 – Comparison of work measurement procedures based on their cost-benefit relationships

Therefore, the characteristics of these procedures alone do not determine which one should be used. As previously mentioned, they must be weighed against the intended benefits and the costs associated with the specific problem.

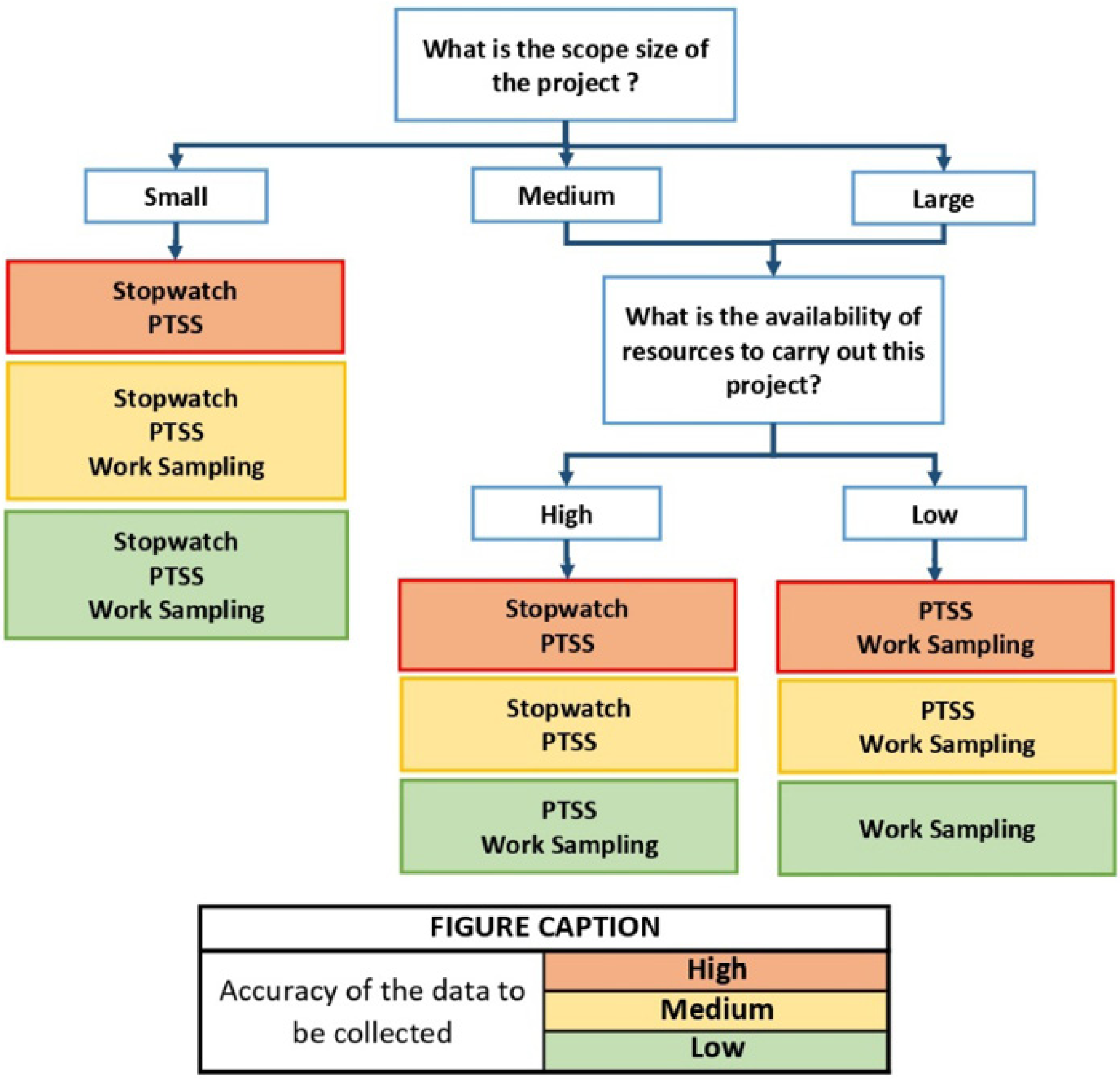


Figure 9.2 – Decision flowchart for selecting the work measurement procedure

Figure 9.2 presents a decision flowchart to aid in selecting the appropriate measurement procedure. Note that, in the end, more than one type of measurement procedure may be recommended for a given combination of data accuracy, scope size, and resource availability.

Suppose it is possible to use more than one measurement procedure, as indicated by the problem's cost–benefit flowchart. In that case, other factors may be considered, such as the cycle time of the operation under analysis relative to the production volume (Table 9.2).

Note in this table that when the cycle time is very long, it may also be appropriate to use historical data and consult subject-matter experts, or even the equipment manufacturer, to obtain benchmarking information or to understand the time parameters under study.

Furthermore, it is crucial to consider other characteristics of these procedures, as discussed in Table 9.1. For instance, if the objective is to understand the variability of work elements, time study (stopwatch timing) becomes the preferred method.

	VOLUME OF PRODUCTION		
CYCLE TIME	**High (1,000 sec.)**	**Medium (100 sec.)**	**Low (10 sec.)**
Long	Work sampling	Work sampling Stopwatch	Expert Opinion Work sampling Historical data
Medium	Work sampling Stopwatch PTSS	Stopwatch Work sampling	Expert Opinion Historical data Stopwatch
Short	PTSS	PTSS Stopwatch	Stopwatch Expert Opinion

Table 9.2 – Which time standards technique do we use, considering the cycle time and the volume of production?

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CHAPTER 10: STOPWATCH TIME STUDY

The time study, through direct timing of operations, is a method used to determine a fair day's work. And what would be a fair day's work?

> **Fair day's work**: The amount of work produced by a **qualified employee** when working at a **normal pace** and **effectively utilizing time** when process limitations do not restrict the work.

As can be seen, it is not such a simple definition. After all, what can we consider as a qualified operator? What is a normal pace? How do we know if we are using our work time effectively?

> **Qualified employee**: Operator, already properly trained in the task, who can perform it without becoming fatigued and without interference from the learning curve.
>
> **Normal pace**: The operating pace should not pose risks to quality, safety, or worker fatigue over time.
>
> **Effective use of time**: To use time effectively is to operate without unplanned rest breaks.

Beyond these conceptual issues of the time study definition, it is essential to highlight that it can be carried out for a wide variety of objectives:

- Establishment of standards.
- Planning: Determination of the need for personnel allocation, calculation of equipment capacity, and planning of workstation and process layout.
- Operator evaluation: Monitoring the employee's development.
- Cost estimation and budget control: Calculation of personnel costs and development of financial reports.

- Cost reduction: Improvements in methods, tools, and working conditions; estimation of personnel cost reduction; and evaluation of employee suggestions.

It is also worth noting that time studies can be conducted in both industrial and service-oriented organizations. In industrial environments, activities are typically more fragmented, allowing the collection of many short-duration cycles with low variability in their work elements. In contrast, in service contexts, the duration of a single work element can often be quite long, limiting the number of observable cycles. Furthermore, due to the high degree of subjectivity inherent in service delivery, the decision-making flow tends to be more complex, with greater variation in its components.

For didactic purposes, this chapter is therefore divided according to two strategies corresponding to two contrasting realities:

- Time studies in industries.
- Time studies in services.

It is important to emphasize that the distinction between product and service is not discrete but continuous. Consequently, there may be situations in which, although the context is industrial, it is more appropriate to apply the strategy described in the section "Time Studies in Services," and vice versa. Therefore, when selecting the most suitable strategy, it is advisable to consider factors such as cycle time, variability of work elements, and degree of subjectivity, among others.

10.1 Stopwatch time studies in industries

Regardless of the specific objective, a time study in an industrial setting can be conducted following the steps below:

Step 1 – Problem definition

The first step in any work measurement procedure is to understand and define the problem in collaboration with key stakeholders.

Once the problem is clearly defined, data should be collected to identify the workstation or operation to be studied. The flow analysis methods described in Chapter 6 can be employed at this stage to examine the activities and their sequence.

In many cases, managers present requests that, upon preliminary analysis, reveal the need to extend the study to other areas or even to redefine its focus.

In addition to selecting the workstations and activities, it is also important to determine which products will be analyzed. If the project scope is broad, it is advisable to work with product families that have similar processing times. If the study is conducted solely on a few high-volume products, any variation in the production mix may compromise its validity. It is therefore necessary to adopt an appropriate time horizon aligned with the problem's characteristics.

Step 2 – Study of the operation to be analyzed

Before initiating a time study, it is essential to gather the available data and thoroughly understand the activities to be evaluated, as well as the workflow in which they are embedded.

Some useful starting points for developing time standards include:

- Experts' estimates.
- Historical data indicating how long an activity has taken, though not necessarily how long it should take.
- Benchmarking, i.e., reference standards from other companies or from the equipment manufacturer.

Step 3 – Stakeholder communication and project team definition

Once the study's scope has been defined, it is crucial to ensure all stakeholders are properly informed. Many time studies are hindered—or even rendered unfeasible—by poor planning and ineffective communication. Alignment should be carried out with all individuals directly or indirectly involved in the study, including:

- Area managers.
- Coordinators and engineers.
- Production leaders and supervisors.
- Operators/employees from all relevant shifts.

The scope and roles must be clearly defined to prevent potential conflicts or resistance. A significant obstacle in time studies is the failure to involve operators or the inclusion of only one shift. Since these are the individuals who actually perform the tasks, they should feel ownership over the project. Additionally, selecting only central-shift operators for the sake of convenience can be problematic. Operators from other shifts may feel excluded and may be less receptive to proposed improvements or changes in work standards.

Motion and time studies are frequently used in cost-reduction projects, which may give stakeholders the impression that the project is focused on "staff reduction." For this reason, one variable that must always be considered is the presence of the person conducting the timing itself, as this can influence the data collected.

This point is well illustrated by the research conducted by Elton Mayo at the Western Electric factory in Hawthorne, which marked the beginning of the development of the human relations school of management. The primary objective of the investigation was to examine working conditions and their relationship to productivity—and, more broadly, to identify and classify the problems present in workplace settings.

Initially, the research methodology did not differ significantly from Taylor's, with the investigators aiming to correlate workers' performance with variables such as lighting, fatigue, and rest periods. However, confusing and inconclusive results indicated that these variables could not be considered independently of the individuals' meanings, attitudes, groups, and concerns about their conditions.

In this way, it became clear that workers' behavior could not be explained solely by individual personality traits acquired outside the organization, but rather by the characteristics of the social organization within the company. The primary determinants of worker behavior should thus be sought in the structure and culture of the group that spontaneously forms within the workplace through interpersonal interactions.

From these studies, the worker ceased to be seen as an isolated psychological entity and began to be understood as part of a group, whose values and norms shape their behavior. It is essential to note, however, that Mayo's studies also had notable limitations, including an inadequate understanding of industrial relations conflicts, limitations in experimental design, an overemphasis on informal groups, and a lack of a systemic perspective.

Therefore, based on the premise that the operator should not be observed merely as an individual but as someone embedded in a broader social organization, appropriate communication before initiating a time study project can help prevent many subsequent issues. The project's final objective must be made clear. The "why" and "how" should take precedence over the "what." If the project involves cost reduction, it is crucial to emphasize that cost savings can be achieved through means other than workforce downsizing.

Firing employees after the project should be avoided whenever possible, as it may demotivate those involved and jeopardize subsequent work that may be necessary. Ideally, a culture of continuous improvement should be fostered, in which project participants are valued and encouraged to rethink and enhance their workplaces continually. If staff reduction becomes necessary, the best approach is to suspend new hiring and allow natural turnover to gradually reduce the workforce to the desired size. Another viable option is to reassign some employees to other positions.

It is important to emphasize that communication with stakeholders must remain consistent throughout the project's execution, clarifying doubts promptly to prevent misunderstandings and premature conclusions.

Step 4 – Definition of the operator to be evaluated

The operator to be evaluated should not be selected randomly or merely for convenience. Several guidelines should be considered in this selection:

- Neither the fastest nor the slowest operator should be chosen. Instead, select an operator close to the average performance (i.e., approximately 50%), as illustrated in Figure 10.1.

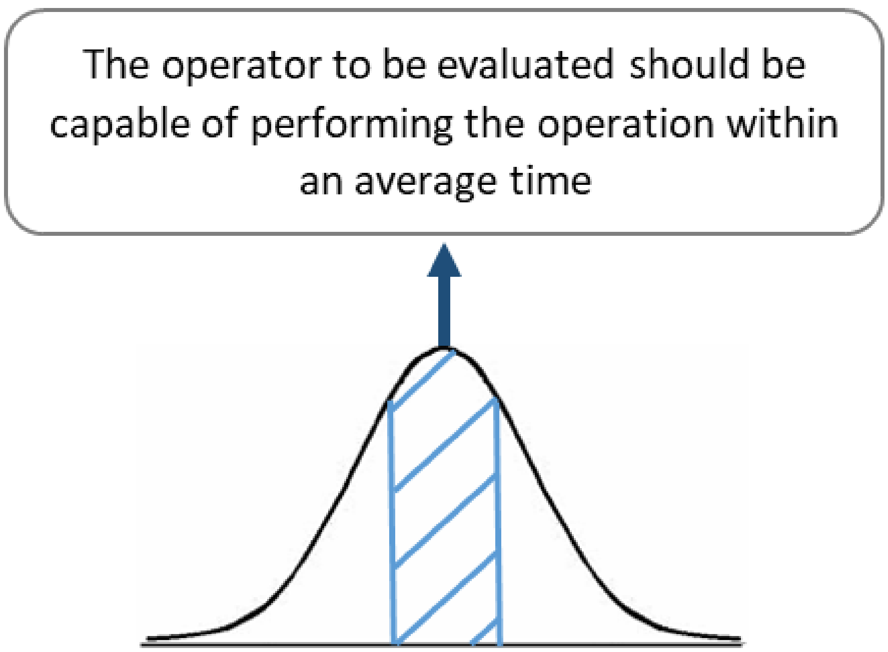


Figure 10.1 – Normal curve of the time required to operate.

- The operator must be adequately trained for the task, ensuring that the learning curve does not affect the collected data.
- It is essential to align expectations with operators beforehand: the

work will be timed, not the operators themselves.

Step 5 – Recording the details about the job

Before conducting the actual timing, it is recommended to observe the operation to understand its sequence, distances traveled, number of employees involved, required tools, and other relevant details.

This stage helps prevent rework in later phases. During this initial assessment, one should avoid being constrained by paradigms—mental maps that are constructed but rarely questioned. Therefore, the initial situation observed should not be regarded as immutable. The observer should not be limited by the physical layout or the number of operators present. Ideally, the project should be approached as a blank slate, making potential improvements more evident and facilitating process optimization.

Step 6 – Study of the elements of an operation

The operation under analysis should be broken down into smaller components, referred to as elements, which represent the smallest increment of work that can be transferred to another person. Defining such elements in this manner is advantageous because it facilitates their transfer between workers, if necessary.

Dividing the operation into work elements is essential because:

- It facilitates the description of operations.
- Standard times can be established for these elements.
- Deviations can be more easily identified.
- Variations in pace within each work element can be evaluated.

To illustrate the concept of work elements, for example, could picking up a hose be considered a work element?

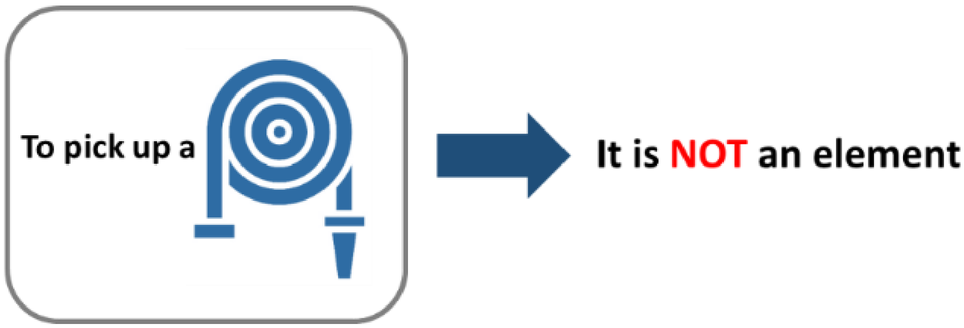


Figure 10.2 – Conceptual illustration of what does *not* constitute an element

The act of picking up a hose should not be considered an element (Figure 10.2). Elements should exhibit a clear beginning, middle, and end. In contrast, picking up a hose and placing it on a table could be considered an element (Figure 10.3).

Figure 10.3 – Conceptual illustration of what constitutes an element

Consequently, some rules can be established for breaking down a given operation into work elements:

- Elements should be as concise as possible while still allowing accurate measurement. They should not be shorter than 4 seconds, as the reaction time required to press the stopwatch may increase data variability. Furthermore, if they are too long, they may conceal problems.
- Manual time should be separated from machine time.
- Constant elements should be separated from variable elements.
- The seven wastes should not be included as work elements. Continuous improvement (kaizen) should be implemented from the planning stage.

There are different classifications of work elements concerning their variability, periodicity, and origin.

A work element, according to its variability, can be classified as:

- Constant: Low variability in the element's time, which remains essentially constant.
- Variable: High variability in the work element's time.

Concerning the origin of the element, it can be classified as:

- Machine: Elements that are primarily dependent on equipment.
- Manual: Elements that depend on the operator and their rate.

In general, machine-related elements are time-fixed elements; however, exceptions to this rule exist. For example, the time a straightening machine takes to straighten a tube can be considered a variable, since the more bent a tube is, the longer it will take to straighten.

We will demonstrate the importance of these classifications with a practical example. A manager assigned engineers the task of improving the performance of a workstation where an operator operated a straightening machine. Recently, this station has experienced a significant reduction in the number of parts produced per work shift.

Initially, the engineers measured the time the operator and the machine spent in each straightening cycle. Based on these measurements, the chart presented in Figure 10.4 was generated.

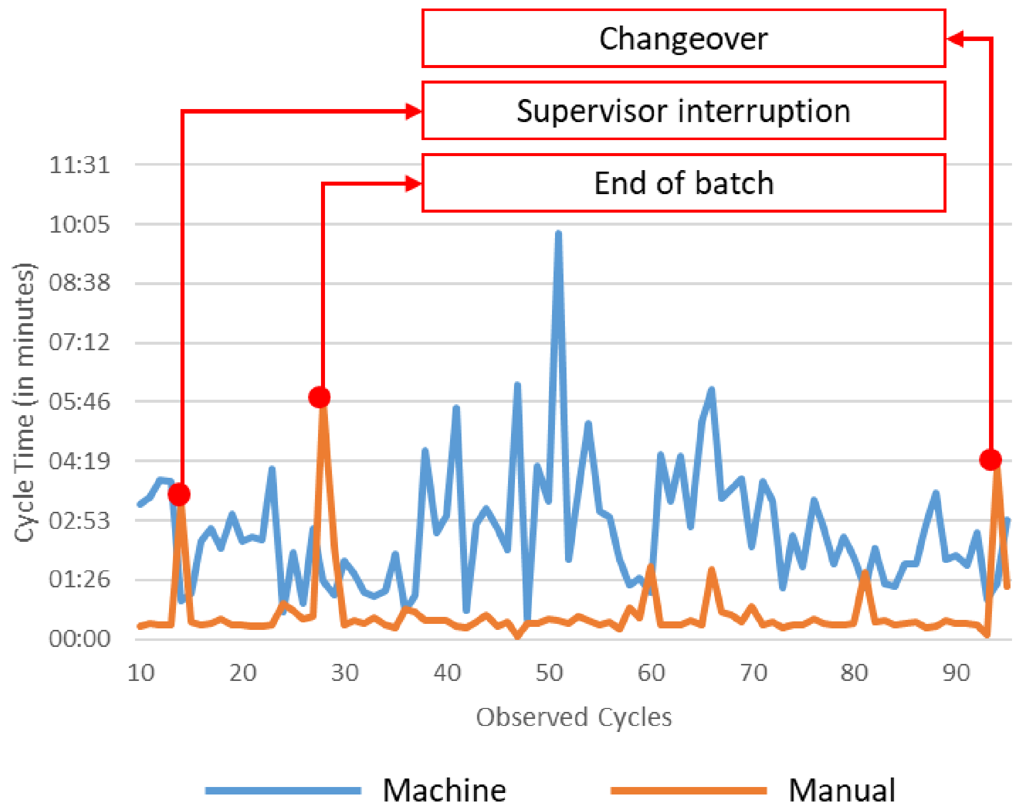


Figure 10.4 – Comparison of machine cycle time versus manual time

Based on the collected data and the generated chart, the engineers concluded that the operator's time throughout the entire cycle—that is, the manual time—was essentially constant. The variations observed in the operator's manual time were due to occasional deviations, such as material changeovers, end-of-batch, and supervisor interruptions. The machine time, however, proved to be highly variable. The machine could take anywhere from 30 seconds to almost ten minutes to straighten a single part. Therefore, the engineers determined that the root cause of the problem was not in the studied workstation but in a preceding workstation that experienced technical issues, which bent the parts and consequently impacted the straightening machine's productivity and resulted in quality-related losses.

This example illustrates the importance of these classifications. It is essential to separate the recorded times into categories, as they aid problem analysis and can guide the identification of the root cause.

In addition to variability and origin, work elements can also be classified according to the periodicity with which they occur:

- Repetitive: Element that occurs every cycle.
- Occasional: Element that occurs in specific cycles (e.g., start and end of batch, quality inspections).
- Foreign: Element that is not necessarily part of the job and should therefore be eliminated (eight wastes).

Such classification specifies which elements should be timed and prevents omitting any of them.

These concepts will be illustrated with a stopwatch time study for a sandwich assembly.

Figure 10.5 – Sandwich assembly

The elements involved in assembling a sandwich (Figure 10.5) were described to determine whether each could be classified as occasional, repetitive, or foreign.

I – Opening the package of sliced bread and other containers.
(X) Occasional ( ) Repetitive ( ) Foreign

II – Taking two slices of bread and placing them on the table.
( ) Occasional (X) Repetitive ( ) Foreign

III – Adding fillings and closing the sandwich.
( ) Occasional (X) Repetitive ( ) Foreign

IV – Picking up napkins that have fallen to the floor.

( ) Occasional ( ) Repetitive (X) Foreign

V – Closing containers and cleaning the table.
(X) Occasional ( ) Repetitive ( ) Foreign

Occasional elements generally occur at the beginning or at the end of a batch. For instance, in sandwich assembly, it was first necessary to set up the table so the process could begin. Thus, "opening the package of sliced bread and other containers" constitutes an occasional element. Similarly, at the end of the process, it was necessary to "close containers and clean the table," which is also an occasional element of this operation.

Elements that recur every time a sandwich is assembled, such as "taking two slices of bread and placing them on the table" and "adding fillings and closing the sandwich," may be classified as repetitive.

Elements that should not be part of the operation, such as the deviation represented by "picking up napkins that have fallen to the floor," must be considered foreign and, therefore, should not be timed.

Once the work elements to be collected have been defined and classified, it is also essential to establish the breakpoints, that is, the specific moments that serve as reference points to separate the work elements to be recorded. These breakpoints indicate when the stopwatch should be activated to start timing the next element. It is recommended to use visual and auditory signals as breakpoints.

Suppose individuals involved in a motion and time study adopt different breakpoints for the same piece of equipment. In that case, the times collected for the elements will be biased and, therefore, non-informative.

Step 7 – Determining sample size

At this stage, the required number of observations to be collected must be defined. This can be established either through standard tables or through statistical formulas.

General Electric (GE), for example, developed a standard table that specifies the number of observations to collect based on the cycle time of the operation under analysis (Table 10.1).

Cycle time	Number of observations to be collected
6 seconds	200
15 seconds	100
30 seconds	60
45 seconds	40
1 minute	30
2 minutes	20
Between 2 and 5 minutes	15
Between 5 and 10 minutes	10
Between 10 and 20 minutes	8
Between 20 and 40 minutes	5
More than 40 minutes	3

Table 10.1 – Number of observations to be collected according to cycle time (Source: GE Time Study Manual)

Statistical methods yield more precise results. These methods assume that the time observations follow a normal distribution with mean x and standard deviation s. Since time studies generally employ small samples, with the number of observations (n) fewer than 30, the t-distribution must be used. The Student's t distribution table is in Appendix 3 of this book.

Considering a significance level α and a confidence level of (1 − α) × 100%, the number of observations to be collected will be determined based on the confidence interval of (1 − α) × 100% of this distribution.

$$\bar{x} \pm \frac{t \times s}{\sqrt{n}}$$

The term ± can be interpreted as an error expression and, accordingly, represented as a fraction of $\overline{x}$, denoted as the variable *k* .

$$\bar{x} \pm \frac{t \times s}{\sqrt{n}}$$

Accordingly, by isolating the variable *n* , which represents the number of cycles to be collected, the following expression is obtained:

$$\bar{x} \pm \frac{t \times s}{\sqrt{n}}$$

Description of the variables in the formula:

n = Number of cycles to be collected
t = Value obtained from Student's t-table
s = Sample standard deviation
k = Acceptable fraction of deviation
$\overline{x}$ = Sample mean

The t-value must be obtained from the table associated with Student's t-distribution, based on the specified significance level and the sample degrees of freedom.

The sample degrees of freedom are calculated by subtracting one from the number of observations collected during the pilot test:

$$Degrees\ of\ freedom = Number\ of\ observations\ in\ the\ pilot\ test - 1$$

The significance level (α) is determined by the individual responsible for data collection. It represents the probability of rejecting the null hypothesis when it is true and is expressed as a percentage. For example, suppose a significance level of 5% is chosen. In that case, it means we are accepting a 5% chance that the difference observed in the study is not real, even though it has been statistically demonstrated to be real.

To illustrate the application of this statistical formula, let us continue with the sandwich assembly example. After analyzing the work elements to be collected, the engineers calculated the sample size. Accordingly, they conducted a pilot study with 20 measurements per element, yielding a mean of 0.40 and a standard deviation of 0.07. In addition, they defined an acceptable deviation fraction (*k*) of 4% and a significance level of 5%, which corresponds to a 95% confidence level. Based on these parameters, the number of observations to be collected was then calculated.

Accordingly, we have:

$n = ?$
$s = 0.07$
$k = 0.04$
$\bar{x} = 0.40$

To determine the t-value from the Student table, the engineers defined the significance level and the degrees of freedom based on the number of measurements from the pilot study:

$$Degrees\ of\ freedom = 20 - 1 = 19$$

$$Significance\ level\ (\alpha) = 0.05$$

Figure 10.6 shows how to look up the critical t-value for a one-tailed or two-tailed table. Thus, as shown in Figure 10.7, considering the significance level as the area in both tails, the value obtained for *t* is:

$$t = 2.093$$

With the variables defined, they proceeded to the calculation of *n* :

$$n = \left(\frac{t \times s}{k \times \bar{x}}\right)^2 = \left(\frac{2.093 \times 0.07}{0.04 \times \overline{0.40}}\right)^2 = 83.84$$

The value obtained was rounded up. Therefore, the engineers concluded that 84 observations should be collected.

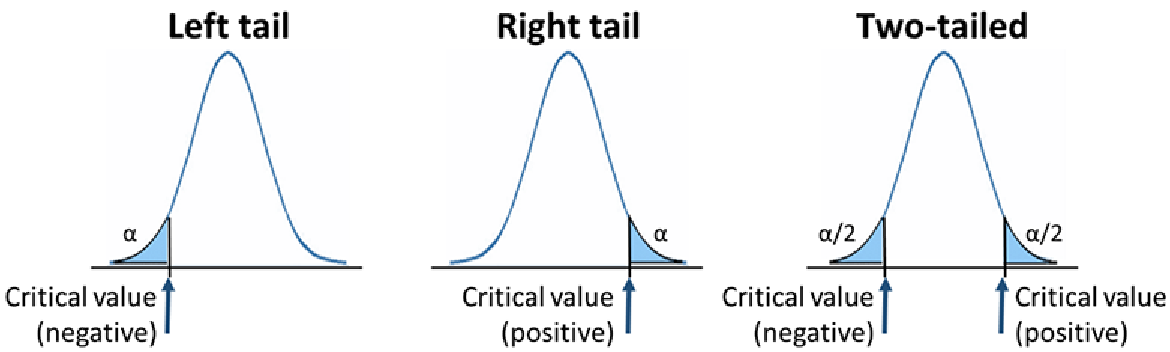


Figure 10.6 – Consulting the critical t-value for one-tailed or two-tailed table

	Amount of area in one tail						
	0.25	0.125	0.05	0.025	0.0125	0.005	0.0025
Degrees of freedom	Amount of area in two tails						
	0.50	0.25	0.10	0.05	0.025	0.01	0.005
1	1.000	2.414	6.314	12.706	25.452	63.657	127.321
2	0.816	1.604	2.920	4.303	6.205	9.925	14.089
3	0.765	1.423	2.353	3.182	4.177	5.841	7.453
4	0.741	1.344	2.132	2.776	3.495	4.604	5.598
5	0.727	1.301	2.015	2.571	3.163	4.032	4.773
6	0.718	1.273	1.943	2.447	2.969	3.707	4.317
7	0.711	1.254	1.895	2.365	2.841	3.499	4.029
8	0.706	1.240	1.860	2.306	2.752	3.355	3.833
9	0.703	1.230	1.833	2.262	2.685	3.250	3.690
10	0.700	1.221	1.812	2.228	2.634	3.169	3.581
11	0.697	1.214	1.796	2.201	2.593	3.106	3.497
12	0.695	1.209	1.782	2.179	2.560	3.055	3.428
13	0.694	1.204	1.771	2.160	2.533	3.012	3.372
14	0.692	1.200	1.761	2.145	2.510	2.977	3.326
15	0.691	1.197	1.753	2.131	2.490	2.947	3.286
16	0.690	1.194	1.746	2.120	2.473	2.921	3.252
17	0.689	1.191	1.740	2.110	2.458	2.898	3.222
18	0.688	1.189	1.734	2.101	2.445	2.878	3.197
19	0.688	1.187	1.729	**2.093**	2.433	2.861	3.174
20	0.687	1.185	1.725	2.086	2.423	2.845	3.153
21	0.686	1.183	1.721	2.080	2.414	2.831	3.135
22	0.686	1.182	1.717	2.074	2.405	2.819	3.119
23	0.685	1.180	1.714	2.069	2.398	2.807	3.104
24	0.685	1.179	1.711	2.064	2.391	2.797	3.091
25	0.684	1.178	1.708	2.060	2.385	2.787	3.078
26	0.684	1.177	1.706	2.056	2.379	2.779	3.067
27	0.684	1.176	1.703	2.052	2.373	2.771	3.057
28	0.683	1.175	1.701	2.048	2.368	2.763	3.047
29	0.683	1.174	1.699	2.045	2.364	2.756	3.038
30	0.683	1.173	1.697	2.042	2.360	2.750	3.030
60	0.679	1.162	1.671	2.000	2.299	2.660	2.915
120	0.677	1.156	1.658	1.980	2.270	2.617	2.860
∞	0.675	1.150	1.645	1.960	2.241	2.576	2.807

Figure 10.7 – Consulting the Student t-distribution table

Step 8 – Preparation for measurement

Before collecting time data, it is recommended to carry out certain preparatory activities, such as:

- Defining who will be responsible for data collection.
- Holding a meeting with these individuals to standardize the collection method, which consists of completing the form and aligning the elements and breakpoints.
- Gathering and informing other stakeholders about the activities to be performed.
- Identifying and organizing necessary objects for data collection, such as a stopwatch, mobile phone, clipboard, forms, or camera.
- Developing the data collection form according to the problem to be addressed.

One crucial caveat concerns the allocation of interns for data collection. Frequently, those responsible for conducting motion and time studies delegate this activity to subordinates, underestimating the importance of the collection process. If these individuals do not recognize the importance of the quality of the data to be collected, why should interns be concerned about it? Countless promising projects become uninformative due to poor-quality data collection. Let us recall the Shit-In-Shit-Out principle (Figure 10.8):

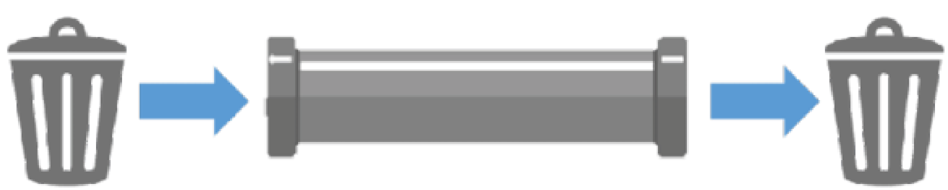


Figure 10.8 – Shit-In-Shit-Out principle

If you put garbage into a system, the results will be garbage, even with cutting-edge technology, the best software, and highly skilled engineers.

In other words, there is no issue in delegating part of the data collection work to interns. However, whenever possible, the project leaders should also participate in the collection process, thereby reinforcing the task's practical value. This practice will help prevent future rework, ensure project quality, and may even provide insights into improving the working method. Ultimately, the longer this key individual remains engaged in the production setting, the more they will learn about the process under study and, consequently, the more opportunities for improvement they will identify.

Another relevant aspect to consider at this stage concerns how timing will be performed. The stopwatch, or any other device used for this purpose (such as a mobile phone), should be kept at eye level so that the observer seldom loses peripheral vision of what is being measured.

There are essentially three methods for stopwatch timing:

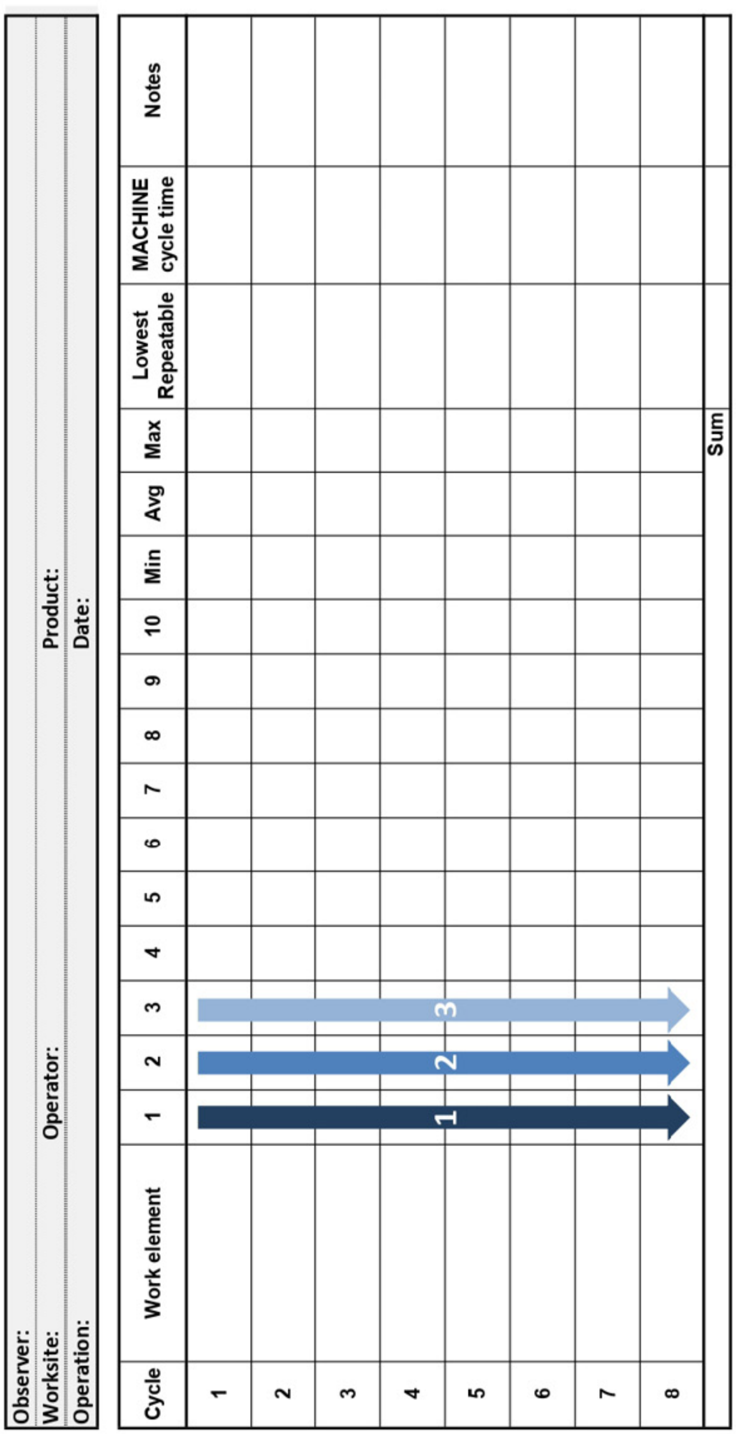
- Continuous timing method: The stopwatch runs throughout the entire study period. This strategy provides greater accuracy in the collected data.
- Snapback method: The stopwatch is reset at the end of each element. This method optimizes time and helps clean the data.
- Cumulative timing: A combination of continuous and repetitive reading that allows direct timing elements. Traditionally, this was performed by using two stopwatches; nowadays, most smartphones offer this function. This method combines the advantages of the two other strategies.

Step 9 – Measurement and time analysis

This book describes two approaches to measuring and analyzing the collected data. The first approach derives from the lean methodology, offering a simpler and faster way to execute this stage. The second is the traditional approach, which yields more accurate results.

Lean approach

The lean approach will be illustrated using the form shown in Figure 10.9, which is also available in Appendix 4 of this book. Regardless of the approach, the form must always begin with the completion of basic information, including the evaluated operation, the observer's name, the name (s) of the worker(s) being observed, the product being produced, the work shift, the date, and any other relevant information.



Observer:
Worksite: Operator: Product:
Operation: Date:

Cycle	Work element	1	2	3	4	5	6	7	8	9	10	Min	Avg	Max	Lowest Repeatable	MACHINE cycle time	Notes
1																	
2																	
3																	
4																	
5																	
6																	
7																	
8																	
														Sum			

Figure 10.9 – Time study observation form (Lean approach)

Time observation sheet: Lean approach

Observer's name: E. G. L.		
Area: Snack bar	**Operator:** X	**Product:** X
Workstation: Sandwich	**Operator's experience time:** X	**Date:** XX/XX/XXXX

Step	Element Description	1	2	3	4	5	6	7	8	9	10	Min	Avg	Max	Lowest Repeatable	Machine Cycle Time	Notes
1	Open the loaf bread package and prepare other containers (open packages, cut ingredients, etc.).	360													360		Occasional element. Therefore, more cycles should be collected.
2	Take two slices of bread and place them on the worktable.	5	4	6	5	3	4	4	4	3	5	3	4.3	6	4		
3	Add the fillings and close the sandwich.	24	26	27	25	25	27	26	30	27	29	24	26.6	30	27		The layout can be improved to reduce unnecessary movements.
4	Close the containers, dispose of the waste, and clean the worktable.										30				30		Occasional element. Therefore, more cycles should be collected.
														Total	70		The operator spent 70 seconds per sandwich (360/10 + 4 + 27 + 30/10).

Figure 10.10 – Example of a filled-out time observation sheet (Lean approach)

These data are not only valuable for traceability in the event of doubts, but can also serve as input for secondary analyses.

In this approach, each row must be filled with the times corresponding to each element, while the columns numbered 1-10 represent each collected cycle. Thus, the form is completed according to the sequence indicated by the blue arrows in the figure. Subsequently, the basic data for each of these elements—such as minimum, average, and maximum values—are calculated. If waste, abnormalities, or variability are identified, they must be recorded in the notes column. According to lean principles, the standard time should correspond to the shortest time that occurs most frequently across the collected cycles. This approach does not rely on average time, as the shortest, most frequently repeated time is considered a more reliable indicator of what can realistically be achieved. Figure 10.10 illustrates an example of how this form is completed for a sandwich assembly operation.

Traditional Approach

In the traditional approach, the form used for time collection is based on several concepts, such as:

- Rating (R): Assessment of the operator's pace in performing the task.
- Observed Time (OT): Time recorded from the stopwatch measurements for each work element.
- Normal Time (NT): observed time adjusted according to the operator's pace.
- Allowances: time to be included for planned breaks.
- Standard Time (ST): final time, calculated by adding allowances to the normal time.

Figure 10.11 presents a time-collection form following the traditional approach, which is also available in Appendix 4. It is worth noting that forms can be developed and adapted according to the specific study being conducted.

During data collection, it is essential to include observations alongside each element and identify potential outliers, such as the eighth cycle of the second work element in Figure 10.12. These represent atypical values within a set of observations and should be removed to avoid inconsistent interpretations of the results. The measured values must be recorded in the "Observed Time (OT)" field.

Furthermore, during data collection, the operator's pace must be assessed to calculate the normal time.

This assessment involves comparing the pace of the operator under observation with the evaluator's concept of a normal pace. Several systems can be used to assess an employee's working pace:

Pace evaluation based on skill and effort.

- Westinghouse System: The pace is evaluated according to skill, effort, conditions, and consistency.
- Synthetic pace evaluation: A method for assessing the operator using standard time data tables.
- Objective pace evaluation: Assessment of the speed and difficulty involved in performing the task.
- Physiological performance evaluation: Relationship between physical work and the amount of oxygen consumed or heart rate.
- Performance rating (most commonly used): Percentage-based assessment that considers only the operator's speed (time or pace).

Once the employee's performance has been rated, the normal time can be calculated:

$$Line\ speed = \frac{5\ pizzas}{0.83} \rightarrow 6\ pizzas\ per\ hour$$

The use of this formula will be illustrated below. To make the example more didactic, it will be assumed that the sandwich assembly operation consists of only two work elements: "take two slices of bread and place them on the table" and "add the fillings and close the sandwich." Let us also assume that the time recorded in the first measurement (Observed Time) was 5 seconds (Figure 10.12). The operator's performance rating was 110. This means the operator performed this element faster, spending less time than the standard time for the operation.

Observer:		
Location:	Operator:	Product:
Operation:		Date:

No.	Work Element	Cycle	1	2	3	4	5	6	7	8	9	10	Average NT	% Allowance	Standard Time	Notes
1		Observed Time (OT)														
		Rating (R)														
		Normal Time (NT)														
2		Observed Time (OT)														
		Rating (R)														
		Normal Time (NT)														
3		Observed Time (OT)														
		Rating (R)														
		Normal Time (NT)														
4		Observed Time (OT)														
		Rating (R)														
		Normal Time (NT)														
5		Observed Time (OT)														
		Rating (R)														
		Normal Time (NT)														
														TOTAL STANDARD TIME		

Figure 10.11 – Time observation sheet (Methods Engineering approach)

Observer's name: E. G. L.		
Area: Snack Bar	Operator: X	Product: X
Operation: Sandwich		Date: XX/XX/XXXX

No.	Work Element	Cycle	1	2	3	4	5	6	7	8	9	10	Average NT	% Allowance	Standard Time	Notes
1	Take two slices of bread and place them on the table	Observed Time (OT)	5	4	6	5	3	4	4	4	3	5	5.1	10	5.7	
		Rating (R)	110	130	90	110	150	130	130	130	150	110				
		Normal Time (NT)	5.5	5.2	5.4	5.5	4.5	5.2	5.2	5.2	4.5	5.5				
2	Add the fillings and close the sandwich	Observed Time (OT)	24	26	27	25	25	27	26	30	27	29	25.4	10	28.3	In the eighth cycle, more time
		Rating (R)	120	100	90	110	110	90	100	100	90	70				was spent because the sandwich
		Normal Time (NT)	29	26	24	28	28	24	26	30	24	20				was assembled incorrectly.
3		Observed Time (OT)														
		Rating (R)														
		Normal Time (NT)														
4		Observed Time (OT)														
		Rating (R)														
		Normal Time (NT)														
														TOTAL STANDARD TIME	34.0	

Figure 10.12 – Example of a filled-out time observation sheet (Methods Engineering approach)

Based on these data, the normal time was calculated:

$$Value\ added\ ratio = \frac{Value\ added\ time}{Lead\ time}$$

It can be observed that, because the operator performed this task at a higher speed than the average, the calculated normal time exceeds the observed time. In other words, an average operator would require more time to complete this task than the observed operator.

Accordingly, nine additional cycles were collected, and the average normal time for this work element was approximately 5.1 seconds (Figure 10.12).

The average normal time does not account for any allowances, which is unrealistic. Therefore, it is necessary to define the allowances to be applied in the standard time calculation. Three types of allowances must be added: personal needs allowance, fatigue, and unavoidable delay allowance.

The first type of allowance refers to time allocated for personal needs, such as restroom use, snacks, and water. For light work, it typically ranges from 2 to 5% (10 to 24 minutes in an 8-hour shift); for heavy work, more than 5% of the time may be reserved for this type of allowance.

The fatigue allowance represents the time intended to offset potential fatigue, which may be physical or mental in origin. Determining it is difficult because subjective variables, such as individual characteristics, cycle duration, and working conditions, come into play. A sound solution is to allocate scheduled rest periods of predefined duration and frequency. For example, one may establish 5- to 15-minute rest breaks in the mid-morning and mid-afternoon. It should be noted that both the duration and frequency of rest breaks will depend on the type of activity.

Finally, the delay allowance refers to unavoidable delays (avoidable delays should not be considered). The machine, the operator, or external factors may cause unavoidable delays. It is important to emphasize that when equipment breakdowns occur, the operator may be reassigned to other tasks. In this case, such waiting times are considered avoidable and are not included in the standard time.

$$Value\ added\ ratio = \frac{Value\ added\ time}{Lead\ time}$$

The values allocated to each of these allowances must be summed to determine the total allowance to be considered in the calculation of the standard time. In this case, the methods engineers established the following allowance values: 3% for personal needs, 2% for fatigue, and 5% for unavoidable delays.

$$\text{Total Allowance} = 3\% +\ 2\% +\ 5\% = 10\%$$

In other words, the total allowance to be considered will be 10%.

After defining the total tolerance, we can proceed to calculate the standard time using two approaches: one is more commonly used, and the other is more accurate.

The formula for calculating the standard time according to the more commonly used approach is derived from the following rule of three:

$$\frac{Normal\ Time}{1} = \frac{Standard\ Time}{1 + \frac{Total\ Allowance}{100}}$$

Accordingly,

$$Standard\ Time\ (Most\ commonly\ used\ approach) = Normal\ Time\ (1 + \frac{Total\ \ Allowance}{100})$$

Considering the example, we have:

$$Standard\ Time\ (Most\ commonly\ used\ approach) = 5.1\left(1 + \frac{10}{100}\right) = 5.6\ seconds$$

The calculation of the standard time using the most accurate approach can, in turn, be expressed by the following rule of three:

$$\frac{Normal\ Time}{1 - \frac{Total\ Allowance}{100}} = \frac{Standard\ Time}{1}$$

Accordingly,

$$Standard\ Time\ (Most\ accurate\ formula) = \frac{Normal\ Time}{1 - \frac{Total\ Allowance}{100}}$$

For example,

$$Standard\ time\ (Most\ accurate\ formula) = \frac{5.1}{1 - \frac{10}{100}} = \frac{5.1}{\frac{90}{100}} = 5.7\ seconds$$

In Figure 10.12, the standard time for the work element was calculated using the most accurate approach.

The total standard time can be obtained by summing the standard times of all the elements involved in the sandwich assembly operation:

$$Total\ standard\ time = 5.7 + 28.3 = 34.0\ seconds$$

Figure 10.13 summarizes the concepts of observed time, normal time, and standard time.

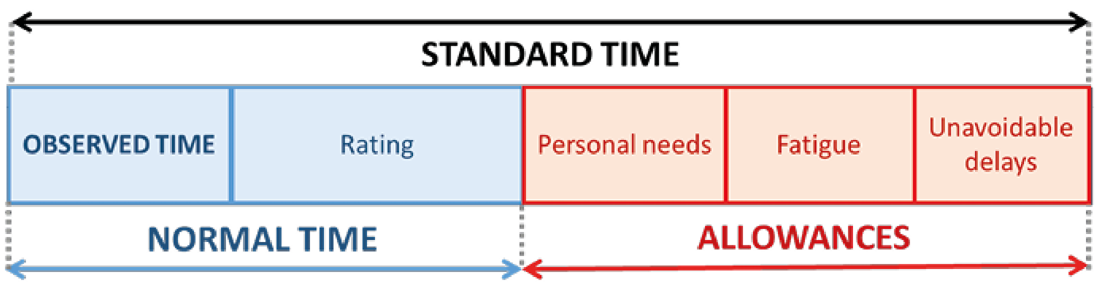


Figure 10.13 – The concepts of observed time, normal time, and standard time.

10.2 Stopwatch time studies in services

When conducting time studies of operations with long cycle times, numerous activities, or frequent interruptions, it can be challenging to perform the analysis using the previously mentioned forms.

In administrative services, for instance, there may be numerous interruptions among work elements that can last for days, weeks, months, or even years. Performing a time study for this type of service requires a data collection strategy that differs from that used in industrial environments, where equipment typically has short cycle times—often only a few minutes—allowing many cycles to be recorded within a relatively short period.

This is also the case for services with a high degree of automation and digitalization, such as those in information technology. This section will describe a possible strategy to be applied in such cases.

Generally, the procedure to follow is similar to the step-by-step method previously mentioned. The main difference lies in steps 6 (Study of the elements of an operation) and 9 (Measurement and time analysis). This section will therefore focus on these stages, although all the aforementioned steps must still be considered in this type of study.

First, in the stage of “Study of the elements of an operation”, all elements that are part of the operation and that should be timed must be identified. Since many service processes involve complex decision-making, it is recommended to validate the work elements using flowcharts, which can be constructed, for example, with post-its to represent all possible decision-making routes (Figure 10.14). These flowcharts may then be digitized, either subsequently or concurrently, in software such as Microsoft Visio and Bizagi. If necessary, very complex flowcharts should be validated in additional meetings.

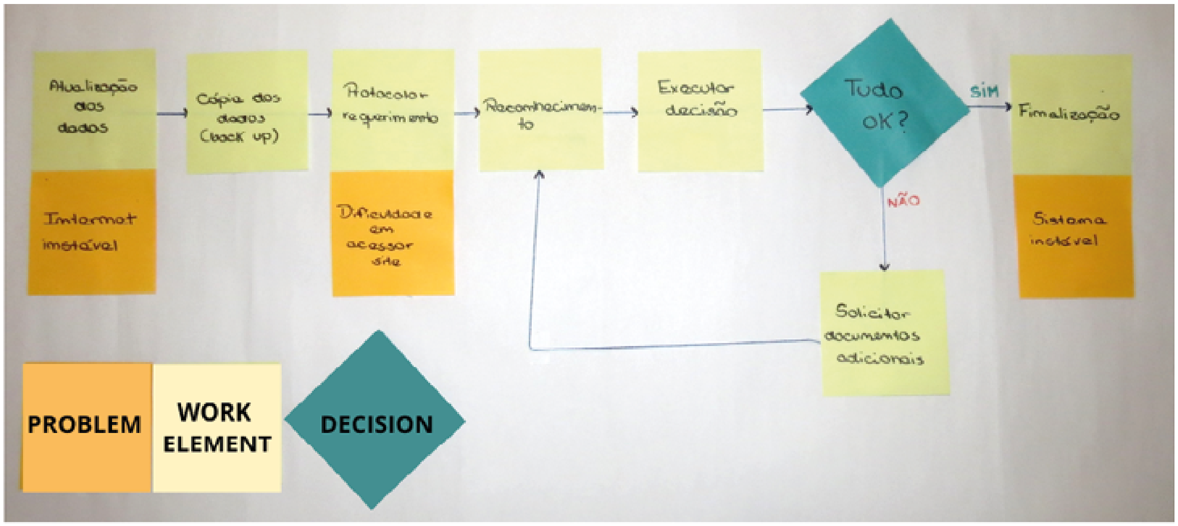


Figure 10.14 – Validation of process elements with post-its

Moreover, when multiple departments or individuals are involved, specific sections can be allocated to highlight when each is acting (Figure 10.15).

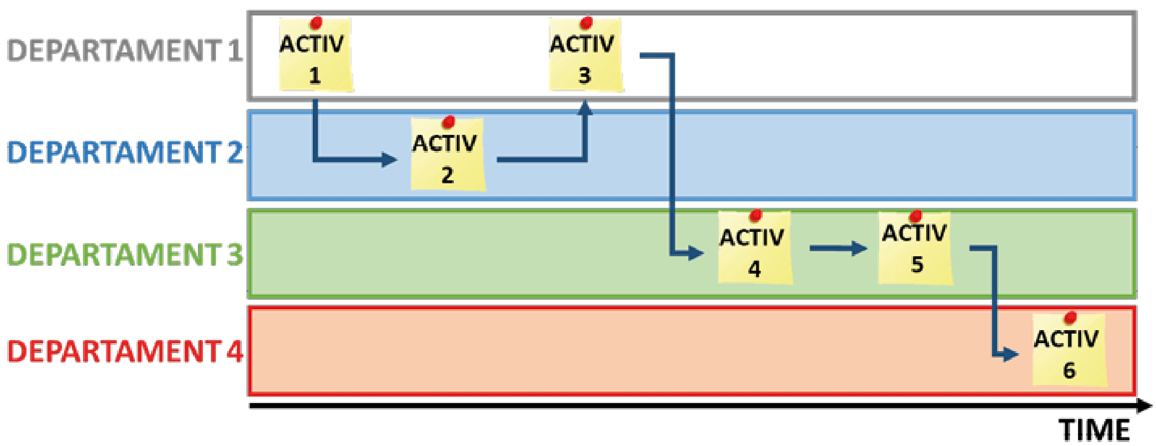


Figure 10.15 – Multidepartmental process flowchart with post-its

Once all work elements for a given operation have been defined, the next step is to collect time data.

During time measurement, the individuals responsible for data collection should use stopwatches, clocks, mobile phones, tablets, or laptops to record the start and end times of each element. Regarding data collection, several strategies may be adopted to record the measured times. For instance:

- Bring the flowchart with post-its, or print the digital file in an appropriate paper size for adequate visibility (A4, A3, ..., up to A0), and note the times of activities on this paper while simultaneously observing the employee under study.
- Record the times directly in a standard spreadsheet during data collection.
- Create a specific form, print it, and complete it on the day of collection with the measured times.

Figure 10.16 illustrates a time-study analysis of an administrative process, as a continuation of the example presented in Figure 10.14, in which activities were measured on two different days, A and B.

It should be noted that, in time-study projects of administrative processes, the duration of the work elements is just as crucial as the interruption time between them. Therefore, it is essential to ensure that all such data are collected to enable an appropriate future analysis. Remember that often there is little time for planning, but, ironically, there is always time left to rework what was poorly planned.

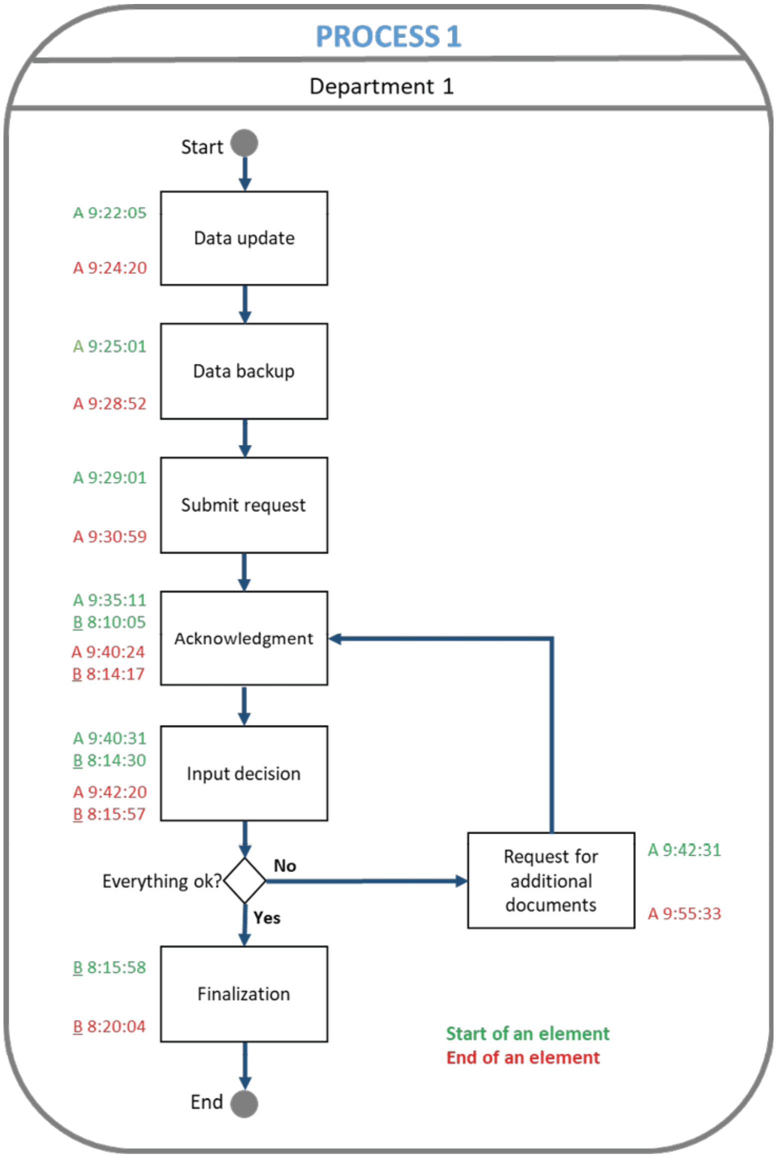


Figure 10.16 – Data collection: Time-study analysis of an administrative process

It can be observed in Figure 10.16 that, based on the start and end times of the elements, their durations and execution sequences can be determined, and deviations in the flow can be identified. Thus, the generated flowchart is validated in parallel with the time measurements. If necessary, the flowchart should be revised.

After or during time measurement, the data must be consolidated into a standard spreadsheet (Table 10.2). This spreadsheet, in addition to serving as a backup and facilitating project knowledge management, may also be helpful when performing data analysis with software such as Microsoft Excel or Minitab.

Element	Start	End	Duration	Notes
Data update	17/02/2020 9:22:05	17/02/2020 9:24:20	00:02:15	Slow internet
Data backup	17/02/2020 9:25:01	17/02/2020 9:28:52	00:03:51	-
Submit request	17/02/2020 9:29:01	17/02/2020 9:30:59	00:01:58	Difficulty accessing the website
Acknowledge ment	17/02/2020 9:35:11	17/02/2020 9:40:24	00:05:13	Solving doubts with the supervisor
	18/02/2020 8:10:05	18/02/2020 8:14:17	00:04:12	-
Implement decision	17/02/2020 9:40:31	17/02/2020 9:42:20	00:01:49	-

	18/02/2020 8:14:30	18/02/2020 8:15:57	00:01:27	-
Request for additional documents	17/02/2020 9:42:31	17/02/2020 9:55:33	00:13:02	-
Finalization	18/02/2020 8:15:58	18/02/2020 8:20:04	00:04:06	Unstable system

Table 10.2 – Data consolidation: Time-study analysis of an administrative process

These spreadsheets must include a "Notes" field. Since the duration of some elements may vary, it is necessary to understand not only HOW LONG each element takes, but also WHY it takes that time and WHICH FACTORS may increase its variability. In other words, the "Notes" field allows quantitative time study analysis to be complemented by a qualitative assessment of what was observed during data collection.

These data must be transformed into information that identifies improvements and supports managers' decision-making.

In the "Observation" field, any occurrences that draw the attention of the person responsible for the measurement should be recorded, such as:

- Identification of the eight types of waste (waiting, inventory, transportation, motion, extra-processing, defects, overproduction, and nonutilized talent).
- Improvement opportunities.
- Materials, documents, tools, and other inputs necessary for executing a work element.
- Interruptions by other individuals, whether for informal conversations or technical consultations with colleagues or

superiors (in person, by phone, or by message).

- Incorrect and imprecise measurements.
- Consultation of standards, manuals, or work procedures.
- Information regarding workstations, technology, and infrastructure, such as mechanical, electrical, or systemic failures.
- The way the work is performed and the incorrect procedures.
- Any other occurrence deemed important according to the project's objective.

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Softwares

Bizagi Modeler – https://www.bizagi.com/plataforma/modeler
Microsoft Office – https://www.office.com/
Microsoft Visio – https://www.microsoft.com/pt-br/microsoft-365/visio/flowchart-Software
Minitab – http://www.minitab.com/

CHAPTER 11:
PREDETERMINED TIME STANDARDS SYSTEMS (PTSS)

Predetermined Time Standards Systems (PTSS) are data standardization systems used to determine the standard times of work elements. The idea is to break down an operation into a sequence of minimal movements with standard time values that can be consulted, for example, from a table.

This time measurement procedure applies to a wide range of manual activities and processes. Furthermore, PTSS can be used for various purposes:

- Development of effective methods before starting production.
- Improvement of current methods by exploring alternative approaches.
- Selection of appropriate tools and equipment.
- Development of accurate activity descriptions for training purposes.
- Elimination of the need to assess operator performance.
- Increased agility in the time collection process.
- Planning of future layouts based on the current model. For example, PTSS can be used to calculate the number of machines each operator will operate.
- Updating standards following changes in methods.

Among the most famous predetermined time systems, we can mention:

- MODAPTS: MODular Arrangement of Predetermined Time Systems.
- MOST: Maynard Operation Sequence Technique.
- MTM: Methods-Time Measurement.

This book will provide a didactic explanation of how the Maynard Operation Sequence Technique (MOST) works, enabling readers to understand it in depth.

11.1 Step-by-Step procedure for a PTSS study

The following step-by-step process can be followed to conduct a time study using a PTSS.

Step 1 – Problem definition

This stage is crucial for the study's success. Planning should not be underestimated, as good planning minimizes rework and errors.

Before starting any motion or time study, the first step is to understand and define the problem in collaboration with the main stakeholders.

Subsequently, data must be collected to select the workstation or activity to be studied. Based on this data analysis, the appropriate method, workstation, and activity to be examined will be defined.

Step 2 – Record the details of the activities studied

A preliminary study must be conducted at the workstation to be analyzed. Some important points to consider are:

- Identification of the tools necessary for the operation.
- Specific characteristics of the workstation.
- Improvement opportunities.
- Quality requirements.
- Safety requirements.
- Layout.
- Number of shifts and operators.

Step 3 – Define the work elements to be filmed

When defining the operations to be recorded, care must be taken regarding sporadic activities such as quality tests and end-of-batch.

Therefore, to avoid rework, all repetitive or occasional activities to be filmed must be defined in advance.

In addition, it is important to plan which product will be chosen for filming. For example, analyzing the portfolio's main products is often preferred. Special care must be taken in this decision, since the production mix may change over time. Thus, it is always advisable to work with product families.

Step 4 – Recording the video

In parallel with filming, it is advisable to take notes on specific operational details, as discussed in Step 2. Anomalies and opportunities for improvement should always be highlighted. It is essential to record the data that will serve as input to complete the MOST form, such as distances traveled and tools used.

Step 5 – Filling the MOST Form

The MOST table is used to determine the normal time for each element.

In practice, these data are entered into the MOST form, which may, for instance, be an Excel spreadsheet. This provides a fast data-entry tool that automatically generates the parameters based on the selected sequence model and calculates the standard time for each element. These times are then automatically aggregated in the spreadsheet and, upon applying the appropriate tolerance, the total standard time is obtained.

The letters corresponding to the sequence models (G, C, and T) and parameters (A, B, G, P, etc.) facilitate data entry in the spreadsheet. Furthermore, electronic data storage supports more effective knowledge management. The spreadsheet can be downloaded from the supplementary materials on this book's official website.

Step 6 – Validating the results

It is always advisable to validate the results obtained to verify whether they are feasible in practice—that is, whether they are not unduly affected by long working hours or potential operator fatigue.

11.2 MOST

Several standard MOST tables exist. Among the main ones are:

- BasicMOST: The most widely used version, particularly for activities with medium cycle times (ranging from a few seconds to up to 10 minutes).
- AdminMOST: Designed for the analysis of administrative and office activities.
- MiniMOST: Intended for precise and detailed analysis of short-cycle activities (less than 20 seconds).
- MaxiMOST: Applied to setups, heavy assembly, and maintenance—that is, to activities with longer cycle times.

This book will focus on explaining BasicMOST, as the logic underlying MOST's application remains essentially the same regardless of its type, making it one of the most widely applicable versions. The key is to select the appropriate MOST standard table for the operation under study.

Before addressing the use of the table itself, some fundamental concepts must be defined. Work should be understood as the displacement of an object's mass. Moreover, an operation is to be broken down into its minimal movements. Consequently, verbs associated with an operation, such as “grasp” and “place”, become the focus of analysis.

MOST employs four levels of analysis, increasing in tangibility, which support the completion of the form: sequence models, phases, parameters, and indices (Figure 11.1).

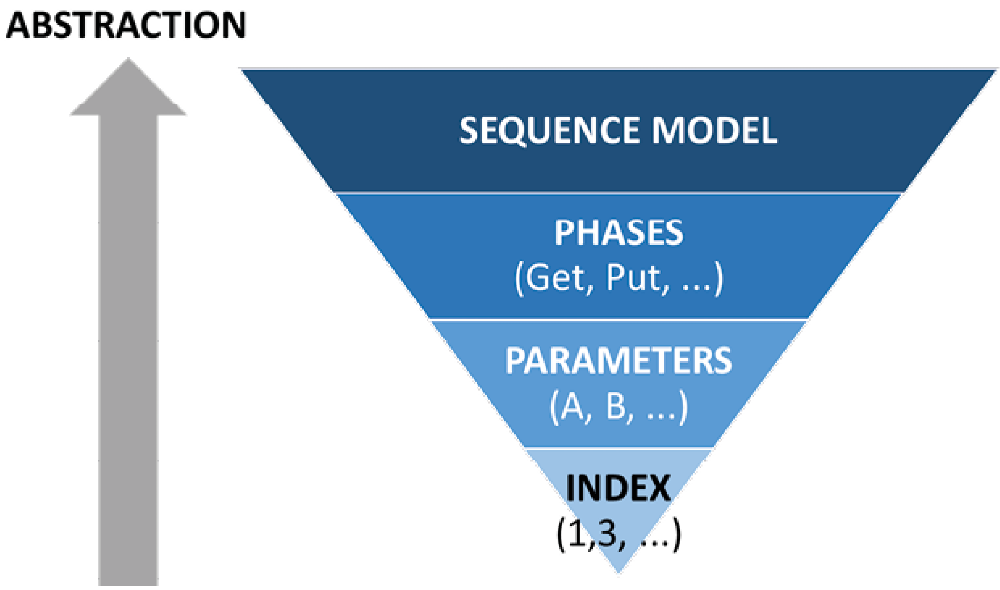

Figure 11.1 – The four levels of analysis in MOST

Three basic sequence models are used to describe a given activity:

- General Move (G): Manual movement of an object freely through space.
- Controlled Move (C): Restricted movements, involving constraints or contact with an object (e.g., lever, handle, or button).
- Tool Use (T): When tools are required, such as a hammer or screwdriver.

Each of these sequence models is structured into phases:

- General Move (G): Get + Put + Return.
- Controlled Move (C): Get + Move/Actuate + Return.
- Tool Use (T): Get Tool + Put Tool + Use Tool + Aside Tool + Return.

Each phase is broken down into letters, called parameters. These, in turn, are assigned an index value based on the movement required to perform a given activity.

The indices are then used to calculate the total time required for the task. Subsequently, the parameters and indices will be analyzed for each sequence model.

11.2.1 General Move (G)

The General Move table is applied when there is a manual displacement of an object freely through space. Thus, a general move consists of the phases of Getting an object, Putting that object elsewhere, and Returning to the original location. The phases Get, Put, and Return can be represented by parameters within the rectangles shown in Figure 11.2.

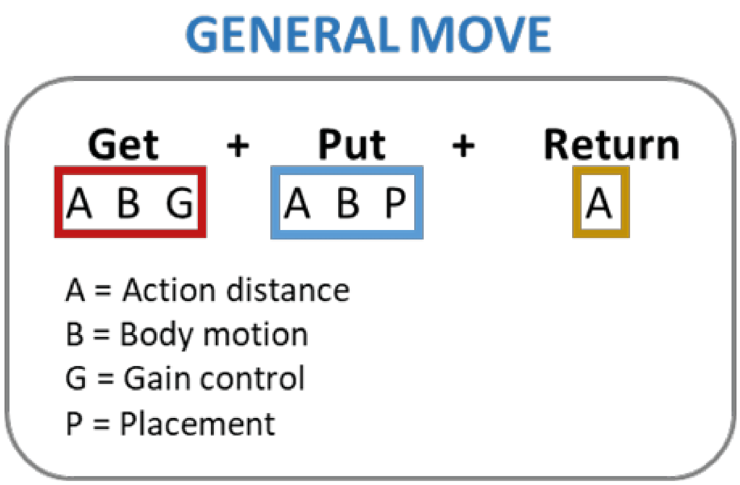

Figure 11.2 – Phases of a General Move (G)

GENERAL MOVE: Get (ABG) + Put (ABP) + Return (A)				
Index	A Action distance	B Body motion	G Gain control	P Placement
0	≤ 2 in. (5 cm)	No body motion	No gain control Hold	No placement Hold Toss
1	Within reach		Grasp light objects	Lay aside Loose fit
3	1-2 steps	Sit without adjustments Stand without adjustments Bend and arise (50% occ.)	Get heavy/bulky Get obstructed Disengage Collect	Loose fit blind Place with adjustments, light pressure OR double placement
6	3-4 steps	Bend and arise		Position with care, precision, blind, obstructed, with heavy pressure OR with intermediate moves
10	5-7 steps	Sit Stand		
16	8-10 steps	Bend and sit Climb on OR climb off Stand and bend Through door		

Table 11.1 – General Move Table

Index	Steps	Distance (m.)
24	11-15	12
32	16-20	15
42	21-26	20
54	27-33	25
67	34-40	30
81	41-49	38
96	50-57	44
113	58-67	51
131	68-78	59
152	79-90	69
173	91-102	78
196	103-115	88
220	116-128	98
245	129-142	108
270	143-158	120
300	159-174	133

Table 11.2 – Extended values of Action distance (A)

The indices assigned to these parameters are listed in Table 11.1. If the horizontal displacement corresponding to the parameter action distance (A) exceeds 10 steps, Table 11.2 should be consulted.

The use of these parameters and indices is exemplified below.

Example – An operator walks 3 steps toward a box on the floor. He then bends down to pick up the box (a light object). Next, he walks 3 steps to a table where the box is to be placed. Ultimately, the operator ends at the same spot where the movement began.

The action of GETTING the box involves an action distance (A), a body motion (B), and the difficulty of gaining control of the object (G). To pick up the box from the floor, the required horizontal displacement is

3 steps. The body motion involves bending down and fully standing up again. And the effort needed to pick up the box is relatively low, since it is a light object.

The action of PUTTING involves an action distance (A), no body motion (B), and the difficulty of placing the box (P). Accordingly, to put the box on the table, a horizontal displacement of 3 steps is required. And the action of placing the box consists of laying it aside on the table.

Finally, you must RETURN to the place of origin, which involves only the action distance (A) parameter. In this case, the operator did not return, so its index value was 0.

Figure 11.3 and Table 11.3 show the indices for this general move example.

At the end, the indices found are added, and the result is multiplied by 10:

6 + 6 + 1 + 6 + 0 + 1 + 0 = 20 x 10 = 200 TMU

The result found is given in Time Measurement Units (TMU), which is a measure that can be converted to seconds, minutes, or hours:

- 1 TMU = 0.00001 hour = 0.0006 minutes = 0.036 seconds;
- 1 hour = 100,000 TMU.
- 1 minute = 1,667 TMU.
- 1 second = 27.8 TMU.

GENERAL MOVE

Get + Put + Return

A6 B6 G1 A6 B0 P1 A0

GET the box (Table 11.3 – red rectangle):

A - 3 steps– index 6

B - Bend and arise to pick up a box – index 6

G - Grasp a light box – index 1

PUT THE box on table (Table 11.3 – blue rectangle):

A - 3 steps– index 6

B - No body motion – index 0

P - Lay aside – index 1

RETURN to place of origin (Table 11.3 – yellow rectangle):

A - No return – index 0

Figure 11.3 – Indices for the general move example

GENERAL MOVE: Get (ABG) + Put (ABP) + Return (A)				
Index	A Action distance	B Body motion	G Gain control	P Placement
0	≤ 2 in. (5 cm)	No body motion	No gain control Hold	No placement Hold Toss
1	Within reach		Grasp light objects	Lay aside Loose fit
3	1-2 steps	Sit without adjustments Stand without adjustments Bend and arise (50% occ.)	Get heavy/bulky Get obstructed Disengage Collect	Loose fit blind Place with adjustments, light pressure OR double placement
6	3-4 steps	Bend and arise		Position with care, precision, blind, obstructed, with heavy pressure OR with intermediate moves
10	5-7 steps	Sit Stand		
16	8-10 steps	Bend and sit Climb on OR climb off Stand and bend Through door		

Table 11.3 – General Move Table (example)

In this example:

200 TMU x 0.036 seconds/TMU = 7.2 seconds

Therefore, 7.2 seconds is the standard time, according to the BasicMOST tables, for walking 3 steps to pick up a light box and then walking 3 steps to place it on a table.

11.2.2 Controlled Move

The Controlled Move sequence model describes the movement of objects along a controlled path or along a restricted path in at least one direction by contact with or attachment to another object. Pushing a button, rotating a knob, and pushing a switch are, accordingly, examples of controlled moves. Therefore, controlled movements comprise the phases of GETTING in touch with an object, such as a lever or a button, MOVING/ACTUATING it, and finally RETURNING to the initial position. These three phases can be represented by the parameters illustrated in the rectangles of Figure 11.4.

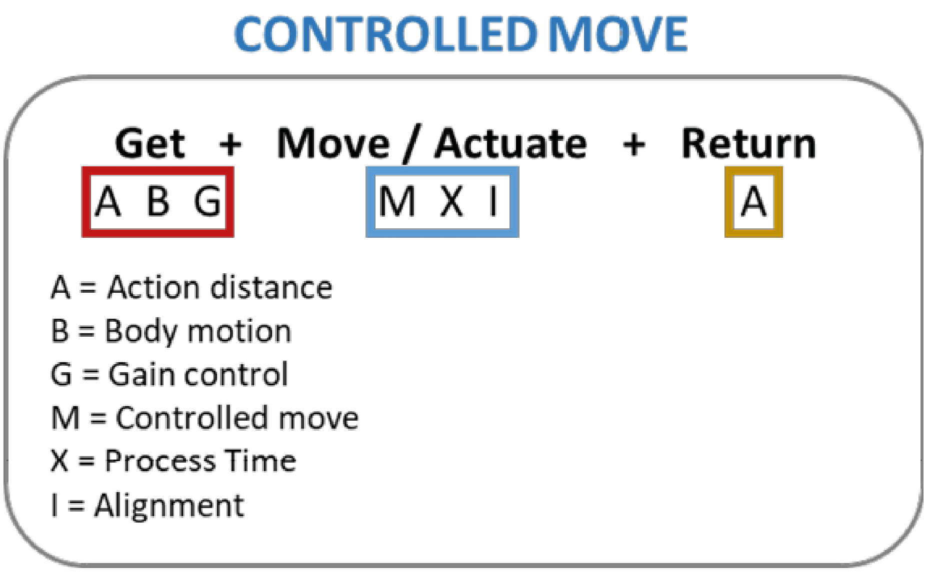

Figure 11.4 – Phases of the Controlled Move sequence model

The parameters A, B, and G have already been described in the presentation on general movements, and their indices are listed in Tables 11.1 and 11.2. Therefore, we will focus on defining the parameters M, X, and I.

The parameter M (Move Controlled) encompasses all manual motions performed in relation to an object under a controlled or restricted displacement (using fingers, hands, or feet). This parameter is subdivided into two categories: Push/Pull/Pivot or Crank.

The parameter X (Process Time) refers to the portion of the task that is governed by mechanisms or by electronic or mechanical machines. In other words, processing time does not include manual actions. For example, after pressing a button, a press machine is activated; thus, the press cycle time serves as the input for determining the index of this parameter.

Finally, the alignment parameter I refers to manual actions performed after the controlled movement or upon completion of the processing time to achieve a specific alignment or orientation of the object. It is important to note that eye movement time must be considered within this parameter, although the normal visual field does not require additional observation time. This parameter is divided into three categories:

- Alignment of typical objects.
- Alignment of machining tools.
- Alignment of nontypical objects.

CONTROLLED MOVE: Get (ABP) + Move/Actuate (MXI) + Return (A)c				
Index	M – Move controlled		X Process time	I Alignment
	Push/Pull/Pivot	Crank		
0	No action	No action	No process time	No alignment
1	Push/Pull/Pivot ≤ 12 in. (30 cm.) Push button Push/Pull switch Rotate knob		0.5 sec.	Align to 1 point
3	Push/Pull/Pivot > 12 in. (30 cm.) Push/Pull with resistance Push/Pull with high control Seat OR Unseat Push/Pull (2 stages) ≤ 12 in. (30 cm.) Push/Pull (2 stages) ≤ 24 in. Total	1 Rev.	1.5 sec.	Align to 2 points ≤ 4 in. (10 cm.)
6	Push/Pull (2 stages) > 12 in. (30 cm.) Push/Pull (2 stages) > 24 in. Total Push with 1-2 steps	2-3 Revs.	2.5 sec.	Align to 2 points > 4 in. (10 cm.)
10	Push/Pull (3-4 stages) Push with 3-5 steps	4-6 Revs.	4.5 sec.	
16	Push with 6-9 steps	7-11 Revs.	7 sec.	Align with precision

Table 11.4 – Controlled move table

The indices for the parameters M, X, and I are listed in Table 11.4. This table presents the alignment (I) indices only for typical objects, since the other two categories are less frequently applied in practice.

The use of these parameters and indices will be illustrated in the following examples.

Example – A press operator pushes a button within reach to actuate a press, which cycles for 2.5 seconds.

The GET phase has the following associated parameters: an action distance (A), a body motion (B), and the difficulty to gain control (G). The button is within reach, no body motion is necessary, and it is a light object.

The MOVE / ACTUATE phase is structured into a controlled move (M), a process time (X), and the alignment parameter. In this example, the controlled move is to push a button, activating a press which cycles for 2.5 seconds. In this case, there was no need for alignment.

CONTROLLED MOVE

Get + Move / Actuate + Return

A1 B0 G1 M1 X6 I0 A0

GET in contact with the button (Table 11.5 – red rectangle):
A - Within reach – index 1
B - No body motion – index 0
G - Grasp light objects – index 1

MOVE the switch (Table 11.6 – blue rectangle):
M - Push button – index 3
X - Press cycles for 2.5 seconds – index 6
I - No alignment – index 0

RETURN to place of origin (Table 11.5 – yellow rectangle):
A - No return – index 0

Figure 11.5 – Indices for the controlled move example

GENERAL MOVE: Get (ABG) + Put (ABP) + Return (A)				
Index	A Action distance	B Body motion	G Gain control	P Placement
0	≤ 2 in. (5 cm)	No body motion	No gain control Hold	No placement Hold Toss
1	Within reach		Grasp light objects	Lay aside Loose fit
3	1-2 steps	Sit without adjustments Stand without adjustments Bend and arise (50% occ.)	Get heavy/bulky Get obstructed Disengage Collect	Loose fit blind Place with adjustments, light pressure OR double placement
6	3-4 steps	Bend and arise		Position with care, precision, blind, obstructed, with heavy pressure OR with intermediate moves
10	5-7 steps	Sit Stand		
16	8-10 steps	Bend and sit Climb on OR climb off Stand and bend Through door		

Table 11.5 – General move table (controlled move example)

Then you must RETURN to the place of origin, which involves only the action distance (A) parameter. In this case, the operator did not return, so its index value was 0.

Figure 11.5 and Tables 11.5 and 11.6 show the indices for this controlled move example.

At the end, the indices found are added, and the result is multiplied by 10:

1 + 0 + 1 + 1 + 6 + 0 + 0 = 9 x 10 = 90 TMU

Converting the result in Time Measurement Units (TMU) to seconds, we have:

90 TMU x 0.036 seconds/TMU = 3.24 seconds

That is, 3.24 seconds is the standard time, according to the BasicMOST tables, for a press operator to push a button within reach to actuate a press that cycles for 2.5 seconds.

CONTROLLED MOVE: Get (ABP) + Move/Actuate (MXI) + Return (A)				
Index	M – Move controlled		X Process time	I Alignment
	Push/Pull/Pivot	Crank		
0	No action	No action	No process time	No alignment
1	Push/Pull/Pivot ≤ 12 in. (30 cm.) Push button Push/Pull switch Rotate knob		0.5 sec.	Align to 1 point
3	Push/Pull/Pivot > 12 in. (30 cm.) Push/Pull with resistance Push/Pull with high control Seat OR Unseat Push/Pull (2 stages) ≤ 12 in. (30 cm.) Push/Pull (2 stages) ≤ 24 in. Total	1 Rev.	1.5 sec.	Align to 2 points ≤ 4 in. (10 cm.)
6	Push/Pull (2 stages) > 12 in. (30 cm.) Push/Pull (2 stages) > 24 in. Total Push with 1-2 steps	2-3 Revs.	2.5 sec.	Align to 2 points > 4 in. (10 cm.)
10	Push/Pull (3-4 stages) Push with 3-5 steps	4-6 Revs.	4.5 sec.	
16	Push with 6-9 steps	7-11 Revs.	7 sec.	Align with precision

Table 11.6 – Controlled move table (example)

11.2.3 Tool use

The tool-use sequence model should be used when tools are needed, such as a hammer, scissors, or a screwdriver. It is worth noting that activities such as writing and reading are also analyzed using this model. Actions that follow this sequence model are listed below:

- Wipe a surface with a cloth.
- Cut a box with a knife.
- Loosen a nut with a wrench.

The phases of the tool use sequence model are basically a combination of the general move and the tool action itself: Get tool (ABG) + Put tool (ABP) + Use tool (*) + Aside tool (ABP) + Return (A) (Figure 11.6).

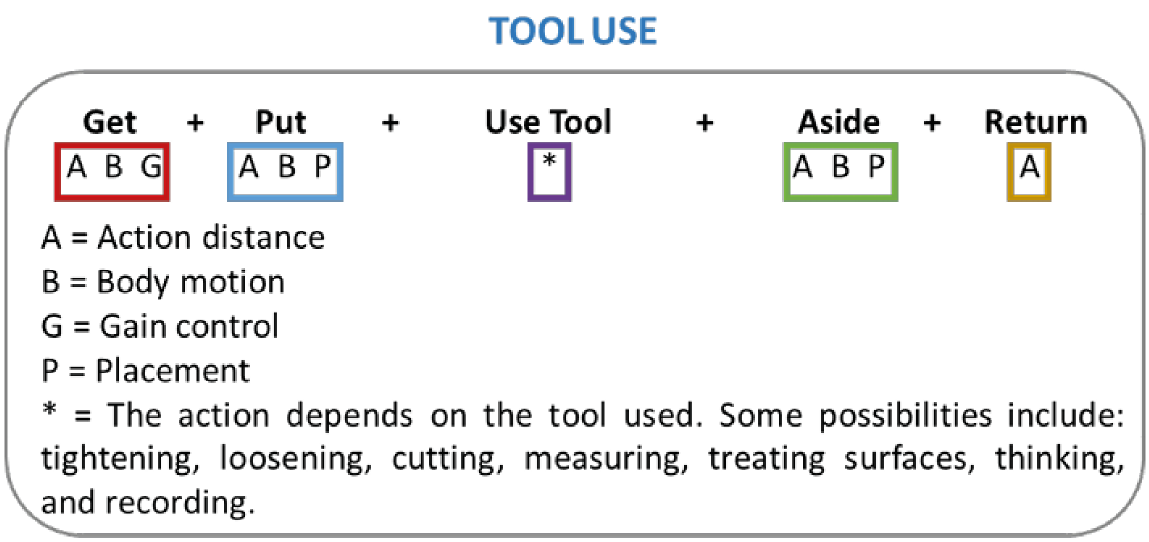

Figure 11.6 – Tool use phases

The indices assigned to each of these parameters are presented in the tables below, according to the action performed by the tool: tightening, loosening, cutting, surface treatment, thinking, and recording.

FASTEN / LOOSEN

For example, the actions of FASTENING or LOOSENING involve the manual or mechanical assembly of an object, which can be carried out using the strength of the fingers, wrists, arms, or the motor power of a tool. The tables that present the indices for tightening and loosening actions are therefore subdivided into:

- Finger action.
- Wrist action.
- Arm action.
- Tool action.

At the end, the specific movement to be performed and the type of tool to be used must be defined. To determine the appropriate index, the following questions should be answered:

1. What is the action to be performed with the tool (loosening, fastening)?
2. What generates the necessary force to act (fingers, wrists, arms, tools)?
3. What is the movement to be performed with the tool (turns, rotations, strikes)?
4. What tool will be used (ratchet wrench, adjustable wrench, screwdriver, hammer, Allen key, hands)?

Tables 11.7 and 11.8 present the indices for the FASTEN and LOOSEN actions. These actions can be performed using various tools, such as fingers, a screwdriver, a ratchet, a T-wrench, an Allen key, a hammer, or a power wrench (Figure 11.7).

Figure 11.7 – FASTEN or LOOSEN tools

The use of these parameters and indices for the FASTEN and LOOSEN actions is illustrated below.

Example – A operator picks up a screwdriver from a table within reach and places it on the head of a screw. Then he turns down the screw 9 wrist turns and sets the tool aside.

The GET TOOL phase has the following parameters:

- Action distance (A): the screwdriver is within reach.
- Body motion (B): no body motion occurs.
- Gain control (G): the screwdriver is a light object.

The PUT TOOL phase is broken down into the following parameters:

- Action distance (A): the head of the screw is within reach.

- Body motion (B): no body motion occurs.
- Placement (P): the screwdriver is placed on the head of a screw with adjustments.

TOOL USE: Get tool (ABG) + Put tool (ABP) + Use tool (*) + Aside tool (ABP) + Return (A)					
FASTEN OR LOOSEN					
Index	Finger action	Wrist action			
	Spins	Turns	Strokes	Cranks	Taps
	Fingers, screw-driver	Hands, screw-driver, ratchet, t-wrench	Wrench, allen key	Wrench, allen key, ratchet	Hand, hammer
1	1	-	-	-	1
3	2	1	1	1	3
6	3	3	2	3	6
10	8	5	3	5	10
16	16	9	5	8	16
24	25	13	8	11	23
32	35	17	10		30
42	47	23	13		39
54	61	29	17		50

Table 11.7 – Tool use table (FASTEN or LOOSEN – Finger and wrist action)

TOOL USE: Get tool (ABG) + Put tool (ABP) + Use tool (*) + Aside tool (ABP) + Return (A)							
FASTEN OR LOOSEN							
Index	Tool action	Arm action					
	Screw diameter	Turns		Strokes	Cranks	Strikes	
	Power wrench	Ratchet	T-wrench, 2-hands	Wrench, allen key	Wrench, allen key, ratchet	Hand, hammer	
1	-	-	-	-	-	-	
3	1/4" (6 mm)	1	-	1	-	1	
6	1" (25 mm)	2	1	-	1	3	
10		4	-	2	2	5	
16		6	3	3	3	8	
24		9	6	4	5	12	
32		12	8	6		16	
42		15	11	8		21	
54		20	15	10		27	

Table 11.8 – Tool use table (FASTEN or LOOSEN – Tool and arm action)

The USE TOOL phase refers to the action of fastening a screw through wrist movements. Therefore, Table 11.7 should be consulted. Furthermore, the tool is a screwdriver, and the movement to be carried out is 9 wrist turns.

The ASIDE TOOL phase involves an action distance (A), a body motion (B), and the difficulty of placing the tool (P). The operator sets the tool aside in a within-reach location, with no body motion.

Then you must RETURN to the place of origin, which involves only the action distance (A) parameter. In this case, the operator did not return, so its index value was 0.

Figure 11.8 and Tables 11.9 and 11.10 present the indices for this example.

TOOL USE: FASTEN OR LOSEN

Get tool +	Put tool +	Tool action +	Aside tool +	Return
A1 B0 G1	A1 B0 P3	*16	A1 B0 P1	A0

GET the scredriver
(Table 11.9 – red rectangle):
A - Within reach – index **1**
B - No body motion – index **0**
G - Grasp light object– index **1**

PUT the screwdriver on the head of a screw
(Table 11.9 – blue rectangle):
A - Within reach – index **1**
B - No body motion – index **0**
P - Place with adjustments – index **3**

FASTEN/LOSEN screw
(Table 11.10 – purple rectangle):
* - 9 wrist turns with a screwdriver – index **16**

Lay ASIDE the screwdriver
(Table 11.9 – green rectangle):
A - Within reach – index **1**
B - No body motion – index **0**
P - Lay aside – index **1**

RETURN to place of origin
(Table 11.9 – yellow rectangle):
A - No return – index **0**

Figure 11.8 – Indices for the tool use example (FASTEN or LOOSEN)

At the end, the indices found are added, and the result is multiplied by 10:

$$1 + 0 + 1 + 1 + 0 + 3 + 16 + 1 + 0 + 1 + 0 = 24 \times 10 = 240 \text{ TMU}$$

Converting the result from Time Measurement Units (TMU) to seconds, we find that 8.64 seconds is the standard time for this fastening operation, according to the BasicMOST tables.

240 TMU x 0.036 seconds/TMU = 8.64 seconds

GENERAL MOVE: Get (ABG) + Put (ABP) + Return (A)				
Index	**A** Action distance	**B** Body motion	**G** Gain control	**P** Placement
0	≤ 2 in. (5 cm)	No body motion	No gain control Hold	No placement Hold Toss
1	Within reach		Grasp light objects	Lay aside Loose fit
3	1-2 steps	Sit without adjustments Stand without adjustments Bend and arise (50% occ.)	Get heavy/bulky Get obstructed Disengage Collect	Loose fit blind Place with adjustments, light pressure OR double placement
6	3-4 steps	Bend and arise		Position with care, precision, blind, obstructed, with heavy pressure OR with intermediate moves
10	5-7 steps	Sit Stand		
16	8-10 steps	Bend and sit Climb on OR climb off Stand and bend Through door		

Table 11.9 – General move table (fasten example)

TOOL USE: Get tool (ABG) + Put tool (ABP) + Tool action (*) + Aside tool (ABP) + Return (A)					
FASTEN OR LOOSEN					
Index	Finger action	Wrist action			
	Spins	Turns	Strokes	Cranks	Taps
	Fingers, screw-driver	Hands, screw-driver, ratchet, t-wrench	Wrench, allen key	Wrench, allen key, ratchet	Hand, hammer
1	1	-	-	-	1
3	2	1	1	1	3
6	3	3	2	3	6
10	8	5	3	5	10
16	16	9	5	8	16
24	25	13	8	11	23
32	35	17	10		30
42	47	23	13		39
54	61	29	17		50

Table 11.10 – Tool use table (fasten example)

CUT OR SURFACE TREAT

The indices for the tool-use actions CUT and SURFACE TREAT are presented in the same table. The action CUT refers to manual activities that separate, divide, or remove part(s) of an object using a sharp-edged hand tool, such as pliers, scissors, or a knife. Meanwhile, the action SURFACE TREAT covers activities related to cleaning material from a surface or applying a substance, coating, or finish to it. It has three categories: Air-Clean, Brush-Clean, and Wipe.

Table 11.11 presents the indices for this tool-use (CUT or SURFACE TREAT) example.

TOOL USE: Get tool (ABG) + Put tool (ABP) + Tool action (*) + Aside tool (ABP) + Return (A)							
CUT OR SURFACE TREAT							
Index	**Cut**				**Surface treat**		
	Pliers		**Scissors**	**Knife**	**Air-clean**	**Brush-clean**	**Wipe**
	Twist/bend	**Cutoff Wire**	**Cut(s)**	**Slice(s)**	**Sq. ft. (0.1 m.²)**	**Sq. ft. (0.1 m.²)**	**Sq. ft. (0.1 m.²)**
1	Grip		1	-	-	-	-
3		Soft	2	1	-	-	1/2
6	Twist Bend-loop	Medium	4	-	1 Spot 1 Point 1 Cavity	1 small object	-
10		Hard	7	3	-	-	1
16	Bend Cotter pin		11	4	3	2	2
24			15	6	4	3	-
32			20	9	7	5	5
42			27	11	10	7	7
54			33				

Table 11.11 – Tool use table (CUT / SURFACE TREAT)

TOOL USE: CUT OR SURFACE TREAT

Get tool	+	Put tool	+	Tool action	+	Aside tool	+	Return
A1 B0 G1		A1 B0 P1		*6		A1 B0 P1		A0

GET scissors
(Table 11.12 – red rectangle):
A - Within reach – index 1
B - No body motion – index 0
G - Grasp light object – index 1

PUT scissors in contact with the paper
(Table 11.12 – blue rectangle):
A - Within reach – index 1
B - No body motion – index 0
P - Loose fit – index 1

CUT using scissors
(Table 11.13 – purple rectangle):
* - 4 scissors cut – index 6

Lay ASIDE scissors
(Table 11.12 – green rectangle):
A - Within reach – index 1
B - No body motion – index 0
P - Lay aside – index 1

RETURN to place of origin
(Table 11.12 – yellow rectangle):
A - No return – index 0

Figure 11.9 – Indices for the tool use example (CUT or SURFACE TREAT)

Example – An office employee reaches for a pair of scissors and cuts a sheet into 4 pieces. In the end, he puts the scissors down on the table.

Now that the reader has become familiar with the phases of the general and controlled move sequence models, the focus will be on describing the tool action phase. The action in this case is to CUT a sheet with SCISSORS. If we consult the Basic-MOST table, we should specify how many pieces will be cut with this tool. In this case, the sheet will be cut into 4 pieces.

Figure 11.9 and Tables 11.12 and 11.13 present the indices for this example.

Then, the indices found are added, and the result is multiplied by 10:

1 + 0 + 1 + 1 + 0 + 1 + 6 + 1 + 0 + 1 + 0 = 12 x 10 = 120 TMU

Converting the result in Time Measurement Units (TMU) to seconds, we have:

120 TMU x 0.036 seconds/TMU = 4.32 seconds

That is, 4.32 seconds is the standard time for this tool-use example (CUT) according to the BasicMOST tables.

GENERAL MOVE: Get (ABG) + Put (ABP) + Return (A)				
Index	A Action distance	B Body motion	G Gain control	P Placement
0	≤ 2 in. (5 cm)	No body motion	No gain control Hold	No placement Hold Toss
1	Within reach		Grasp light objects	Lay aside Loose fit
3	1-2 steps	Sit without adjustments Stand without adjustments Bend and arise (50% occ.)	Get heavy/bulky Get obstructed Disengage Collect	Loose fit blind Place with adjustments, light pressure OR double placement
6	3-4 steps	Bend and arise		Position with care, precision, blind, obstructed, with heavy pressure OR with intermediate moves
10	5-7 steps	Sit Stand		
16	8-10 steps	Bend and sit Climb on OR climb off Stand and bend Through door		

Table 11.12 – General move table (cut example)

TOOL USE: Get tool (ABG) + Put tool (ABP) + Tool action (*) + Aside tool (ABP) + Return (A)							
CUT OR SURFACE TREAT							
Index	Cut				Surface treat		
	Pliers		Scissors	Knife	Air-clean	Brush-clean	Wipe
	Twist/bend	Cutoff Wire	Cut(s)	Slice(s)	Sq. ft. (0.1 m.^{2})	Sq. ft. (0.1 m.^{2})	Sq. ft. (0.1 m.^{2})
1	Grip		1	-	-	-	-
3		Soft	2	1	-	-	1/2
6	Twist Bend-loop	Medium	4	-	1 Spot 1 Point 1 Cavity	1 small object	-
10		Hard	7	3	-	-	1
16	Bend Cotter pin		11	4	3	2	2
24			15	6	4	3	-
32			20	9	7	5	5
42			27	11	10	7	7
54			33				

Table 11.13 – Tool use table (cut example)

RECORD / THINK

The tool action RECORD refers to manual actions performed with a writing or marking instrument to record information. Therefore, this tool can be branched as follows:

- Write: digits or words.
- Mark: digits.

Meanwhile, the tool action THINK is related to the use of sensory mental processes, particularly those involving visual perception. It has the following options:

- Inspect: based on the number of points to inspect.
- Read: digits/single words or text of words.

TOOL USE: Get tool (ABG) + Put tool (ABP) + Tool action (*) + Aside tool (ABP) + Return (A)						
RECORD (write and mark) OR THINK (inspect and read)						
Index	Record			Think		
	Write		Mark	Inspect	Read	
	Digits	Words	Digits	Points	Digits Single words	Text of words
1	1	-	Check Mark	1	1	3
3	2	-	1 Line	3	3 Gauge	8
6	4	1	2	5 Touch for heat	6 Date OR Time	15 Date OR Time
10	6	-	3	9 Feel for defect	12	24
16	9 Signature OR Date	2 Signature OR Date	5	14		38
24	13	3	7	19		54
32	18	4	10	26		72
42	23	5	13	34		94
54	29	7	16	42		119

Table 11.14 – Tool use table (RECORD / THINK)

The use of these parameters and indices for the RECORD or THINK actions can be found in Table 11.14, and an example is presented below.

Example – An operator picks up a job card (within reach), reads the instructions (54 words), and sets the card 3 steps away.

Again, the focus will be solely on describing tool use. It is important to note that after picking up the job card, it is not necessary to place it anywhere so it can be read. The THINK tool action consists of READING a TEXT OF WORDS. As 54 are read, the index is 24.

Figure 11.10 and Tables 11.15 and 11.16 present the indices related to this THINK example.

TOOL USE: RECORD OR THINK

Get tool	+	Put tool	+	Use tool	+	Aside tool	+	Return
A1 B0 G1		A0 B0 P0		*24		A6 B0 P1		A0

GET a job card
(Table 11.15 – red rectangle):
A - Within reach – index **1**
B - No body motion – index **0**
G - Grasp light objects – index **1**

PUT the job card
(Tabela 11.15 – retângulo azul):
A - No action distance – index **0**
B - No body motion – index **0**
P - No placement – index **0**

THINK (READ) the instructions
(Table 11.16 – purple rectangle):
* - Read the instructions (54 words) – index **24**

ASIDE the job card
(Table 11.15 – green rectangle):
A - Walk 3 Steps – index **6**
B - No body motion – index **0**
P - Lay aside – índice **1**

RETURN to place of origin
(Table 11.15 – yellow rectangle):
A - No return – index **0**

Figure 11.10 – Indices for the tool use example (RECORD / THINK)

GENERAL MOVE: Get (ABG) + Put (ABP) + Return (A)				
Index	**A** Action distance	**B** Body motion	**G** Gain control	**P** Placement
0	≤ 2 in. (5 cm)	No body motion	No gain control Hold	No placement Hold Toss
1	Within reach		Grasp light objects	Lay aside Loose fit
3	1-2 steps	Sit without adjustments Stand without adjustments Bend and arise (50% occ.)	Get heavy/bulky Get obstructed Disengage Collect	Loose fit blind Place with adjustments, light pressure OR double placement
6	3-4 steps	Bend and arise		Position with care, precision, blind, obstructed, with heavy pressure OR with intermediate moves
10	5-7 steps	Sit Stand		
16	8-10 steps	Bend and sit Climb on OR climb off Stand and bend Through door		

Table 11.15 – General move table (think example)

TOOL USE: Get tool (ABG) + Put tool (ABP) + Tool action (*) + Aside tool (ABP) + Return (A)						
RECORD (write and mark) OR THINK (inspect and read)						
Index	Record			Think		
	Write		Mark	Inspect	Read	
	Digits	Words	Digits	Points	Digits Single words	Text of words
1	1	-	Check Mark	1	1	3
3	2	-	1 Line	3	3 Gauge	8
6	4	1	2	5 Touch for heat	6 Date OR Time	15
10	6	-	3	9 Feel for defect	12	24
16	9 Signature OR Date	2	5	14		38
24	13	3	7	19		54
32	18	4	10	26		72
42	23	5	13	34		94
54	29	7	16	42		119

Table 11.16 – Tool use table (think example)

Accordingly, we have:

1 + 0 + 1 + 0 + 0 + 0 + 24 + 6 + 0 + 1 + 0 = 33 x 10 = 330 TMU

Finally, converting the result in Time Measurement Units (TMU) to seconds, we find that 11.88 seconds is the standard time for this operation.

330 TMU x 0.036 seconds/TMU = 11.88 seconds

11.2.4 Develop your own table!

In this chapter, the most important BasicMOST tables were presented. Some less-used tables, such as those related to MEASURING actions and to the USE OF A MANUAL CRANE, were not addressed. If, during the study of a given operation, the reader does not find the required tables, it is worth remembering that it is also possible to consult

AdminMOST, MiniMOST, and MaxiMOST, as described at the beginning of the chapter.

However, if the reader remains with this problem, after consulting these other tables, this section will teach how to create a predetermined time system for an action, for example, glue. A step-by-step guide to creating this pattern will be provided.

Step 1 – Definition of the sequence model

The first step is to define which sequence model will be applied to the action. It is worth recalling that in BasicMOST, there are three models:

- General move.
- Controlled move.
- Tool use.

The most appropriate model must be selected according to the action. It is also possible to combine two models, if necessary. In the example under consideration, the action of GLUING may be classified as a TOOL USE movement, in which the glue is regarded as the tool employed. This action may therefore be subdivided into the following phases and parameters:

- GET glue (ABG).
- PUT glue in contact with an object, such as paper (ABP).
- ACTION of the glue (*).
- ASIDING the glue and putting it in its designated storage location (ABP).
- RETURN to the point of origin (A).

Once the sequence model has been defined, we may proceed to the next stage. The actions of GETTING, PUTTING, ASIDING TOOL, and RETURNING may be consulted in Tables 11.1 and 11.2, whereas the GLUING table must be developed.

Step 2 – Identification of factors affecting action time

In mathematics, a dependent variable (y) can be defined in terms of several independent variables (x_1, x_2, ..., x_n). At this stage, the objective is to determine which independent variables will influence the time required to complete the gluing task.

Through brainstorming, some of these variables can be identified, such as:

- Type of glue: Liquid glue or glue stick.
- Area to which the glue will be applied: Measured in square meters (m^2) or square centimeters (cm^2).

Other factors may also be considered, such as the surface on which the glue will be applied. Would the required time be the same when applying glue to paper, wood, or polystyrene? In any case, for simplicity, this example will focus exclusively on the two independent variables listed above.

We can, accordingly, build our own table for the GLUE action.

Step 3 – Building the table

In this step, the tool-use table (GLUE) will be built based on the independent variables listed in the second step.

We are going to create a column for each of the two types of glue: liquid glue and glue stick. In addition, we need to relate the indices to some other quantitative variable. In this case, we will define the index of the gluing action based on the area where the glue will be applied. After all, the larger the area to be glued, the longer we will spend on this action. Thus, this measure will be in square feet since this example considers a small area. At the end, we have a use tool table for the action GLUE (Table 11.17).

TOOL USE Get tool (ABG) + Put tool (ABP) + Tool action (*) + Aside tool (ABP) + Return (A)		
Index	GLUE	
	Liquid glue	Glue stick
	Sq. ft.	Sq. ft.
1		
3		
6		
10		
16		
24		
32		
42		
54		

Tabela 11.17 – Tool use table (GLUE)

Finally, all that remains is to fill in the square feet values for each index.

Step 4 – Completing the table

In this step, the standard times for each category related to the action GLUE are studied. In this case, we can use liquid glue or a glue stick.

In each experiment, the measurement of glue should be correlated with the time spent gluing with a specific type of glue. Thus, the table would be progressively filled.

It is essential to note that, for example, index 1, when multiplied by 10, totals 10 TMU, which is approximately 0.36 seconds.

Index 1 = 10 TMU x 0.036 seconds/TMU = 0.36 second

The use of these parameters and indices will be exemplified: index 3 represents 3 x 0.36 seconds, that is, 1.08 seconds. The logic is similar for the other indices.

At the end of this step-by-step, the reader will have built their own table.

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CHAPTER 12: WORK SAMPLING

The third measurement procedure is work sampling, a technique used to investigate the proportion of time an operator or piece of equipment spends performing different activities. It is a method that evaluates work through a large number of observations taken at random intervals.

In other words, it is a technique for sampling work based on the premise that, with a sufficiently large number of observations, the sample characteristics tend to resemble those of the entire population (Figure 12.1). The accuracy of this technique, therefore, depends on both the number of observations and the interval used for collecting random samples.

If the sample size is insufficient or the sampling period does not reflect typical working conditions, the results may be inaccurate.

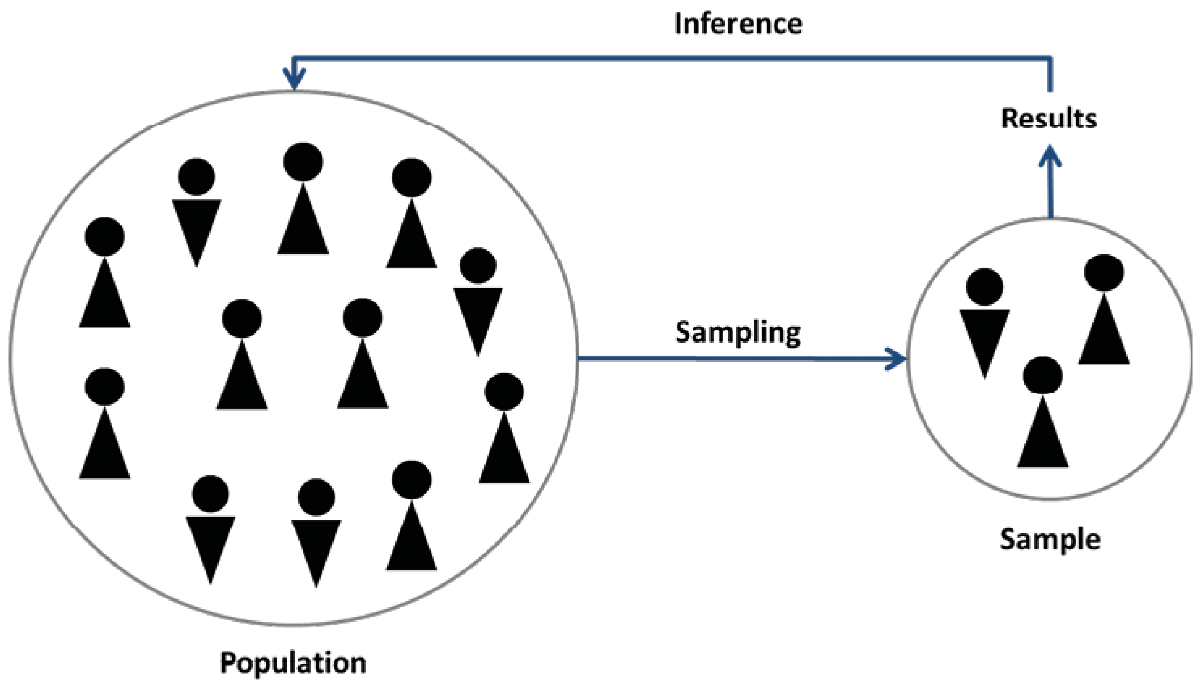


Figure 12.1 – Work Sampling

This method was initially employed in the British textile industry. In 1940, it was first applied in the United States under the name "ratio-delay study." Despite being developed decades ago, work sampling remains widely used in both industry and service sectors today. It can be employed for various purposes, including:

- Determining equipment and personnel utilization.
- Establishing allowances (tolerances).
- Setting standard times.

It is a valuable technique in various contexts. For example, a manufacturing company's sales department may use it to determine the percentage of time sales representatives spend on selling activities. Work sampling has also been used in banking studies to compare the proportion of time employees spend on tasks requiring high-level skills versus those requiring minimal qualifications. In other words, the methodology is broadly applicable across industries, including hospitals, restaurants, airports, and other organizations.

As discussed in previous chapters, time studies and predetermined time systems are also methods for similar purposes. What, then, differentiates work sampling from these other work measurement techniques? Its advantages can be summarized in two words: speed and low cost. Therefore, when high measurement precision is not essential, or when financial, human, or time resources are limited, work sampling is preferable to time studies and predetermined time systems.

Due to its lower time and cost demands, work sampling is commonly used in industrial settings. However, the method's simplicity is often overestimated, leading to improper application without the necessary statistical foundation. As the name suggests, work sampling is firmly grounded in statistical and probability theory.

ADVANTAGES	DISADVANTAGES
Continuous observation over extended periods is not required.	Its potential is underutilized when evaluating a single piece of equipment or operator.
Shorter data collection time.	Not recommended when machines or operators are distributed over a large area.
Low operating costs.	This methodology should not be applied to repetitive short-cycle operations.
Fewer people are required to conduct the study.	Results generally provide less information and detail than time studies (chronometric analyses).
A single observer can simultaneously collect data on	When a work sampling study is conducted for a group of machines

several operators and pieces of equipment.	or operators, only the group average is obtained — individual differences are not assessed.
Data can be collected over more extended periods (days or weeks), reducing the influence of special causes.	Caution is needed when interpreting results, as their level of detail and reliability depend heavily on proper study planning.
Operators are not subjected to prolonged data collection, which could otherwise influence their behavior.	Results may take operators and managers longer to understand due to the statistical nature of work sampling.
Less training and prior expertise are required for those conducting the study.	Work sampling studies depend on the operator's working method; changes in the method or operator behavior can compromise results, requiring new studies.
Less fatiguing and monotonous than continuous observation studies.	Observers may overlook key principles of work sampling, such as defining the maximum tolerable relative error and, consequently, determining the appropriate sample size.
No need for time measurement devices such as stopwatches or cameras.	Considerable time is required to plan and analyze the work elements and subdivisions to be evaluated.
The time required for analyzing the collected data is relatively low.	It does not measure other dimensions of work activities, such

	as the specific duration of each task or the quality of the work performed.
Occasional interruptions do not compromise or invalidate the work sampling study.	

Table 12.1 – Advantages and disadvantages of work sampling

12.1 The theory of Work Sampling: Binomial distribution

Work sampling is based on the binomial distribution, which is used to describe studies conducted with *n* independent observations, each of which has two possible outcomes: present or absent.

Let *p* be the probability of the occurrence of an event *E*, and *q* = 1 -*p* the probability of the non-occurrence of an event *E*, which is complementary to *E*. Thus, the probability that the event of interest occurs *x* times in *n* observations is given by the following formula:

$$P(x) = \frac{n!}{x!\,(n-x)!} \cdot p^n \cdot q^{n-x}$$

Description of the variables in the formula:

p(x): Probability that the event of interest occurs *x* times in *n* observations

x: Number of times the event of interest occurs

n: Total number of observations conducted

p: Probability that the event of interest occurs in each observation

q = (1 - p): Probability that the event of interest is absent in each observation

This expression is known as the Binomial Law of Probability and can only be applied under the following conditions:

- The collection of observations is repeated *n* times under the same conditions.
- Each observation has only two possible outcomes: event *E* is either present or absent.
- The probability of an event *E* being present (*p*) is constant across all n observations.
- The observations are independent of one another.

The binomial distribution has a mean equal to *np* and a variance equal to *npq*, that is, *np(1 - p)*. When working with a large number of n observations, it becomes difficult to calculate probabilities using the binomial distribution. In such cases, the distribution can be approximated by a normal distribution. After all, since a binomial random variable represents the count of occurrences from repeated and independent observations, the Central Limit Theorem can be applied.

The approximation of the binomial distribution by the normal distribution is satisfactory when *n* is sufficiently large in relation to the value of *p*, that is, when this condition holds:

$$np > 5 \ \ e \ \ n(1-p) > 5$$

Therefore, work sampling studies require a large number of samples to be collected, as a normal distribution is appropriate under these conditions. The sample proportion $\hat{p} = X/n$, where *X* represents the number of times the event *E* is present in the *n* observations, and it approximately follows a normal distribution with a mean equal to *p*, and the standard deviation ($\sigma_{\hat{p}}$) is given by the following expression:

$$P(x) = \frac{n!}{x!\,(n-x)!} \cdot p^{n} \cdot q^{n-x}$$

Description of the variables in the formula:

$\sigma_{\hat{p}}$: Standard deviation of the sample proportion

n: Number of random observations conducted

p: Probability of occurrence of the studied element (event of presence)

q = (1 - p): Probability of non-occurrence of the studied element (event of absence)

Accordingly,

$$Z = \frac{\hat{p} - p}{\sigma_{\hat{p}}}$$

It has approximately a standard normal distribution represented by *Z* the distribution (Figure 12.2). The probabilities calculated from *Z* can therefore be regarded as approximate probabilities for the sampling process, and the "Cumulative Probabilities of a Standard Normal Distribution (*Z*)" table in Appendix 3 may be consulted.

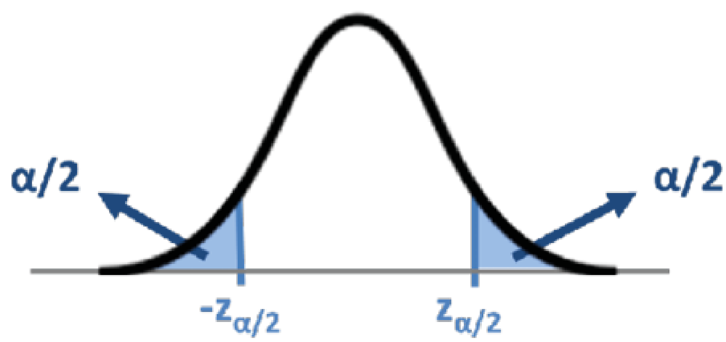


Figure 12.2 – Z Distribution

Based on Figure 12.2, it can be observed that:

$$P\{-Z_{\alpha/2} \leq Z \leq Z_{\alpha/2}\} = 1 - \alpha$$

So that:

$$P\left\{-z_{\alpha/2} \leq \frac{\hat{p} - p}{\sigma_{\hat{p}}} \leq z_{\alpha/2}\right\} = 1 - \alpha$$

Which, when rearranged, becomes:

$$P\{\hat{p} - z_{\alpha/2}\sigma_{\hat{p}} \leq p \leq \bar{\hat{p}} + z_{\alpha/2}\sigma_{\hat{p}}\} = 1 - \alpha$$

Thus, if we consider a significance level (α) of 5%, by consulting the cumulative area table of the standard normal distribution (z), it follows that $z_{\alpha/2}$ = $z_{0,025}$ = $z_{0,975}$ = 1,96 (Figure 12.3). By substituting the estimate, we obtain:

$$P\left\{\hat{p} - 1{,}96\sqrt{\frac{\hat{p}\hat{q}}{n}} \leq p \leq \bar{X} + 1{,}96\sqrt{\frac{\hat{p}\hat{q}}{n}}\right\} = 0{,}95$$

Área acumulada da distribuição normal-padrão (z)

z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0	0.5000	0.5040	0.5080	0.5120	0.5160	0.5199	0.5239	0.5279	0.5319	0.5359
0.1	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.5675	0.5714	0.5753
0.2	0.5793	0.5832	0.5871	0.5910	0.5948	0.5987	0.6026	0.6064	0.6103	0.6141
0.3	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.6443	0.6480	0.6517
0.4	0.6554	0.6591	0.6628	0.6664	0.6700	0.6736	0.6772	0.6808	0.6844	0.6879
0.5	0.6915	0.6950	0.6985	0.7019	0.7054	0.7088	0.7123	0.7157	0.7190	0.7224
0.6	0.7257	0.7291	0.7324	0.7357	0.7389	0.7422	0.7454	0.7486	0.7517	0.7549
0.7	0.7580	0.7611	0.7642	0.7673	0.7704	0.7734	0.7764	0.7794	0.7823	0.7852
0.8	0.7881	0.7910	0.7939	0.7967	0.7995	0.8023	0.8051	0.8078	0.8106	0.8133
0.9	0.8159	0.8186	0.8212	0.8238	0.8264	0.8289	0.8315	0.8340	0.8365	0.8389
1	0.8413	0.8438	0.8461	0.8485	0.8508	0.8531	0.8554	0.8577	0.8599	0.8621
1.1	0.8643	0.8665	0.8686	0.8708	0.8729	0.8749	0.8770	0.8790	0.8810	0.8830
1.2	0.8849	0.8869	0.8888	0.8907	0.8925	0.8944	0.8962	0.8980	0.8997	0.9015
1.3	0.9032	0.9049	0.9066	0.9082	0.9099	0.9115	0.9131	0.9147	0.9162	0.9177
1.4	0.9192	0.9207	0.9222	0.9236	0.9251	0.9265	0.9279	0.9292	0.9306	0.9319
1.5	0.9332	0.9345	0.9357	0.9370	0.9382	0.9394	0.9406	0.9418	0.9429	0.9441
1.6	0.9452	0.9463	0.9474	0.9484	0.9495	0.9505	0.9515	0.9525	0.9535	0.9545
1.7	0.9554	0.9564	0.9573	0.9582	0.9591	0.9599	0.9608	0.9616	0.9625	0.9633
1.8	0.9641	0.9649	0.9656	0.9664	0.9671	0.9678	0.9686	0.9693	0.9699	0.9706
1.9	0.9713	0.9719	0.9726	0.9732	0.9738	0.9744	0.9750	0.9756	0.9761	0.9767
2	0.9772	0.9778	0.9783	0.9788	0.9793	0.9798	0.9803	0.9808	0.9812	0.9817
2.1	0.9821	0.9826	0.9830	0.9834	0.9838	0.9842	0.9846	0.9850	0.9854	0.9857
2.2	0.9861	0.9864	0.9868	0.9871	0.9875	0.9878	0.9881	0.9884	0.9887	0.9890
2.3	0.9893	0.9896	0.9898	0.9901	0.9904	0.9906	0.9909	0.9911	0.9913	0.9916
2.4	0.9918	0.9920	0.9922	0.9925	0.9927	0.9929	0.9931	0.9932	0.9934	0.9936
2.5	0.9938	0.9940	0.9941	0.9943	0.9945	0.9946	0.9948	0.9949	0.9951	0.9952
2.6	0.9953	0.9955	0.9956	0.9957	0.9959	0.9960	0.9961	0.9962	0.9963	0.9964
2.7	0.9965	0.9966	0.9967	0.9968	0.9969	0.9970	0.9971	0.9972	0.9973	0.9974
2.8	0.9974	0.9975	0.9976	0.9977	0.9977	0.9978	0.9979	0.9979	0.9980	0.9981
2.9	0.9981	0.9982	0.9982	0.9983	0.9984	0.9984	0.9985	0.9985	0.9986	0.9986
3	0.9987	0.9987	0.9987	0.9988	0.9988	0.9989	0.9989	0.9989	0.9990	0.9990
3.1	0.9990	0.9991	0.9991	0.9991	0.9992	0.9992	0.9992	0.9992	0.9993	0.9993
3.2	0.9993	0.9993	0.9994	0.9994	0.9994	0.9994	0.9994	0.9995	0.9995	0.9995
3.3	0.9995	0.9995	0.9995	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9997
3.4	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9998

Figure 12.3 – Consulting the cumulative area of the Standard Normal Distribution (Z-Score Table)

Consequently, in work sampling studies, a sample of *n* observations is used to estimate the probability *p*. From the confidence level of the interval given by (1-α)×100%, for *m* samples of *n* size drawn from the same population, m → ∞, it is expected that the value of *p* will lie 95% of the time within the confidence interval:

$$\hat{p} - 1{,}96\sqrt{\frac{\hat{p}\hat{q}}{n}} \leq p \leq \bar{X} + 1{,}96\sqrt{\frac{\hat{p}\hat{q}}{n}},$$

Which can be represented graphically, as shown in Figure 12.4.

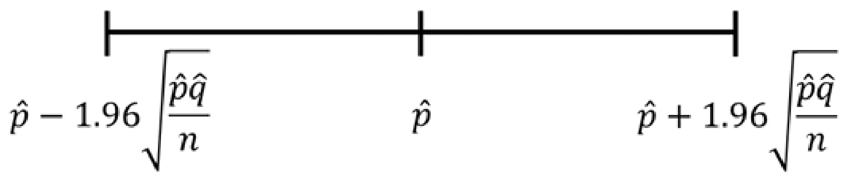


Figure 12.4 – Graphical representation of the confidence interval (α = 5%)

Consequently, it is possible to estimate the required sample size for a given degree of accuracy. From the equation above, we have that $1.96\sqrt{pq/n}$ is the acceptable deviation limit (*l*) from the actual value of *p* within a confidence interval of 100(1 - 0.05)%.

$$l = z_{\alpha/2}\sigma_{\hat{p}} = z_{\alpha/2}\sqrt{\frac{pq}{n}}$$ Fórmula 1

$$l = z_{0{,}025}\sigma_{\hat{p}} = 1{,}96\sqrt{\frac{pq}{n}}$$

Thus, *n* can be isolated to determine the number of samples to be collected, according to the chosen level of significance.

$$n = \frac{{z_{\alpha/2}}^2 pq}{l^2} = \frac{{z_{\alpha/2}}^2 p(1-p)}{l^2}$$

Considering a 95% confidence level, we then have:

$$n = \frac{1{,}96^2 pq}{l^2} = \frac{3{,}84pq}{l^2} = \frac{3{,}84p(1-p)}{l^2}$$

It is important to note that when more than one worker and/or piece of equipment is observed simultaneously, the observations are not considered independent, and the formulas presented above cannot be applied.

Studies involving correlated observations must use the standard deviation shown in **Formula 1**:

$$\sigma = \left[\frac{\sum [y(j)^2/n(j)] - Np^2}{N(m-1)}\right]^{\frac{1}{2}}$$

Description of the variables in the formula:

y(j): Number of “idle” operators, or another category of interest, in the *j*-th sample

n(j): Number of grouped units studied, which may vary according to the *j*-th sample or remain constant regardless of the sample

m: Number of samples collected

N: Total number of observations. If the value of *n(j)* is constant regardless of the sample, then

N=mxn(j). Otherwise: $N = \sum_{j=1}^{m} n(j)$

p: Actual occurrence percentage of the element under study $p = \sum y(j) / n$

12.2 Step-by-step procedure for conducting a work sampling study

Step 1 – Problem definition

a. Description of the main objectives of the project or problem.

b. Definition of activities and categories of interest

The purpose of the study will guide both the extent and the level of detail in subdividing the categories to be evaluated. When conducting a more general study, it may be appropriate to work with fewer categories. However, in specific projects, it may be necessary to subdivide categories into activities to examine them in greater detail.

It is important to emphasize that work sampling is more efficient when the number of categories is kept small, as this facilitates monitoring of the observation object. Moreover, there must be no overlap between these categories and activities.

Step 2 – Communication of the project to stakeholders

a. Approval of the proposed activities by supervisors.

b. Alignment of the study's purpose with operators and other relevant stakeholders.

Step 3 – Form development

Once approval and stakeholder alignment are achieved, a checklist can be developed to document the data to be collected. The form should present a user-friendly interface to facilitate its use and subsequent analyses.

Step 4 – Preliminary study

a. Conducting a short-duration study (one or two days) to determine the percentage of occurrence of the activities and categories.

b. Verification of the adequacy of both the number and the definition of activities and categories: Should any be added or removed? Were they clearly defined? Is there any overlap between them?

c. Testing of the developed form to check whether adjustments are necessary: Is the form easy to use? Can data be recorded at the pre-established intervals without haste and without compromising the quality of the record?

Step 5 – Work sampling planning

a. Determination of the quantity and quality of variables to be observed: operators and equipment.

b. Determination of the desired level of accuracy in the results, which will be defined based on the tolerance or maximum acceptable relative error, according to a given level of significance.

The level of significance (α) is generally 5% or 1%, which corresponds, respectively, to a z-value of 1.96 and 2.56.

c. Determination of the number of observations to be collected.

From the definition of the maximum tolerable error and the desired confidence level, the required number of observations can be determined.

For example, consider a study aimed at calculating the required sample size at the 5% significance level to estimate the proportion of time an employee spends on non–value–added activities. Moreover, suppose that the maximum tolerable error for the true proportion of time spent on these activities is 1%. Based on a preliminary study, employees spend an average of 10% of their time on non–value–added activities, such as waiting. Thus, we have $\hat{p}$ = 0.1 and $\hat{l}$ = 0.01. These assumptions are represented graphically in Figure 12.5.

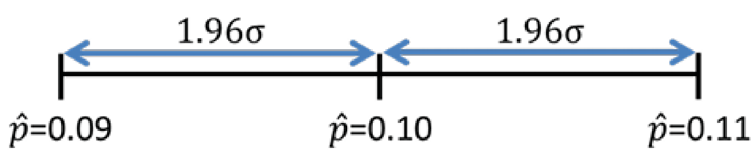


Figure 12.5 – Graphical representation of the confidence interval for the percentage of time spent on non-value-added activities (α = 5%)

Therefore, using the formulas presented previously, we can calculate the number of observations to be collected.

$$n = \frac{{z_{0.025}}^2 \times p \times (1-p)}{l^2} = \frac{3.84 \times 0.1 \times 0.9}{0.01^2} = 3{,}456 \; observations$$

However, if the observers in this study do not have sufficient time to complete all 3,456 observations and can only collect 1,000, the resulting confidence interval error would be approximately 2%.

$$l = z_{0.025}\sigma_{\hat{p}} = 1.96\sqrt{\frac{pq}{n}} = 1.96\sqrt{\frac{p(1-p)}{n}} = 1.96\sqrt{\frac{0.1(0.9)}{1{,}000}} = 0.019 = 1.9\%$$

Thus, the larger the sample size, the greater the accuracy and representativeness of the results.

It is worth noting that several software tools are currently available to determine the required sample size in a work sampling study, including QM for Windows (a free software), Work Measurement Software developed by Quetech Ltd., and Umt Plus, developed by Laubrass. These tools enhance work sampling studies by providing faster, more accurate results.

d. Determination of the observation frequency

The observation frequency, that is, the rate at which observations are collected within a predetermined period (hours, days, or weeks), depends mainly on two inputs:

- The number of samples/observations to be collected, as calculated in the previous subsection.
- The resources available for data collection (personnel and time).

As one of the main objectives of a work sampling study is to obtain a representative sample, it is advisable to design a study that requires more than one day of data collection. By extending observations over a longer period—such as weeks or even months—the reliability of the study increases, since any special cause variations are diluted over time.

For example, if 1,000 observations are to be collected over a period of 25 consecutive days, it will be necessary to collect 1,000/25 = 40 observations per day. It is important to note that other factors also affect the determination of the observation frequency, including the nature of the work being studied.

e. Determination of the moment at which each observation object's activity will be recorded.

Observations may be conducted at predetermined intervals or at random. When data collection intervals are defined randomly, an instrument must be used to generate random numbers. This may be achieved through scientific calculators, tables, or electronic spreadsheets.

f. Creation of detailed data collection plans (routes to be followed).

g. When other individuals collect data, it is necessary that they be adequately trained.

Step 6 – Data collection

a. Recording of data and observations.

The observer must not attempt to anticipate or infer the activity being performed by the observation object. The activity must be recorded precisely as it occurs.

The observer should move to a predetermined fixed point, observe the activity under study, and record it in the form.

It is equally important for the observer to be aware that they must not only focus on "what" is being observed, but also attempt to understand the "why." Such insights may prove relevant when considering potential future improvements to a workstation.

To reduce the impact of observers' presence on the behavior of the observed—a common effect when people are being observed—data collection may, for instance, be conducted using cameras.

b. Daily summary of collected data.

Note: Statistical quality control techniques may be employed during data collection, such as control charts (Figure 12.6). Since work sampling deals with percentages, one may, for example, construct charts of the defective fraction (p) and establish their limits based on a distance of 3α from the sample mean, i.e.,

$$3\sigma = 3\sqrt{\frac{pq}{n}} = 3\sqrt{\frac{p(1-p)}{n}}$$

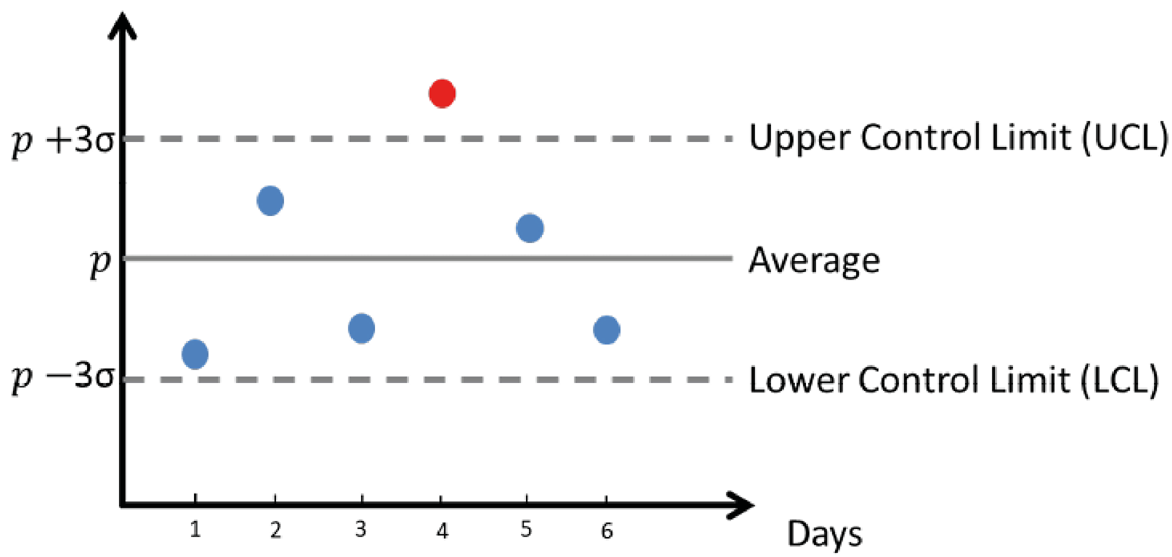


Figure 12.6 – Control chart for work sampling.

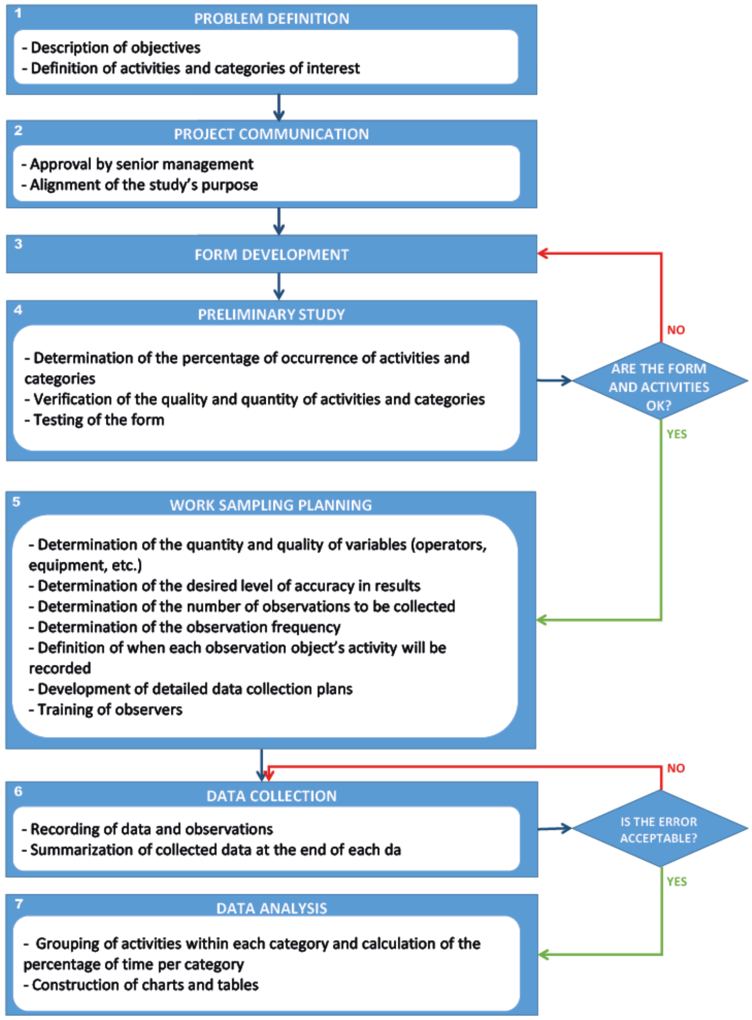


Figure 12.7 – Step-by-step procedure for a work sampling study

For a more in-depth understanding of the use of control charts in conjunction with work sampling, it is recommended to consult the books written by Barnes or Freivalds.

Step 7 – Data analysis

a. Grouping of activities into each category and calculation of the percentage of time per category.

b. Construction of charts and tables.

c. Development of recommendations and conclusions.

Figure 12.7 summarizes the steps described above.

12.3 Work sampling in industries

Work sampling will be illustrated through a case study in the automotive industry, which is undertaking a cost-reduction project. One of the project's objectives was to analyze two lathes with similar technical specifications in the machining sector. These machines represented the bottleneck in the production process under study, and the goal was to determine which one should be prioritized for improvements to achieve a greater capacity gain in less time.

Given the limited time available for the project and the need to avoid an in-depth study of the equipment, the work sampling technique was chosen. The activities performed by the lathe operators were categorized into 11 groups:

- Value-adding activity: an activity that adds value for the customer.
- Quality inspection.
- Cleaning.
- Performing adjustments and corrections.
- Providing explanations.
- Absence.
- Handling and transporting products and items.

- Administrative tasks.
- Movement/relocation.
- Waiting.
- Searching for materials.

The objective was to estimate the percentage of time operators spent on value-adding activities compared with other categories. The determination of the time proportion spent by operators on each of these activities is based on the theory that the relative frequency of observations is a reliable measure of the percentage of time spent on a given operation.

Therefore, a work sampling study was conducted in which observers recorded the activity the operator was performing every minute. Each piece of equipment was observed for 1 hour, yielding 60 observations per lathe. Tables 12.2 and 12.3 summarize the data collected for the two machines.

Activity	Quantity	Sum	Percentage
Value-adding	𝍸 𝍸	10	16.7%
Quality inspection	|	1	1.7%
Cleaning	||||	4	6.7%
Repairing	||||	5	8.3%
Talking	𝍸 |	6	10.0%
Abscence	||||	5	8.3%
Handling and transporting	||	2	3.3%

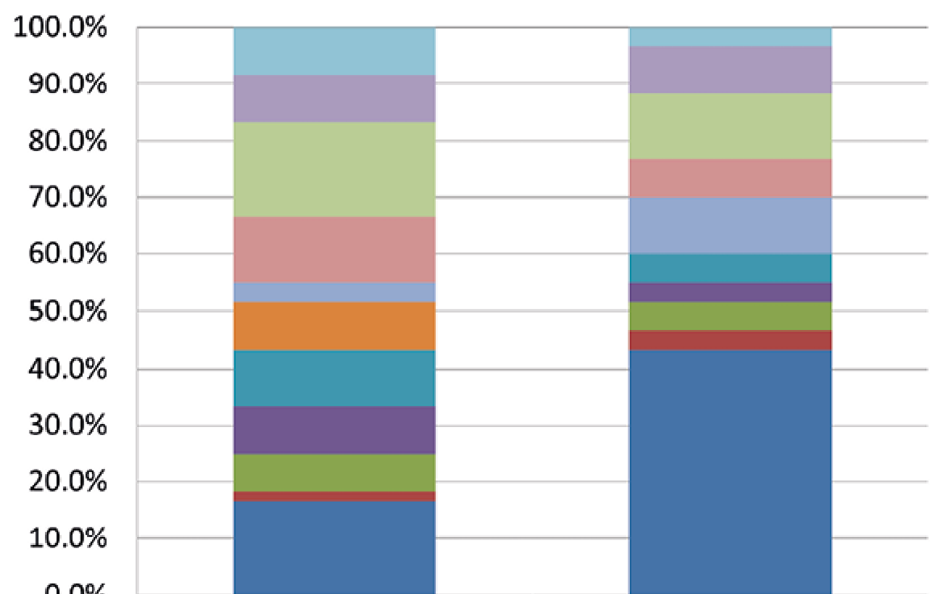
Administrative tasks	𝍸 ||	7	11.7%
Movement / Walking	𝍸 𝍸	10	16.7%
Waiting	||||	5	8.3%
Searching for materials	||||	5	8.3%
Sum	**-**	**60**	**100%**

Table 12.2 – Work sampling form (Machine 1)

Activity	Quantity	Sum	Percentage
Value-adding	𝍸 𝍸 𝍸 𝍸 𝍸 |	26	43.3%
Quality inspection	||	2	3.3%
Cleaning	|||	3	5.0%
Repairing	||	2	3.3%
Talking	|||	3	5.0%
Abscence	Ø	0	0.0%
Handling and transporting	𝍸 |	6	10.0%
Administrative tasks	||||	4	6.7%
Movement /	𝍸 ||	7	11.7%

Walking			
Waiting	||||	5	8.3%
Searching for materials	||	2	3.3%
Sum	**-**	**60**	**100%**

Table 12.3 – Work sampling form (Machine 2)



	Machine 1	Machine 2
Searching for materials	8.3%	3.3%
Waiting	8.3%	8.3%
Movement / Walking	16.7%	11.7%
Administrative tasks	11.7%	6.7%
Handling and transporting	3.3%	10.0%
Absence	8.3%	0.0%
Talking	10.0%	5.0%
Repairing	8.3%	3.3%
Cleaning	6.7%	5.0%
Quality inspection	1.7%	3.3%
Value-adding	16.7%	43.3%

Figure 12.8 – Equipment utilization comparison

Based on the collected data, a chart was generated to compare the utilization of both machines (Figure 12.8). As shown in this figure, the percentage of time the operator of Machine 1 effectively spent on core activities was significantly lower (16.7%) than that of the operator of the second lathe (43.3%). Consequently, the managers of this manufacturing facility decided to implement improvements to Lathe 1, as the work sampling analysis indicated it offered greater opportunities for capacity gains.

12.4 Work sampling in services

Although commonly used in industrial environments, work sampling applies to a wide range of service operations, as illustrated by the following examples from restaurants and hospitals.

12.4.1 Case 1: Work sampling in restaurants

In the restaurant industry, customer contact is a key aspect. In a particular study, researchers from Cornell University aimed to use work sampling to assess customer interaction in family restaurants compared to mid-scale establishments. Essentially, their main research question was: "How much time do servers spend in contact with restaurant customers relative to other performed activities?"

To address this, the researchers categorized the servers' activities into eight groups:

- Guest Contact: Moments of interaction with the customer. This category encompasses tasks such as taking orders, interacting with guests, and serving food and beverages.
- Walk-empty: When the server walks through the establishment without carrying food or drink orders.
- Walk-full: When the server moves through the restaurant while carrying food or beverages.
- Bus: Clearing and cleaning tables after customers leave.

- Prepare: When the server is preparing or finalizing orders to be delivered to customers.
- Can't see: Tasks performed by the server outside of the customer's view. The study did not aim to specify these activities.
- Check: When the server presents or processes the bill.
- Rest: When the server is taking a break.

Servers essentially perform two primary functions: first, ensuring that customers feel satisfied and comfortable; second, delivering food and beverages efficiently. The emphasis placed on each dimension varies by restaurant type. After all, it involves a trade-off that must be carefully considered to maintain an appropriate balance between customer interaction and service efficiency.

Figure 12.9 illustrates how efficiency, customer contact, and sales opportunities vary across restaurant types.

Because the managers of these restaurants rarely had time to consistently evaluate their employees, work sampling proved the most appropriate methodology. A total of 24 restaurants were studied, with half being family-owned and the other half mid-scale establishments. Furthermore, the restaurants were assessed during both lunch and dinner service.

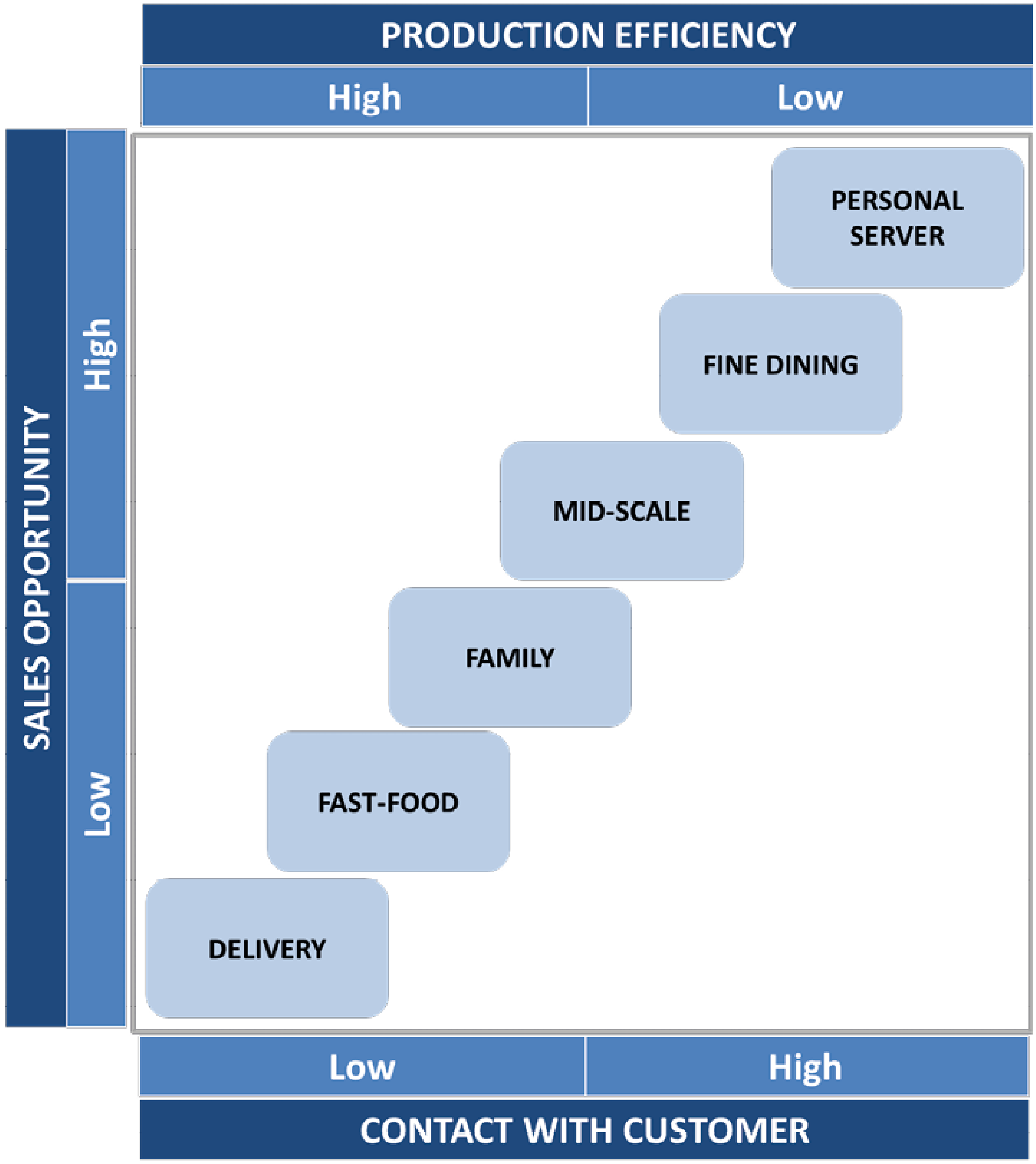
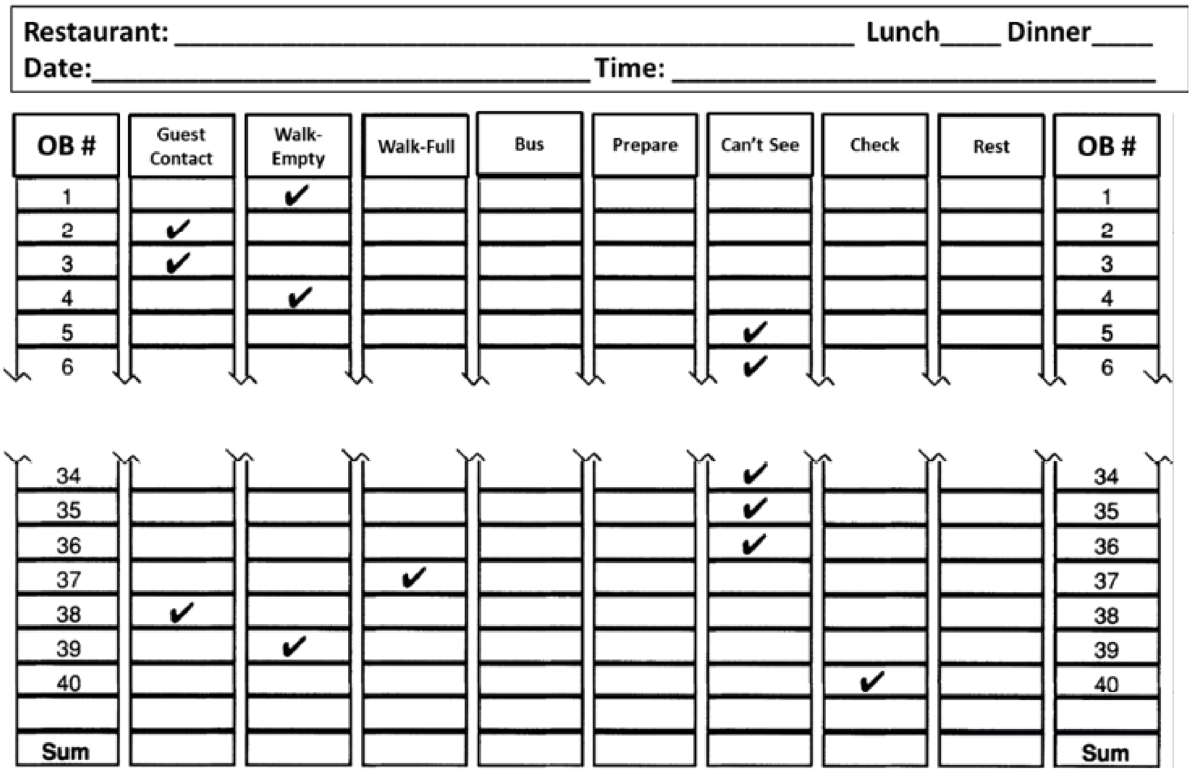


Figure 12.9 – Restaurant concepts: efficiency, contact, and sales

Based on the activity categories, observation forms were developed for use during data collection. Figure 12.10 presents the data collection instrument that was designed.



Restaurant: ______________________ Lunch____ Dinner____
Date: ______________________ Time: ______________________

OB #	Guest Contact	Walk-Empty	Walk-Full	Bus	Prepare	Can't See	Check	Rest	OB #
1		✔							1
2	✔								2
3	✔								3
4		✔							4
5						✔			5
6						✔			6
…									…
34						✔			34
35						✔			35
36						✔			36
37			✔						37
38	✔								38
39		✔							39
40							✔		40
Sum									Sum

Figure 12.10 – Work sampling form (Restaurants study)

Observers simultaneously evaluated two servers from each restaurant for at least 90 minutes. Every minute, the activity being performed by server 1 was recorded by marking a check next to the corresponding task. Halfway between each observation of server 1, the observer would then record the activity of server 2 (Figure 12.11). To ensure realistic results, data collection was conducted during peak service periods, with observers seated at tables offering a distinct vantage point to facilitate the evaluation of the servers.

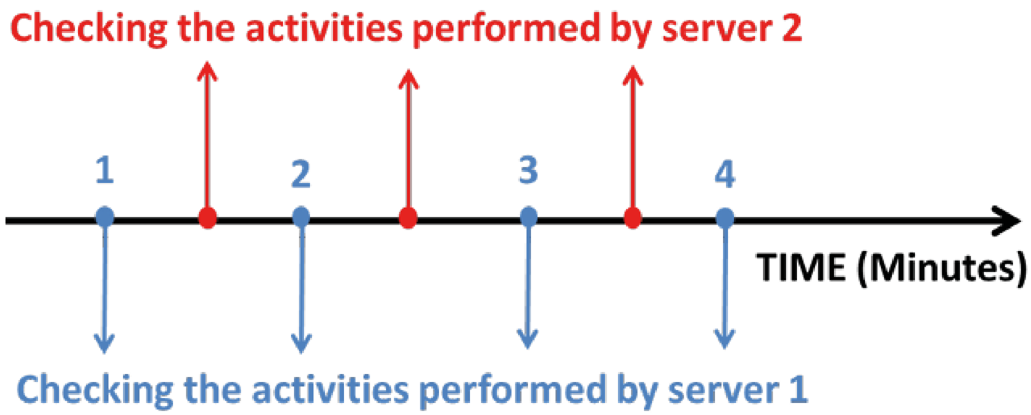
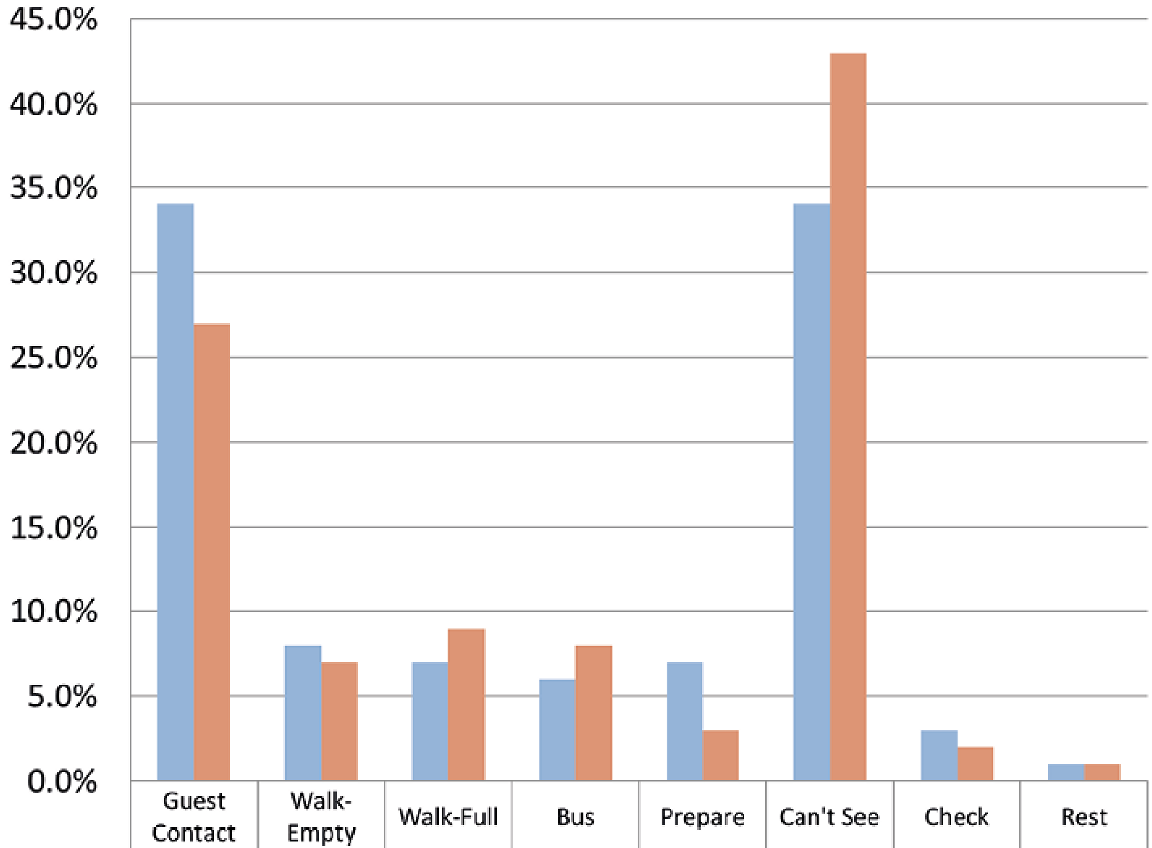


Figure 12.11 – Simultaneous data collection strategy for two servers

Based on the collected data, the researchers constructed charts (Figures 12.12 and 12.13) and drew several noteworthy conclusions. Overall, on average, servers spent approximately one-third of their time in direct interaction with customers.

Figure 12.12 presents a chart comparing work sampling between family and mid-scale restaurants. The graph reveals that the two types of restaurants can be primarily differentiated by two categories: "customer contact" and activities performed out of customers' sight. While mid-scale restaurants generally allocated 34% of their time to customer interaction, family-owned establishments allocated 27%. Regarding activities conducted out of customers' sight, mid-scale restaurants spent less time (34%) than family restaurants (43%).

Figure 12.13 analyzes sampling by meal type (lunch or dinner) and restaurant type (mid-scale or family). Comparing meal periods across the two kinds of restaurants, it was observed that servers spent more time in customer contact and out-of-sight activities during dinner than during lunch.



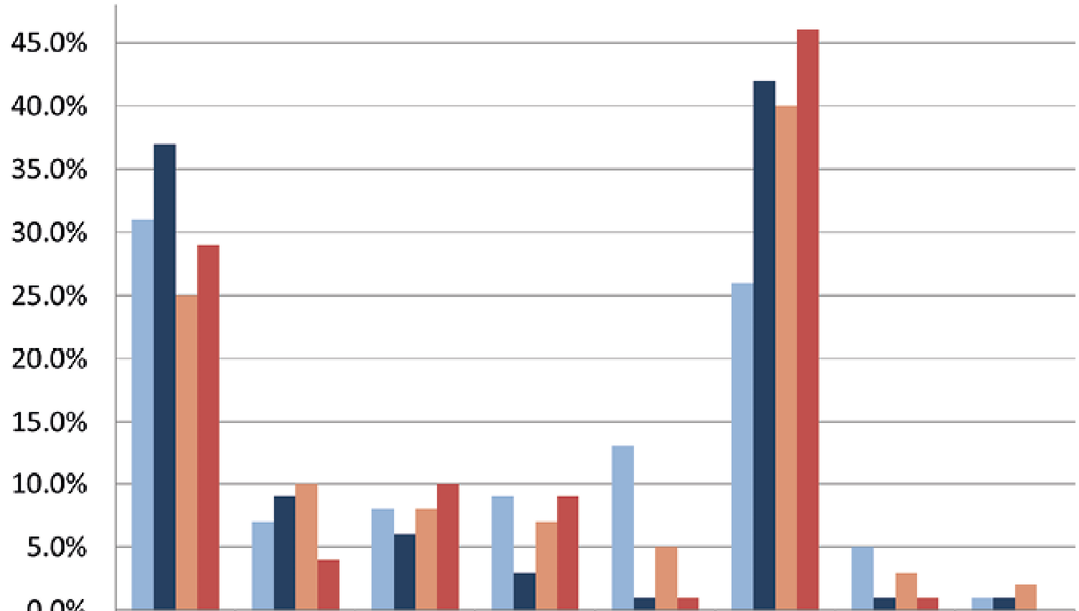
	Guest Contact	Walk-Empty	Walk-Full	Bus	Prepare	Can't See	Check	Rest
Mid-Scale	34.0%	8.0%	7.0%	6.0%	7.0%	34.0%	3.0%	1.0%
Family	27.0%	7.0%	9.0%	8.0%	3.0%	43.0%	2.0%	1.0%

Figure 12.12 – Comparison of work sampling between family and mid-scale restaurants

These results and charts were subsequently presented to the owners of two mid-scale restaurants that participated in the study, as data analysis made it possible to consider restructuring the waitstaff's tasks to emphasize specific activity categories aligned with the restaurant's business strategy.

In both establishments, there was surprise at the percentage of time spent in customer interaction, which was significantly higher than expected.

One of the restaurants, located in a business district, for example, set a goal to reduce this percentage, considering its target audience: most of its customers are business professionals who prioritize service efficiency. The owner then proposed several possible improvements to the business, including making the menu more self-explanatory to reduce the common questions customers would otherwise ask the waitstaff.



	Guest Contact	Walk-Empty	Walk-Full	Bus	Prepare	Can't See	Check	Rest
Lunch (Mid-Scale)	31.0%	7.0%	8.0%	9.0%	13.0%	26.0%	5.0%	1.0%
Dinner (Mid-Scale)	37.0%	9.0%	6.0%	3.0%	1.0%	42.0%	1.0%	1.0%
Lunch (Family)	25.0%	10.0%	8.0%	7.0%	5.0%	40.0%	3.0%	2.0%
Dinner (Family)	29.0%	4.0%	10.0%	9.0%	1.0%	46.0%	1.0%	0.0%

Figure 12.13 – Work sampling analysis by meal period and restaurant type

The owner of the other restaurant, in turn, considered the study potentially helpful in assessing differences in service among waitstaff and for identifying which strategies might be correlated with sales and tips, based on the percentage of time each server spent in contact with customers.

Regarding the "can't see" category, the owners concluded that the layout and design of each establishment, as well as operational policies, significantly affected the proportion of time waitstaff spent performing tasks out of the customers' view.

12.4.2 Case 2: Nurse practitioners study

This second study aimed to understand variations in work patterns among nurses across different areas of practice and geographic locations in Australia—a potentially valuable insight into how different practices influence patient outcomes. The study was part of a larger three-phase project titled the Australian Nurse Practitioner Project (AUSPRAC), which employed multiple methods to analyze the impact of the nursing role in Australia.

The activities performed by the nurses were categorized into four macro-categories:

- Direct care: Activities performed in the patient's presence. Example: providing explanations to patients, their families, and/or caregivers.
- Indirect care: Activities performed away from the patient, such as team coordination, documentation, and collaboration with other professionals.
- Service-related tasks: Activities not directly related to patient care, including meetings, training, research, and administrative tasks.
- Personal activities: Activities unrelated to the previously mentioned categories, such as meals, breaks, schedule adjustments, personal phone calls, and social interaction with colleagues.

Participation code:

WORK SAMPLING INSTRUMENT

Date:		Date:		Date:		Date:		Date:		Date:	
Time	Activity Code	Time	Activity Code	Time	Activity Code	Time	Activity Code	Time	Activity Code	Time	Activity Code
0		0		0		0		0		0	
10		10		10		10		10		10	
20		20		20		20		20		20	
30		30		30		30		30		30	
40		40		40		40		40		40	
50		50		50		50		50		50	
60		60		60		60		60		60	
70		70		70		70		70		70	
80		80		80		80		80		80	
90		90		90		90		90		90	
100		100		100		100		100		100	
110		110		110		110		110		110	

Nurse practitioner activities

Direct care	Indirect care	Service-related	Personal
1. Physical assessment	14. Handover	23. Travel	30. Personal
2. History taking	15. Fills out standardized forms	24. Computer data retrieval: service	
3. Communicates diagnosis	16. Documents in progress notes & charts	25. Research & audit	
4. Requests diagnostic investigations/procedures	17. Computer data entry: patient	26. Meetings & administration	
5. Performs diagnostic investigations/procedures	18. Computer data retrieval: patient	27. Preceptoring	
6. Analyses/interprets diagnostic investigations	19. Coordinates care	28. Continuing professional development: self	
7. Performs/manages therapeutic procedures	20. Discharge planning	29. Provision of professional development: others	
8. Prescribes medication	21. Used references for patient care (text/electronic)		
9. Administers medication	22. Sets up & prepares room/equipment		
10. Interacts with patient/family/caregiver			
11. Teaching			
12. Initiates patient transfers/discharge			
13. Telemedicine			

Figure 12.14 – Work sampling form (Nurse practitioners study)

These four macro-categories comprised 30 specific work micro-activities. Based on the definition of these activities, a data collection form (Figure 12.14) was developed using a coding system corresponding to the nurses' activities (Table 12.4). The form was designed to encompass a broad range of contexts in which nursing work occurs and was subsequently tested and validated across three data collection sites.

Following validation of the form, all observers responsible for data collection participated in a tailored training program for this study. The training included practical observation and recording exercises, supported by a computer-assisted instructional program based on a video of a nurse's work routine.

Data were collected from a random sample of 30 nurses at 10-minute intervals over 2-hour blocks within a 6-week sampling frame, spanning a two-week work period. Each nurse contributed 480 observations and 80 hours of data.

Direct care
1. Physical assessment
2. History taking
3. Communicates diagnosis
4. Requests diagnostic investigations/procedures
5. Performs diagnostic investigations/procedures
6. Analyses/interprets diagnostic investigations
7. Performs/manages therapeutic procedures
8. Prescribes medication

9. Administers medication
10. Interacts with patient/family/caregiver
11. Teaching
12. Initiates patient transfers/discharge
13. Telemedicine
Indirect care
14. Handover
15. Fills out standardized forms
16. Documents in progress notes & charts
17. Computer data entry: patient
18. Computer data retrieval: patient
19. Coordinates care
20. Discharge planning
21. Used references for patient care (text/electronic)
22. Sets up & prepares room/equipment
Service-related
23. Travel
24. Computer data retrieval: service
25. Research & audit
26. Meetings & administration

27. Preceptoring
28. Continuing professional development: self
29. Provision of professional development: others
Personal
30. Personal

Table 12.4 – Nurse practitioner activities

It is worth noting that some of the forms (15%) could not be fully completed due to occasional and unexpected absences. In total, data collected from 30 nurses across six Australian states amounted to 12,189 individual observations. After excluding data on the personal category, which was not the study's focus, 11,032 observations remained.

Figures 12.15 and 12.16 present graphs generated from the collected data, with descriptive statistics produced using the Statistical Package for the Social Sciences (SPSS).

Considering the first chart presented, the percentage distribution of time across the three macro-categories analyzed revealed only slight variation:

- Direct care: 36.1%.
- Indirect care: 32.1%.
- Service-related: 31.8%.

In other words, nurses distributed their time almost equally among direct care, indirect care, and service-related activities. These findings challenge nursing staff's perceptions of their daily tasks. In a previous survey conducted by AUSPRAC involving numerous nursing professionals, participants estimated that 61.5% of their time was spent on direct patient care, nearly double the proportion identified in this study (36.1%).

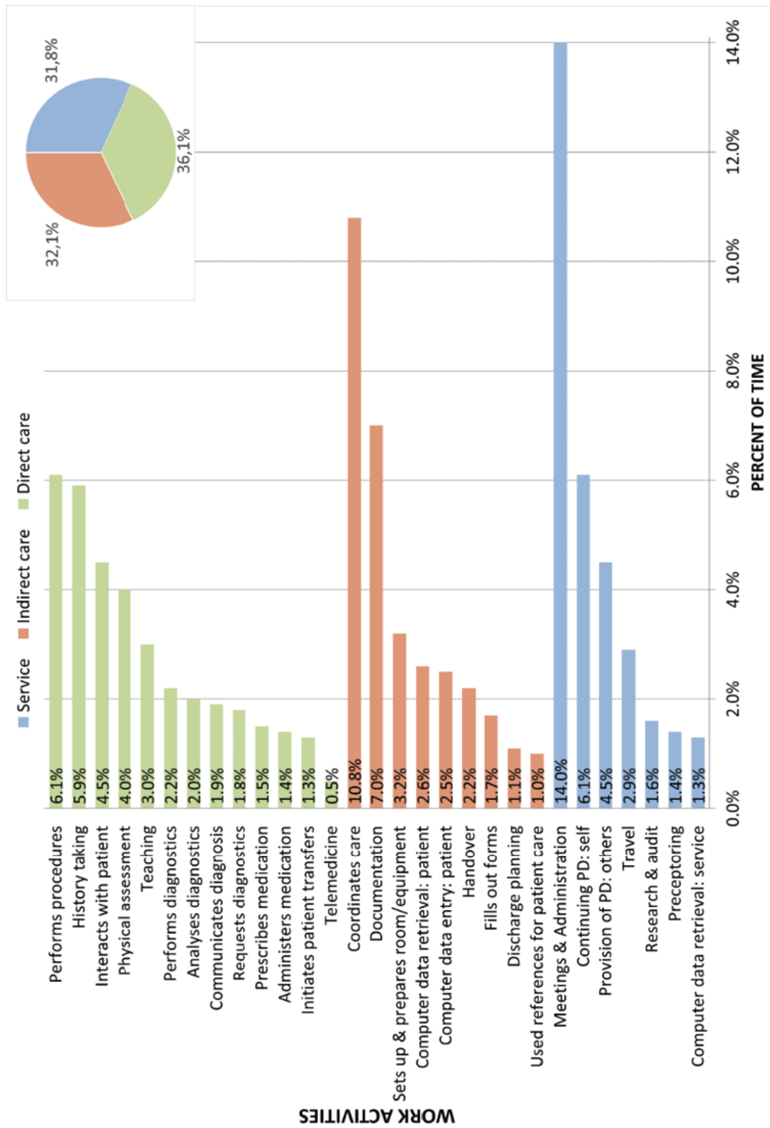


Figure 12.15 – Nurse practitioner work activities

Previous research had also suggested that approximately half of nurses' working time was spent directly with patients. It is essential to note that this relatively low proportion of time spent on direct patient care is inconsistent with international standards for the nursing profession, which emphasize providing clinical services to individual patients or communities.

Another notable finding is that only 1.6% of these professionals' time is dedicated to research and audits. Nurses must continually engage in continuous improvement to ensure the delivery of quality, evidence-based care. The importance of research in nurses' professional practice is emphasized in Australian work policies and standards, such as those developed by the Australian Nursing and Midwifery Council (ANMC).

Figure 12.16 presents the top ten activities performed by these nurse practitioners. The first five activities (meetings & administration, coordinates care, documentation, performs procedures, and continuing PD: self) account for 44% of these workers' work schedule.

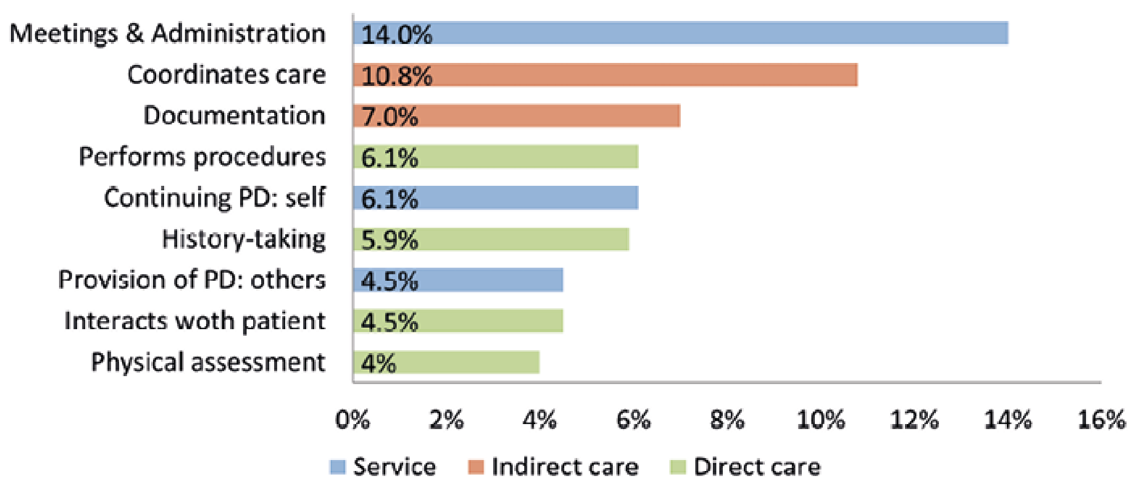


Figure 12.16 – Top ten work activities of nurse practitioners

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Softwares

QM for Windows – free software
SPSS (Statistical Package for the Social Sciences) – https://www.ibm.com/analytics/spss-statistics-software
UMT Plus, desenvolvido pela Laubrass – https://www.laubrass.com/umtplus/
Work Measurement Software, desenvolvido pela Quetech Ltd. – https://www.quetech.com/

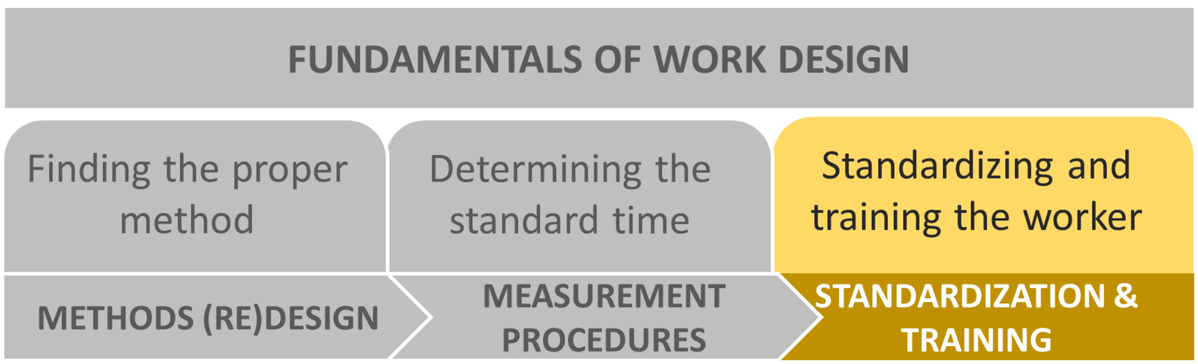
UNIT 4

STANDARDIZATION AND TRAINING

- Standardization of operations
- Training and development

UNIT 4:
STANDARDIZATION AND TRAINING

Once the methods and standard times are defined, standards can be developed or updated, and, consequently, the necessary training can be carried out. Therefore, the last unit, which deals with standardization and training, should not be neglected, since the biggest challenge is not improving the methods but sustaining the results.



- **Chapter 13:** Standardization of operations
- **Chapter 14:** Training and development

Operation standardization involves documenting the work method and its standard times. In this chapter, the three main types of standards will be discussed: operational, visual, and managerial.

Finally, training involves understanding the learning process, defining the trainer’s role, and developing the training.

CHAPTER 13: STANDARDIZATION OF OPERATIONS

After identifying the most effective method and the time required for each work element, the results of the motion and time studies must be documented in accordance with standard procedures. These standards formalize the most appropriate method for carrying out a given task, ensuring safety, quality, ergonomics, ergomotricity, and efficiency. Standards are vital because they ensure the correct method is applied sustainably. Without standardization, it is natural for individuals performing a task to modify their work methods over time, which may lead to the loss of improvements or to failure to adhere to the established procedure. Figure 13.1 illustrates the performance distribution in a workplace where the method was not properly standardized or monitored. It is evident that the lack of standardization leads to high variability in performance.

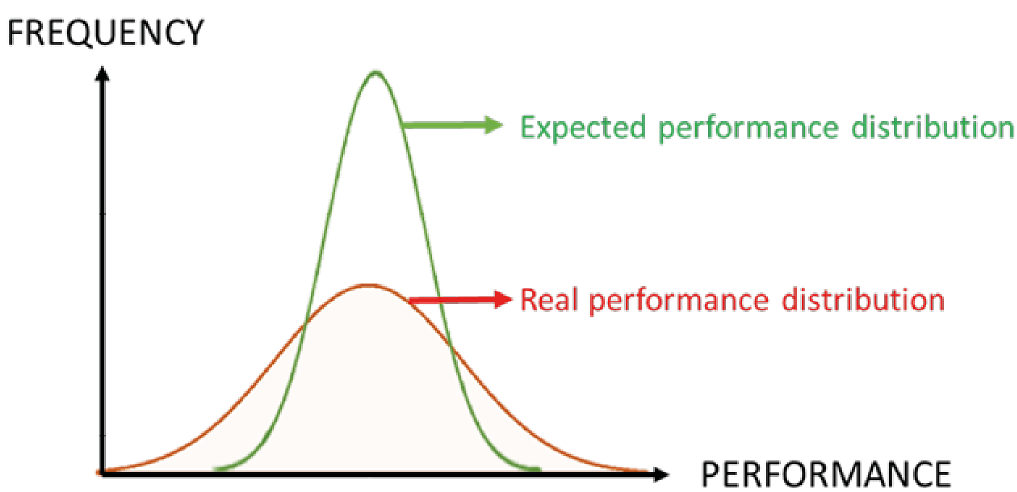


Figure 13.1 – Performance distribution in a workplace where the method was not properly standardized or monitored

In addition to reducing performance variability, standards serve as tools for training, quality assurance, management, and continuous process improvement (Figure 13.2).

As a training tool, standards can be clearly communicated to employees. Moreover, when displayed visually near workstations, they enable quick, easy updates. This is particularly relevant when working with job rotation and multi-skilled workers.

Standards are also valuable quality tools, as they provide a basis for audits and serve as a guide in the root cause analysis of quality issues.

Moreover, standards serve as management tools, providing insights into process capabilities, highlighting deviations when time and method standards are not met, and thereby facilitating daily management of workstations.

Finally, standards serve as tools for continuous improvement by supporting the identification and elimination of waste.

Figure 13.2 – Standards' purposes

In short, standards offer a wide range of benefits to organizations that implement them, such as:

- Predictability to support continuous improvement initiatives.
- A solid foundation for training and auditing activities.
- Assurance of adequate levels of safety, quality, ergonomics,

ergomotricity, and efficiency.

- Preservation of operational know-how (knowledge management).
- Task measurability.
- Repeatability and reproducibility in task execution.
- Variability control.
- Process stability in terms of capacity and capability.
- Support in identifying cause-and-effect relationships.
- Guidance and reference for motion and time studies.

However, to achieve such benefits, standards must remain "living documents." That is, they should be continuously updated whenever necessary. For this to occur, it is essential that the individuals who perform the work feel a sense of ownership over the standards. Furthermore, the process of updating these standards must not be overly bureaucratic, as it can be demotivating. Otherwise, the standards risk becoming rigid and obsolete—eventually ending up forgotten in a drawer.

If you want to assess whether a given standard is effective, ask the worker responsible for the task to explain it to you. Often, the difficulty begins with merely locating the standard—and if it has not been updated in a long time, this alone indicates that it serves more as decoration than as a tool for maintaining quality.

To keep standards "alive," it is also crucial to encourage the consistent use of visual management, regardless of the type of standard. For instance, if the standard is developed using digital tools but not made available in physical form, it may hinder ongoing improvement and updates. Therefore, it is recommended that even computer-generated standards be printed and displayed near the relevant workstations, along with pens or markers, so that employees can note suggested changes as they improve the process.

Another critical point is that standards should not be limited to stating merely "what" should be done. They must also explain "how" and "why." This is vital to ensure that employees understand the rationale behind each procedure and are thus more likely to sustain the correct method.

There are essentially three types of standards (see Figure 13.3):

- Operational standards define the standard work method to be followed. The standard work instruction, the standard work combination sheet, and the standard work sheet typically represent these.
- Visual standards support visual management of operations and help identify when work is not being performed in accordance with the standard.
- Managerial standards outline the actions to take when deviations occur or problematic situations arise.

These three types of standards will be presented below.

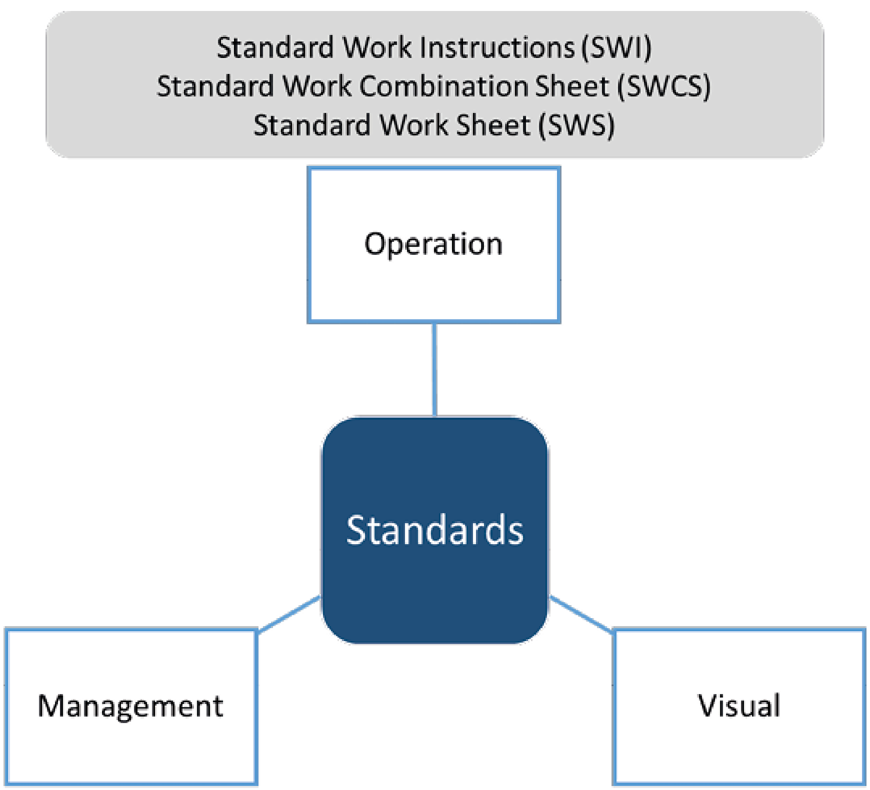


Figure 13.3 – The three types of standards

13.1 Operating procedures

Operating procedures are work standards that serve as references for carrying out specific operations. Thus, they bring several benefits to organizations that adopt them, such as guaranteeing a certain level of performance, task reproducibility, and reducing variability. They therefore facilitate the training of new employees and the conduct of audits.

These standards typically encompass not only value-added activities, but also necessary non-value-added activities, which represent work that does not add value but is necessary under current conditions. For example, stacking and unstacking are required in charcoal production but are non-value-added activities (Figure 13.4).

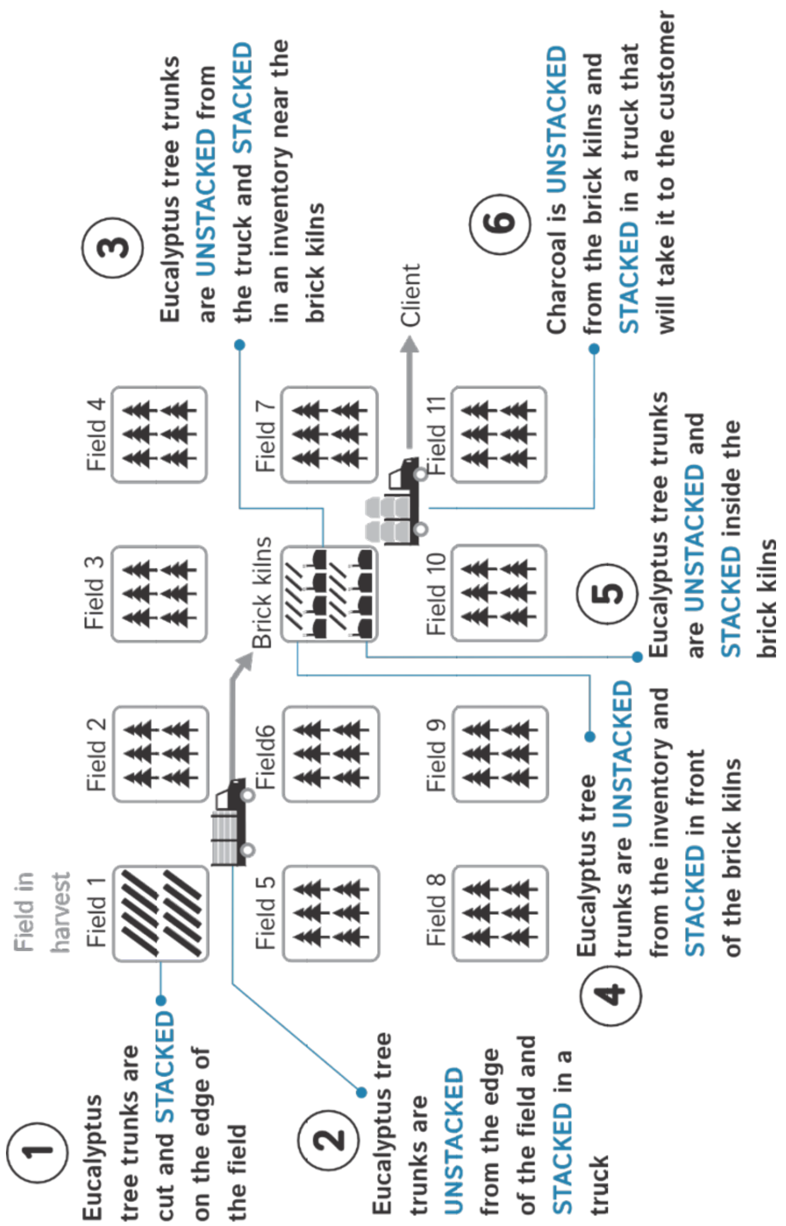


Figure 13.4 – Example of necessary non-value-added activities: to stack and to unstack during charcoal production

The process begins at the harvesting stage, when eucalyptus trees are felled and stacked at the edge of the plot, awaiting transport to the carbonization facilities. Next, the wood is unstacked and restacked onto trucks for transportation. Typically, before carbonization, it is unstacked and restacked into intermediate storage areas. Subsequently, front-end loaders will unstack and restack the wood in front of the carbonization kilns. Finally, it is unstacked and restacked inside the kilns. In total, the wood must be stacked and unstacked at least five times throughout the entire process.

Since eucalyptus logs are generally heavy, stacking and unstacking consume significant time and resources. Moreover, upon closer examination, these standardized, non-value-adding tasks do not add value to the process; they are merely required by the current production machinery and technological constraints. It is essential to note, however, that these standardized steps can often be re-evaluated and refined to eliminate such waste. For instance, it is conceivable to develop a technology that would require stacking and unstacking the wood only once. This could be achieved, for example, if the wood were stored in a type of container from the moment of harvest through to its insertion into the carbonization kiln.

In addition to value-adding work and standardized waste, a comparison between the standard work procedure and the actual work performed by employees often reveals anomalies and dysfunctions that are neither value-adding nor necessary, such as delays and rework.

Figure 13.5 depicts an operator's work where part of the work adds value, part represents standardized waste, and part is purely non-value-adding.

Regarding the dysfunctions and anomalies that may be identified when comparing actual employee activity to the standard method (i.e., the nominal task), the continuous updating of these standards becomes even more critical. Figure 13.6 illustrates how such standards should be monitored and updated.

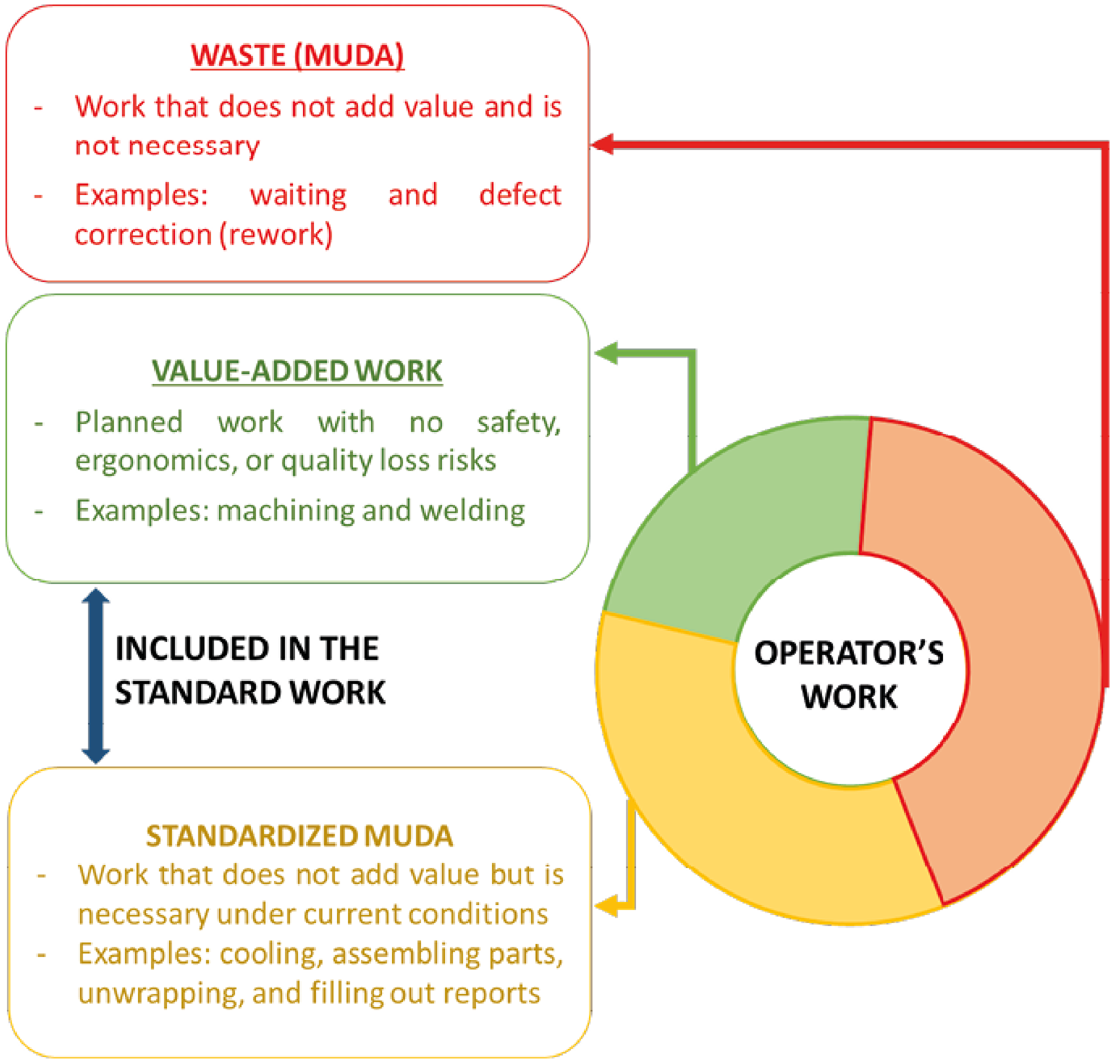


Figure 13.5 – The components of an operator's work

After the standardized work method has been documented, it must be continuously compared with the current method followed by the employee(s). If deviations are identified, they must be analyzed. If the technique has been modified in a way that leads to a less favorable situation—whether in terms of safety, quality, ergonomics, motor ergonomics, and/or efficiency—actions must be taken to correct these anomalous conditions and restore compliance with the recorded initially standardized method.

However, if the analysis of deviations reveals opportunities for improvement in the standardized work method, these desirable characteristics should be incorporated to promote continuous improvement of the work method.

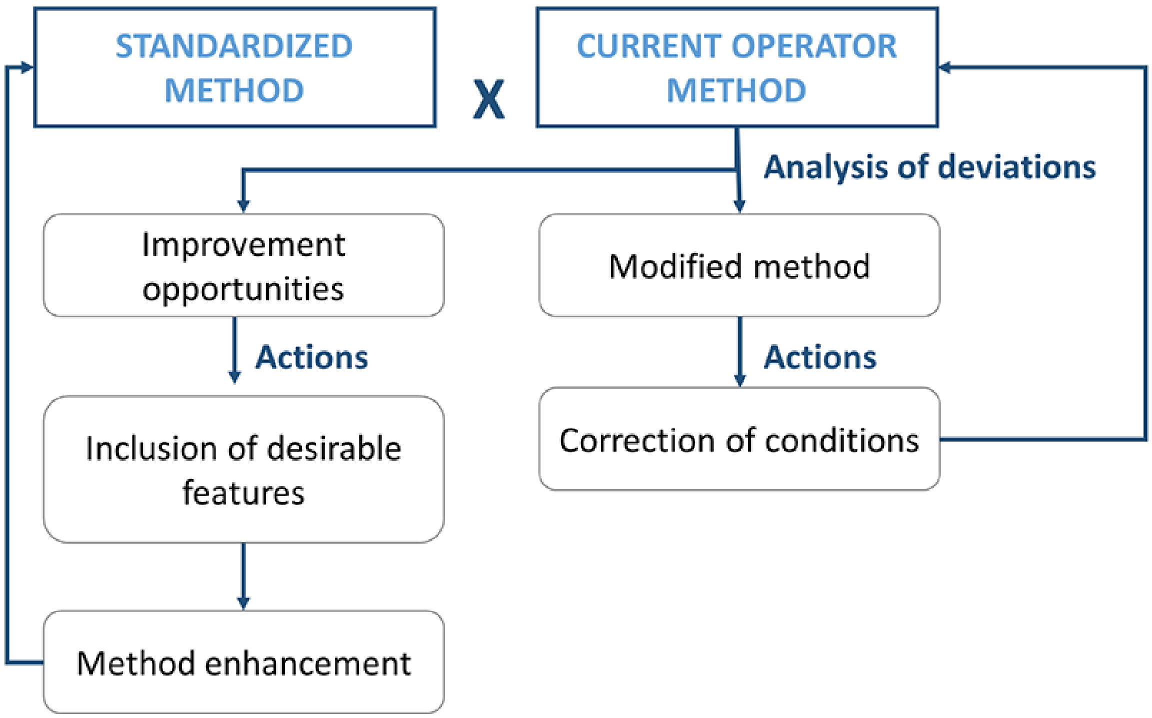


Figure 13.6 – Monitoring and updating of the standardized method

There are essentially three standardized operational work patterns widely adopted in industry, which will be presented in detail below:

- Standard Work Instructions (SWI).
- Standard Work Combination Sheet (SWCS).
- Standard Work Sheet (SWS).

13.1.1 Standard Work Instructions – SWI

The document Standard Work Instructions (SWI) has broad applicability in industry, aiming to organize work elements in a predefined sequence and to highlight the time required for each element, so that this cyclical pattern can be successfully repeated by all operators who apply it.

Thus, SWIs serve several purposes:

- To highlight waste and standardized muda within the process.
- To ensure the correct sequence with a focus on safety, quality, ergonomics, ergomotricity, and efficiency.
- To make explicit the expected time for the execution of each work element, as well as the total cycle time.
- To serve as a basis for audits and training.

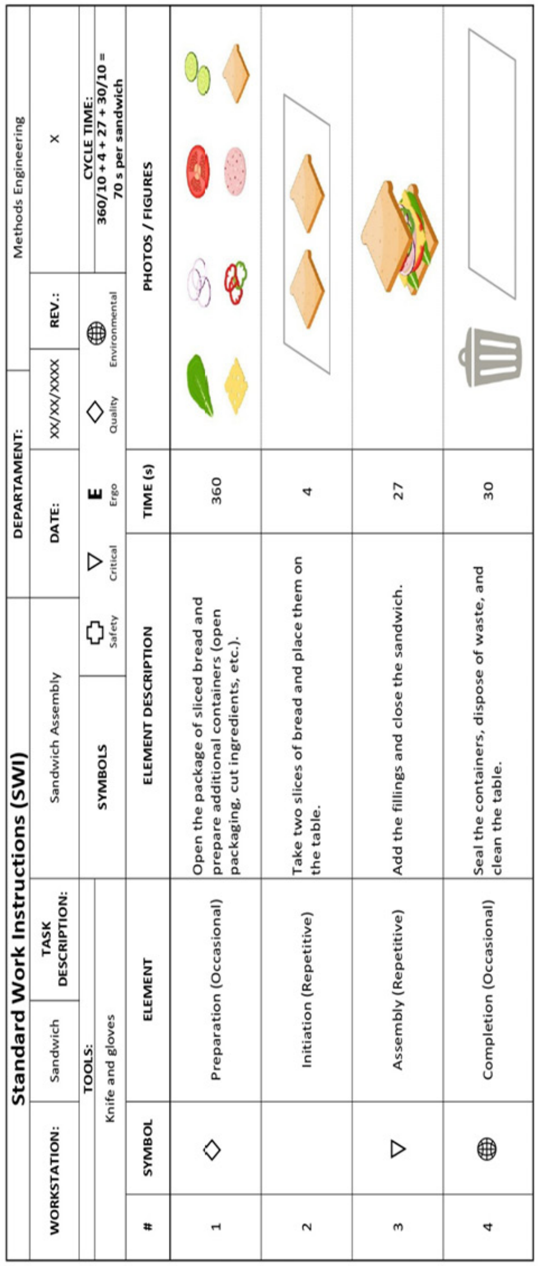
Figure 13.7 presents a Standard Work Instruction (SWI) for the sandwich assembly operation. Additionally, a blank SWI form is available in Appendix 4 of this book. To develop the standard, the following steps should be followed:

- Complete all information in the header and footer, including workstation identification, name of the person who developed the standard, tools used, cycle time, or any other relevant data.
- Number, name, and describe each work element based on the motion and time study. The standard must represent a complete work cycle. Therefore, it is essential to include all relevant elements —whether occasional or repetitive—that must be considered within the cycle.
- Use symbols to highlight critical work elements that involve ergonomic, quality, safety, and/or environmental considerations and that require special attention.
- Identify the type of each work element: whether it is occasional or repetitive. Irregular or exotic elements should not be included in the standard.
- Record the time required for each work element and include photographs to illustrate each step.
- Finally, calculate the total cycle time. To do so accurately, it is necessary to consider both occasional and repetitive element times, normalized by the number of units processed. For example, in

Figure 13.7, the processing unit is a product (a sandwich), but it could also be a person or a piece of information. In this case, since the repetitive elements refer to the preparation of a single sandwich, their times do not need to be divided. However, occasional elements, such as opening a new loaf of sliced bread (containing 20 slices), occur every 10 sandwiches and therefore must have their times divided by 10.

Thus, the total cycle time is given by:

$$\frac{360}{10} + 4 + 27 + \frac{30}{10} = 30 \; seconds \; per \; sandwich$$



Standard Work Instructions (SWI)

WORKSTATION:	Sandwich	TASK DESCRIPTION:	Sandwich Assembly	DEPARTAMENT:		Methods Engineering
				DATE: XX/XX/XXXX	REV.:	X
TOOLS: Knife and gloves			SYMBOLS	Safety / Critical / Ergo (E) / Quality / Environmental		CYCLE TIME: 360/10 + 4 + 27 + 30/10 = 70 s per sandwich

#	SYMBOL	ELEMENT	ELEMENT DESCRIPTION	TIME (s)	PHOTOS / FIGURES
1	◇	Preparation (Occasional)	Open the package of sliced bread and prepare additional containers (open packaging, cut ingredients, etc.).	360	
2		Initiation (Repetitive)	Take two slices of bread and place them on the table.	4	
3	▷	Assembly (Repetitive)	Add the fillings and close the sandwich.	27	
4	🌐	Completion (Occasional)	Seal the containers, dispose of waste, and clean the table.	30	

Figure 13.7 – SWI Form for sandwich assembly

13.1.2 Standard Work Combination Sheet (SWCS)

The Standard Work Combination Sheet (SWCS) is a well-established standard that originated in the automotive industry. The SWCS visually presents the workflow in a chart format, highlighting waiting times, operator movements, equipment time, cycle time, and takt time.

Thus, the SWCS offers several benefits:

- It helps to balance the workload among operators.
- It supports synchronization between operators and equipment.
- It facilitates the identification of waste, such as idle time, unnecessary movements, and line imbalance.

This document is handy in scenarios where:

- A single operator controls multiple machines or pieces of equipment.
- Several operators work in sync on a production line.
- Various tactical schemes are employed, meaning a variable number of operators are assigned to specific workstations based on the production mix, the number of operators available for the line, or the volume of open orders.

The SWCS can be created using various formats, including post-it notes, spreadsheets, or physical forms. Regardless of the method used, the following observations should be considered when completing the form:

- Fill in all information in the header and footer, which should be developed based on the problem and the workstation being studied.
- Follow the same numbering and naming logic for work elements as used in any existing standard work instructions or standardized work diagrams for those same workstations, as these standards are complementary.
- The SWCS must be developed individually for each workstation.

- It is also helpful to highlight the takt time within the SWCS.
- The standard represents a work cycle, so it is vital to ensure that, by the end of the cycle, the operator always returns to the starting point.

A blank SWCS form can be found in Appendix 4 of this book. Figure 13.8 presents the SWCS for the toaster example introduced in Figure 7.2. As illustrated in that figure, part of the operator's time is idle. Improvements were therefore implemented to utilize this idle time to begin preparing another slice of toast. In addition, a second toaster was acquired, capable of toasting two slices simultaneously in the same time it previously took to toast one.

Following these improvements, the operator still needed to walk for one second to reach the toaster. Figure 13.9 presents the SWCS for the same example after the improvements, as shown in Figure 7.4. As observed in Figures 13.8 and 13.9, the cycle time per slice was reduced from 25 seconds to 13.5 seconds. Note that in Figure 13.8, the operator did not need to walk; hence, transitions between work elements are marked by a solid vertical line. However, in Figure 13.9, the operator must walk for one second each time they approach the toaster. Therefore, the work elements are separated by the symbol "~~~~~~~~~~~~~".

13.1.3 Standard Work Sheet (SWS)

The Standardized Work Sheet (SWS) is designed to represent the operator(s)' workflow within a layout. This standard is useful in situations where:

- The operator must move across the workspace to perform work elements.
- The operator controls multiple pieces of equipment.
- Multiple operators work in coordination within the same work area.

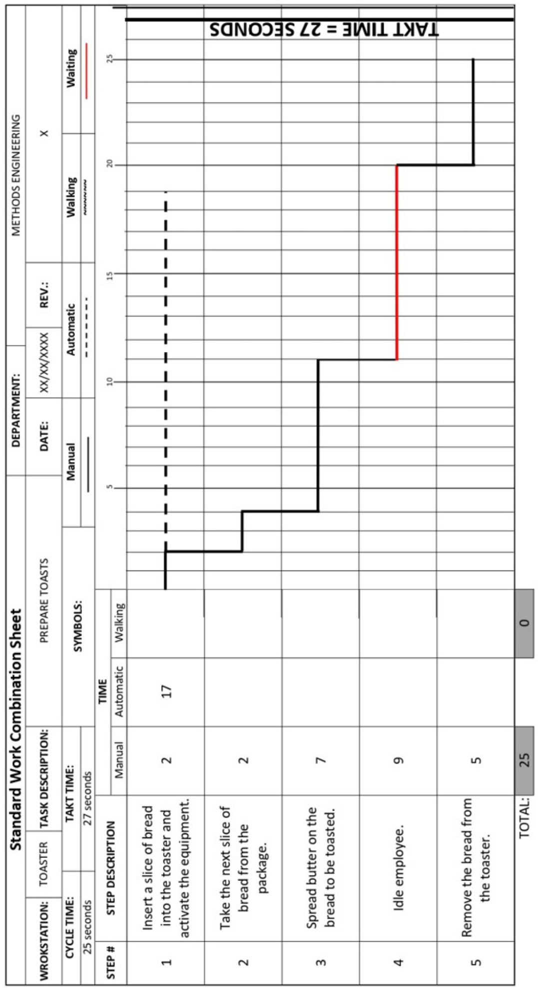


Figure 13.8 – SWCS for the toast preparation activity before improvements (based on Figure 7.2)

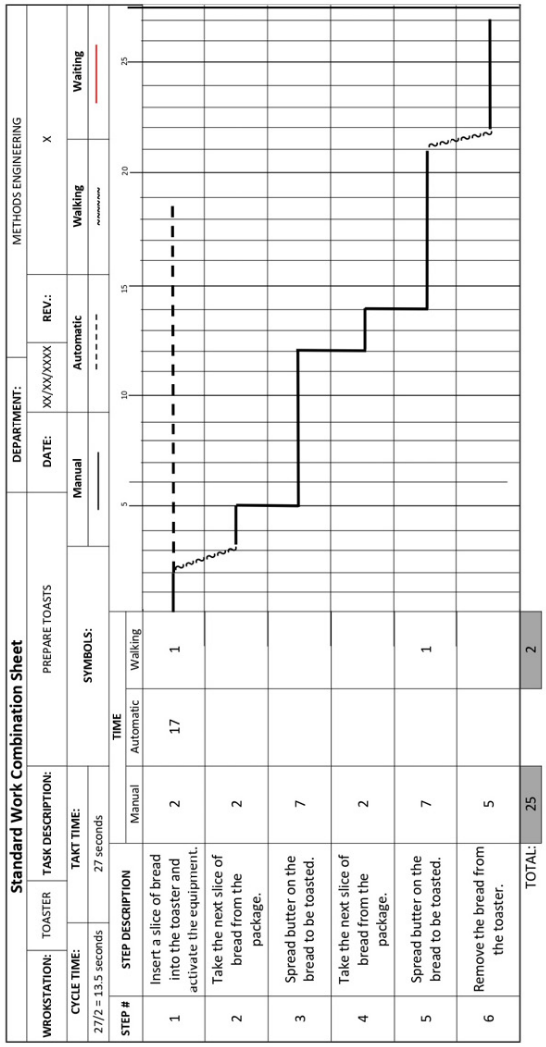
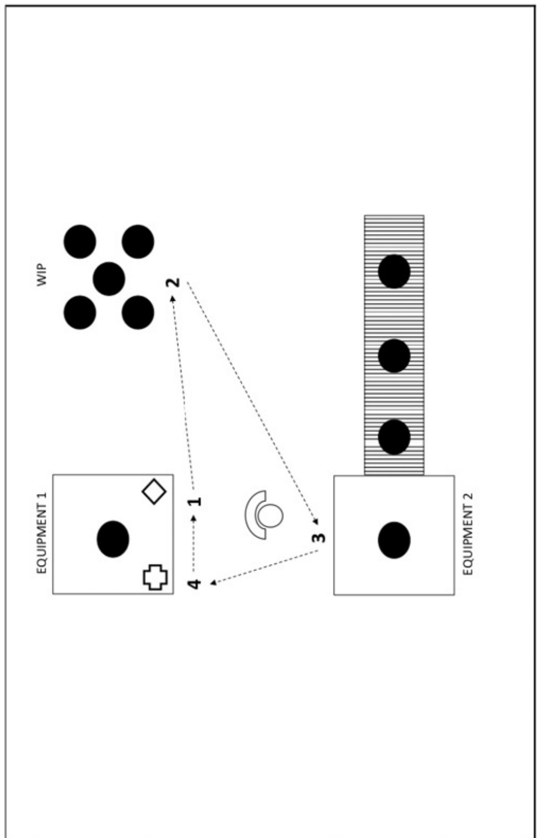


Figure 13.9 – SWCS for the toast preparation activity after improvements (based on Figure 7.4)



#	Step
1	Remove the part from Equipment 1.
2	Place the removed part in the Work In Progress (WIP).
3	Remove the part from Equipment 2.
4	Load the removed part and activate Equipment 1.

Figure 13.10 – Example of SWS

Figure 13.10 presents an SWS created in the production area. Blank SWS forms for sketching and final drafting can be found in Appendix 4 of this book.

13.2 Visual Standards

Visual standards are used in the visual management of work processes. Human beings perceive approximately 83% of information through vision and 11% through hearing (Figure 13.11). It is no coincidence that emergency services use both light and sound signals when necessary—such as in police vehicles and ambulances—to capture people's attention and facilitate quick operations.

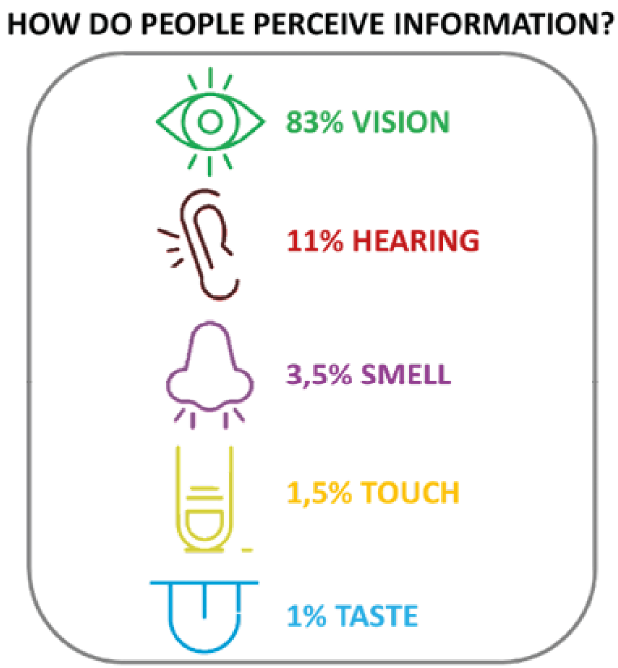


Figure 13.11 – Information perception by human senses

As the name suggests, visual standards rely on visual cues to make information easier to interpret and more accessible. The goal is that anyone passing through a given area should be able to easily identify deviations from the standard work procedure. In this way, control can be exercised by all. After all, in a continuous improvement environment, everyone is expected to actively participate in the process.

In our daily lives, we encounter numerous examples of visual standards, especially in traffic. Road signs, traffic lights, and lane markings constantly provide us with information on how to behave while driving or walking. These visual standards are also widely used across industries, airports, hospitals, banks, and retail stores.

Visual management can be implemented through various resources such as signs, labels, illustrations, and graphs. It can be used, for example, to identify sources of danger or reference values. In Figure 13.12, which pressure gauge makes it easier and more accessible to detect a deviation? As observed, visual standards offer several benefits, including time savings and reduced quality and safety issues.

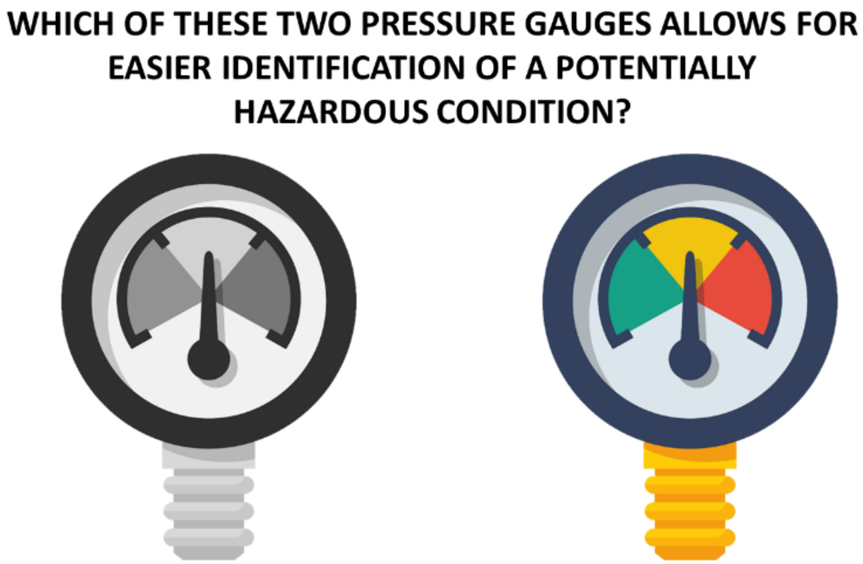


Figure 13.12 – Example of visual management on the pressure gauge

For instance, in hospitals, saline solution and petroleum jelly can easily be confused—this poses a serious risk, as administering petroleum jelly instead of saline solution could result in patient death. By applying visual management, such risks are reduced (see Figure 13.13).

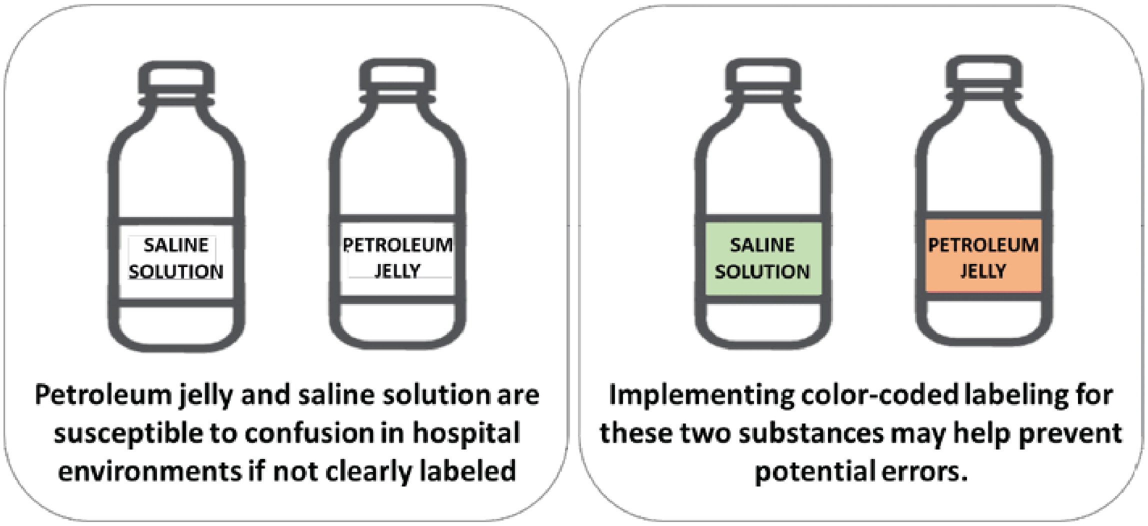


Figure 13.13 – Example of a visual standard to differentiate between saline solution and petroleum jelly

13.3 Management standards

Management standards are designed to guide actions when work deviates from established procedures or when problematic situations arise. They facilitate operational and managerial decision-making. A managerial standard may take the form of:

- A decision-making flowchart that clearly outlines the steps to be taken when a deviation is detected.
- Visual tables or charts that, for instance, present tactical schemes for operator allocation based on different scenarios.
- Temporally arranged Post-it notes can be used to manage improvement actions to be implemented throughout the year.
- A visual board for sequencing and monitoring patient care (medications, physiological routines, and professional visits), as well as the cleaning and release of hospital rooms.

It is important to emphasize that the three types of standards discussed in this chapter are complementary. Their combined use enhances the sustainability of the results achieved. For example, integrating managerial and visual standards facilitates the identification of deviations and enables appropriate responses.

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CHAPTER 14: TRAINING AND DEVELOPMENT

In general, training programs are developed with the following objectives:

- To prepare individuals for the execution of various tasks.
- To provide opportunities for continuous personal development, not only in their current roles but also anticipating potential future positions.
- To generate behavioral change, which may involve the transmission of information, the development of concepts and skills, or the modification of attitudes.

In motion and time studies, training sessions, and presentations are required at various points throughout the project, and their objectives vary depending on the project's scope and business area.

Figure 14.1 illustrates key moments during a motion and time study when presentations and training are necessary. At the outset of the project, it is crucial to introduce the project and its objectives to all stakeholders involved. Before data collection begins, the individuals responsible for this task must be trained on the forms, activities, and other essential points, including the data collection breakpoints.

During data analysis, it is also crucial that the involved personnel are trained to ensure an impartial and aligned analysis. When work standards are updated, operators must be trained in the new standard across all work shifts. Finally, the results achieved are usually presented to management in project closing meetings.

This figure illustrates that each type of presentation and training must be planned uniquely and independently, as the target audience, participants, and objectives vary across the phases of a motion and time study.

Consequently, this chapter aims to present the theory behind the science of training and development, enabling the reader to choose the best strategy for the type of presentation or training to be conducted. Within this field, it is essential to understand issues such as the learning process, the instructor's role, the development of training sessions, and the importance of promoting the use and updating of the standards that underpin these training activities.

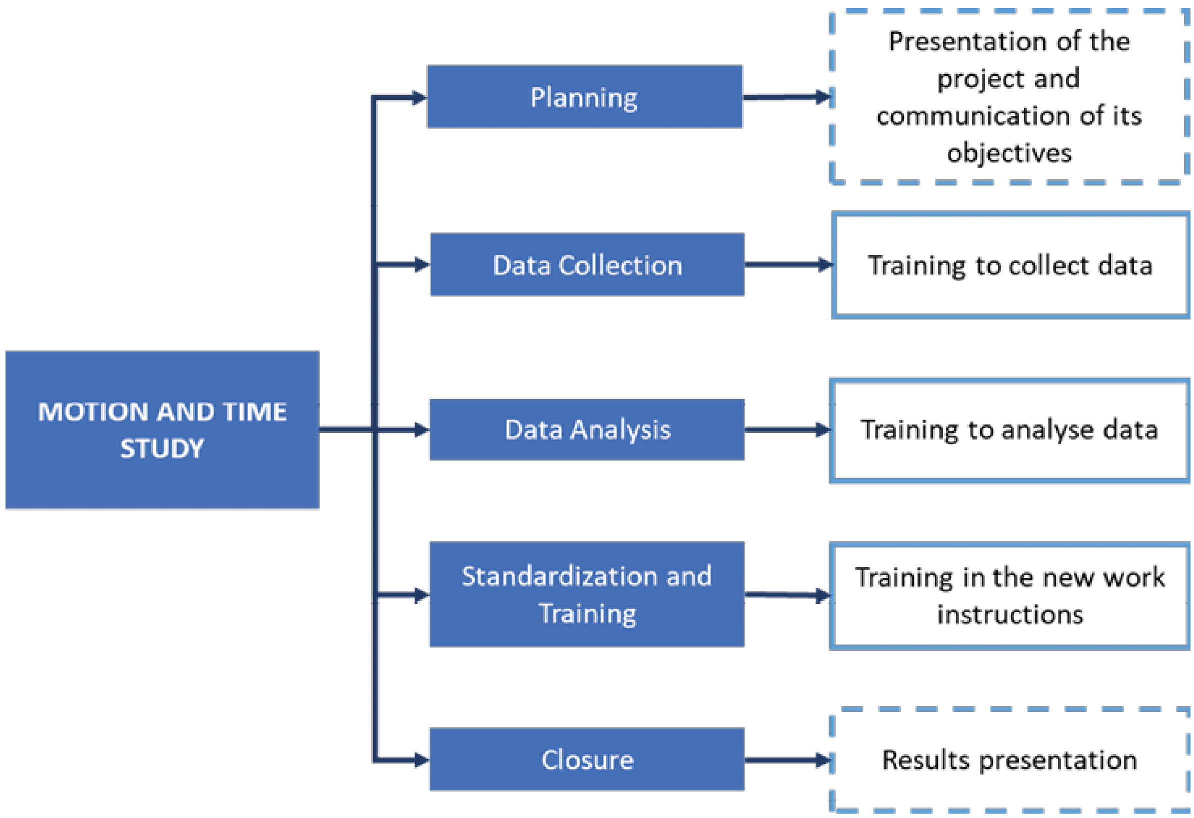

Figure 14.1 – Training in motion and time studies

14.1 Learning Process

Learning results from interactions between mental structures and the environment. It is a complex process in which it is impossible to control all variables. Therefore, understanding how the learning process works is essential to optimizing it during training.

First, generic aspects of the learning process will be presented, followed by a focus on its specificities in terms of motion and time studies.

General learning process

Four key factors significantly influence training:

1. Attention (Figure 14.2): Perception of critical features.
2. Retention (Figure 14.2): The ability to remember actions even when a model is not available.
3. Motor reproduction: After perceiving the new behavior, the repetition of activities should be translated into actions.
4. Reinforcement: Continuous reinforcement of what has been learned through different situations.

Based on Figure 14.2, it is evident that people perceive and retain information primarily through nonverbal channels. Thus, feelings, voice characteristics, facial expressions, and body language are key elements in the learning process.

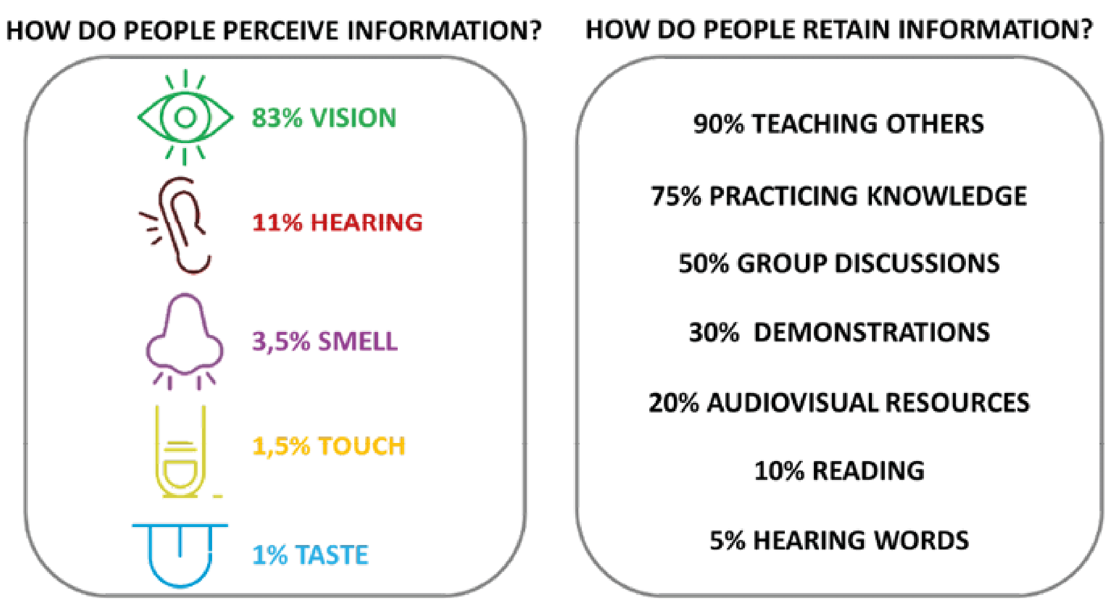

Figure 14.2 – Perception and retention of information

According to andragogy, the science that studies the best practices for guiding adult learning, individuals are motivated to learn when their needs and interests are satisfied. Therefore, it is essential first to understand the needs of the people participating in the training, as this will influence their attention, information retention, and future availability to reproduce and reinforce the learning.

It is therefore crucial for the instructor to understand psychological factors such as stress, needs, and rewards to motivate and engage participants effectively during training. People naturally aim to work with as little stress as possible and as much benefit as possible.

Maslow's hierarchy of needs, illustrated in Figure 14.3, helps us understand how to manage these human needs in a training context. Each hierarchical level of the pyramid must be satisfied before an individual seeks to fulfill the subsequent need.

The most basic needs are physiological, corresponding to survival necessities such as food and hydration. Maslow's theory can be related to Frederick Herzberg's theory, which distinguishes between factors whose presence is satisfying (motivational factors) and those whose absence causes dissatisfaction (hygiene factors) in the workplace.

At the basal level of work-related needs, examples include adequate compensation, suitable physical working conditions (such as lighting, acoustics, and ergonomics), and regular rest breaks.

Once these needs are met, physical and psychological safety needs become important. In the workplace context, this level concerns issues such as job stability and occupational safety (e.g., the risk of workplace accidents).

The third level, social needs, encompasses the desire for attention, friendship, social belonging, and meaningful relationships with coworkers and supervisors.

At the fourth level, esteem needs, employees strive for competence and accomplishment, express a desire for self-respect, or seek to satisfy their ego. This is typically addressed through recognition policies and promotion opportunities.

At the top of the pyramid, the final level is self-actualization. Once all other needs are fulfilled, the worker seeks to feel self-fulfilled. It is essential to note that this need varies from person to person: while some people find fulfillment in operational roles, others only feel satisfied when managing their own business. This hierarchical level can be exemplified by factors such as the degree of challenge in the work, the level of participation in decision-making, the autonomy and freedom, and the encouragement of diversity.

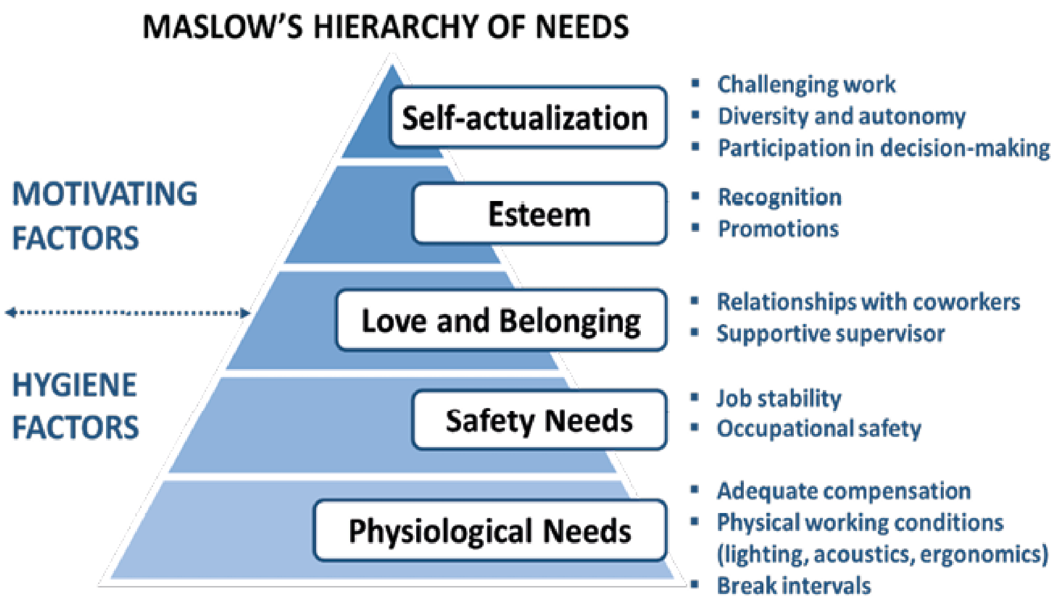

Figure 14.3 – Maslow's hierarchy of needs

Maslow's hierarchy of needs is therefore a tool for managing motivation and planning training programs that foster a more open attitude toward learning. When individuals participate in a training session, they typically do so in response to higher-level needs in Maslow's hierarchy of needs, such as self-esteem and self-actualization. The instructor must keep this in mind to motivate participants and, consequently, engage them throughout the training process.

However, lower-level needs should not be neglected, as outlined in Maslow's Pyramid. For instance, insisting that participants remain in the session until a predetermined lunch break is scheduled may not be wise. Hunger is a fundamental and subjective physiological need, and it is not possible to control when individuals will experience it. Once they do, they are unlikely to maintain attention, rendering that segment of the training unproductive.

Another key aspect of the learning process is recognizing the necessity of patience. Anxiety and learning are far from synonymous. In fact, anxiety tends to hinder the learning process. One valuable strategy that instructors can employ is the deliberate use of silence. When an instructor poses a question to a participant and waits between three and five seconds for a response, this pause can significantly enhance the participant's learning.

In conclusion, learning is not an end in itself but rather a continuous process that involves recognizing learning opportunities and, from them, changing one's thoughts, behaviors, and habits to achieve comprehensive learning (Figure 14.4).

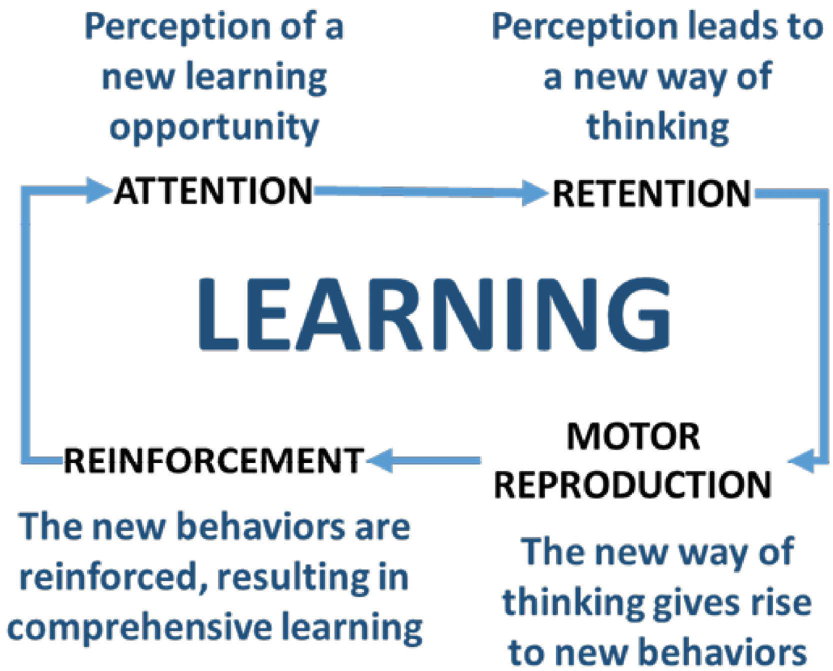

Figure 14.4 – The continuous process of learning

The learning process in motion and time studies

Regarding the learning process, particularly in the context of training in motion and time studies and improvements, it is essential to recognize that learning comprises two primary components: cognitive and motor learning. In motion and time studies, it is vital that both mental and motor learning occur following training. Therefore, it should not be expected that an employee will be ready to execute a new work method immediately after training. On the contrary, the opposite premise should be adopted: training represents merely the starting point of a broader process of change.

Furthermore, another critical aspect concerning learning in motion and time studies is that many failures in defining standard times result from neglecting the learning curve. This curve applies at both the individual and organizational levels. Individual learning refers to improvements in the time required to perform a task, primarily resulting from the person performing it—e.g., enhanced motor and/or cognitive coordination, fewer errors, and reduced reaction time. In contrast, organizational learning refers to improvements in task execution time arising from changes in manufacturing processes—such as tools, equipment, or work methods.

Thus, training must be continuous rather than one-time, and the employee's learning curve must be monitored (Figure 14.5) to optimize results from a motion and time study.

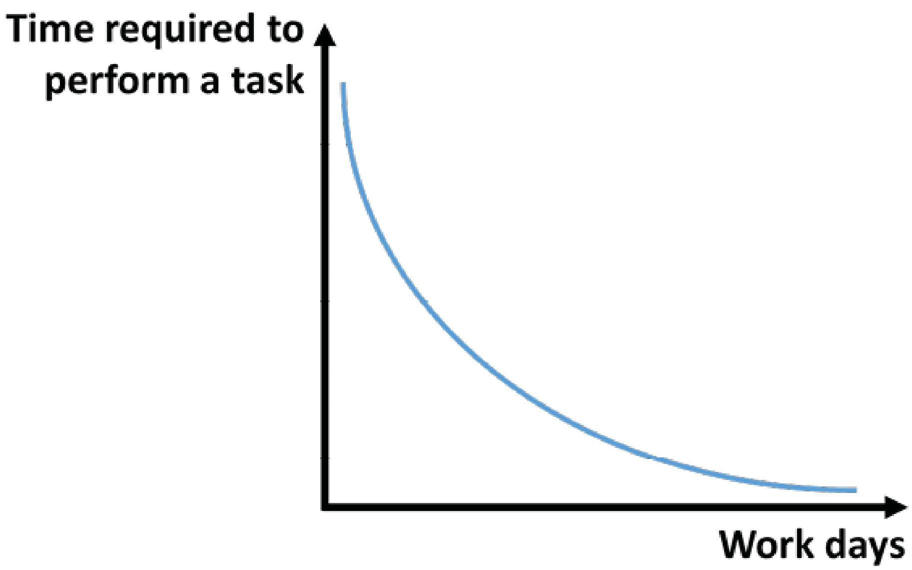

Figure 14.5 – Learning curve of an operation

14.2 The instructor role

Many training sessions are compromised because it is not always clear to the instructor themselves what their role is. The central role of the instructor is to work with, not for, the participant. That is, training should be a bidirectional process, not a unidirectional one in which the trainer speaks and the audience listens. When conducted bidirectionally, the goal or final product of the training naturally represents a process of change in its participants. After all, learning only truly occurs when it generates behavioral change. Therefore, it is natural that good training provokes some discomfort and questions in participants. These are the primary drivers of learning and behavioral change.

To work effectively with the participant, the instructor must develop skills such as active listening and resistance management to achieve excellence in their work.

Developing active listening

Many factors vary from one training session to another, including the audience, location, available resources, allocated time, and even the participants' psychological state. Thus, the keyword for an instructor is ACTIVE LISTENING.

Accordingly, a good instructor must possess active listening, which evolves through the following stages:

1. Ignoring.
2. Assuming.
3. Selecting.
4. Paying attention.
5. Developing empathy.

The highest level of active listening, therefore, is empathy. And this is not easy at all. The instructor must always make the training relatable and human. After all, if we aim to become machines, we will eventually be replaced by them. The difference between remote learning and face-to-face training becomes evident only when the instructor can empathize with and humanize the process.

Active listening is challenging to develop. It involves learning to listen more than to speak. And listening is not limited to sound waves in space: we must "listen" to the participants, the environment, and even to ourselves. Thus, others are fundamental to our process of developing active listening, and this often requires psychological growth—something that therapy and theater courses can help with.

For instance, we must "listen" to the energy of the audience we are engaging with. If the audience emits low energy, the instructor must radiate high energy to uplift them. In contrast, if the participants transmit excessive energy, the instructor should reduce their own to balance it with the group's.

In summary, rigid training sessions will lead to rigid learning. Therefore, training must be fluid. Uncertainties and unexpected situations will always arise. It is not the instructor's role to ignore or confront them directly. In fact, they should embrace these moments and know how to extract the maximum value from them, thereby optimizing learning. A good instructor is not afraid of the dark: they know that it is precisely in the dark that students begin to shine with their own light.

Dealing with Resistance

Another important aspect of the instructor's role is knowing how to deal, for example, with resistance, which may manifest through different behaviors:

- "Give me more details": the participant repeatedly asks the instructor for more details on a topic.
- Lack of interest in participating: the participant shows little motivation to ask questions or actively engage in the training.
- Constant interruptions: The participant continuously interrupts the training session.
- Impracticality: The participant constantly requests practical examples and repeatedly emphasizes that "in practice, it is different."
- Indirect attacks: The participant "attacks" the instructor indirectly through phrases and body language. In this case, the instructor should not take it personally.
- Silence: If the participant remains passive and silent during the training, the instructor should encourage participation.

- Excessive rationalization: The participant engages in continuous rationalization. In this case, the instructor should bring the participant back to practical matters.

The instructor must develop the ability to deal with resistance. For this purpose, it is essential to view resistance as a natural process rather than a personal offense. When resistance is observed, it is not the instructor that participants resist, but rather the challenge of making a difficult choice or confronting a reality they have been avoiding. Consequently, the instructor must remain alert to identify possible resistance and encourage participants to express it.

Such resistance generally arises as a consequence of three main factors:

- Most people find it challenging to deal with change.
- Job or role stability is a priority for employees.
- People have social needs and, consequently, are influenced by the group to which they belong.

Firstly, most people, regardless of their job or hierarchical position, resist any change related to their work standards and routines. After all, human beings are driven by habits; when those habits are altered, discomfort and unease ensue.

Secondly, employees naturally seek security in their roles, a natural result of a self-preservation instinct. Moreover, changes in work standards and methods are often perceived as efforts to increase productivity. The immediate reaction is the belief that if production increases, fewer resources will be needed and, consequently, staff may be reduced. The solution to this issue is for management to be transparent and avoid generating such fears, for example, by making it clear that natural turnover within the department will be responsible for reducing the number of resources or reallocating them.

Finally, the worker, as a member of a group, unconsciously receives proposed changes from external individuals, such as managers, consultants, or employees from other departments, with a certain degree of hostility.

It is therefore essential that instructors understand the psychological and social effects of methods, work patterns, and remuneration systems to mitigate any resistance.

Guidelines for creating an effective training program

Dale Carnegie presents interesting techniques and principles for dealing with people, winning their empathy, and influencing their thinking and actions without offending them or creating resentment (Table 14.1).

Fundamental Techniques in Handling People
1. Instead of criticizing people, try to understand them. *Don't criticize, condemn, or complain.*
2. Remember that all people need to feel important; therefore, try to figure out the other person's good point. *Give honest and sincere appreciation.*
3. Remember that all people are interested in their own needs; therefore, talk about what they want and show them how to get it. *Arouse in the other person an eager want.*
Six ways to make people like you
1. Become genuinely interested in people.
2. Smile.
3. Remember that a person's name is to them the sweetest and most important sound in any language.

4. Become an attentive listener. Encourage others to talk about themselves.
5. Talk in terms of the other person’s interests.
6. Make the other person feel important and do it sincerely.
Twelve ways to win people to your way of thinking
1. The only way to get the best of an argument is to avoid it. *You can’t win an argument!*
2. Show respect for the other person’s opinions. Never tell anyone: “You’re wrong.”
3. If you’re wrong, admit it quickly and emphatically.
4. Begin in a friendly way. *A drop of honey catches more flies than a gallon of gall.*
5. Get the other person saying “yes, yes” immediately. *In talking with people, don’t begin by discussing the things on which you differ. Begin by emphasizing—and keep on emphasizing—the things on which you agree.*
6. Let the other person do a great deal of the talking.
7. Let the other person feel that the idea is theirs.
8. Try honestly to see things from the other person’s point of view.
9. Be sympathetic to the other person’s ideas and desires.
10. Appeal to the nobler motives. *We must believe that people are honest and want to discharge their*

obligations.
11. Dramatize your ideas.
12. Throw down a challenge.
Nine ways to change people without giving offense or arousing resentment
1. Begin with praise and honest appreciation.
2. Call attention to people's mistakes indirectly.
3. Talk about your own mistakes before criticizing the other person.
4. Ask questions instead of giving direct orders. *No one likes to take orders.*
5. Let the other person save face.
6. Praise the slightest improvement and praise every improvement. Be "hearty in your approbation and lavish in your praise."
7. Give the other person a fine reputation to live up to.
8. Use encouragement. Make the fault seem easy to correct.
9. Make the other person happy about doing the thing you suggest.

Table 14.1 – The Dale Carnegie approach

Another critical point is that the instructor must recognize that it is not their obligation to know everything. Humility is the foundation of learning. A good teacher never ceases to be a student, always eager to learn. Therefore, more important than the instructor acknowledging their vulnerability and lack of knowledge about specific issues is their ability to motivate and show the way to solve those issues.

A person will never be a good leader or good instructor if they have a constant need for self-affirmation. Most people have likely encountered teachers, instructors, or coworkers with such characteristics. The instructor should not seek to be the center of attention or attempt to demonstrate their superiority and intelligence to the participants. On the contrary, the focus should always be on the participants and their needs.

To achieve excellence in their work, instructors must be motivated, responsible, and competent to carry it out (Figure 14.6). Work based solely on motivation and responsibility will be flawed—after all, it will lack competence. Work based only on responsibility and competence will be forced if the instructor lacks the motivation to perform it. Ultimately, work driven by motivation and competence, but lacking responsibility, will be devoid of value.

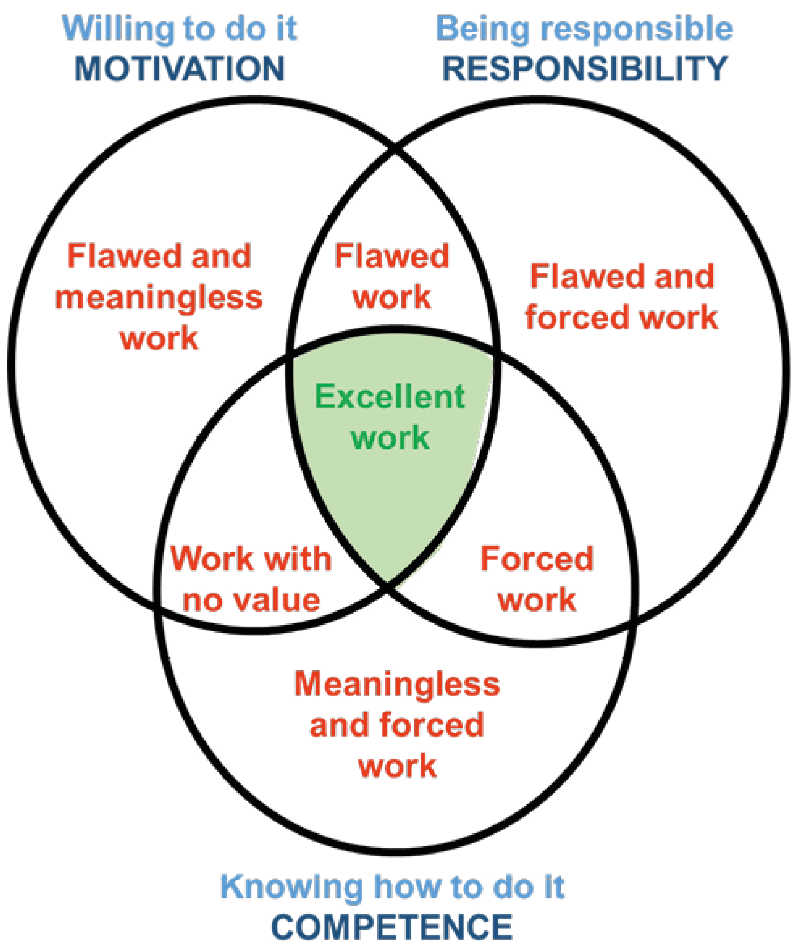

Figure 14.6 – Skills of a good instructor

14.3 Creating an effective training program

While developing training programs, we must also follow the DMAIC or PDCA cycle. After all, proper planning is a prerequisite for the training to meet its intended objectives.

Thus, in the planning phase, we must follow the step-by-step procedure below:

- Definition of the objective.
- Considerations regarding infrastructure and the type of training.
- Strategy for utilizing instructional resources.
- Development of the content.
- Selection of the evaluation process.

Each of these steps is addressed in detail below.

Definition of the objective

The objective essentially answers the question: "What do we want to achieve with this training?" To provide an adequate answer, it is essential to identify the target audience clearly. Therefore, we must also ask ourselves: "Who will be our target audience?" These two questions are intrinsically linked. If we intend to deliver the same training to both managers and operators, we will undoubtedly encounter difficulties. Thus, each training program must be developed with a clearly defined objective, tailored to the participant audience.

These initial questions should not be answered in isolation by the training organizer. A study must be conducted with key individuals from various departments to identify the needs to be addressed.

Considerations regarding infrastructure and the definition of the type of training

It is also crucial to define the required infrastructure. One must ask: "Where will the training be conducted: in a classroom or the production area?," "What else must be considered?," and "What are the critical factors for the success of the training?"

These questions must be answered in light of the identified objectives. Motion and time training sessions can be conducted according to one or more of the following options:

- On-the-job training: The employee in training is accompanied by more experienced colleagues during the initial learning phase of the new method as they execute work. This training offers several benefits, including reducing anxiety among beginners, encouraging employees to maintain consistent work standards, and minimizing errors in work methods.
- Based on written instructions: Simple descriptions of the work

method to be performed are useful for straightforward operations or for processes in which the employee is reasonably familiar with the procedure and, therefore, only needs to make minor adjustments to the work method.

- Based on the illustrated instructions: Photographs can be used alongside written instructions to increase training efficiency. Moreover, it is recommended that, whenever possible, visual standards be used—as discussed in the previous chapter—at the workstation to facilitate maintaining the desired standard in the employee's routine.
- In-person simulations/demonstrations: Physical training using models, simulators, or real equipment is an excellent option for complex methods. This strategy enables employees to practically experience the activities to be performed in a safe environment that promotes learning and encourages feedback. A classic example is flight simulator training for future pilots.
- Remote training: With the development of information technology and the internet, training through videos and interactive online materials has become increasingly common due to its scalability. That is, this term refers to the ability to serve numerous additional people at an extremely low incremental cost. Thus, it is useful, for example, when the goal is to standardize training across different branches of a company worldwide. Furthermore, videos allow the dynamics of a process—such as the interrelationships among movements, parts, and tools—to be demonstrated more effectively than illustrations can. Not to mention that the person in training has the freedom to control the pace and duration of viewing, allowing them to go back and review any procedure or part of the training they have doubts about, if necessary.

It is worth noting that these options are complementary and should be selected based on the training program's objective.

Strategy for utilizing instructional resources

Regarding didactic resources, recent technological advancements have created several possibilities, including computer-based resources, Extended Reality (XR) headsets, visits to the production area, videos and software, practical exercises, whiteboards, flipcharts, dynamic presentations, PowerPoint, Prezi, and more.

These resources are complementary in optimizing learning and should be selected based on the objective and type of training to be conducted. Videos and software, for example, can be used to show the dynamics of the process, such as the relationships between movements and tools, in a more didactic way than static images. These are simple methods that facilitate their replication. However, it is worth emphasizing that for more complex operations, it is essential to complement this type of training with other options, such as on-the-job training, simulations, or demonstrations.

Another option is to use parables, stories, and practical examples to illustrate the points. These approaches enrich learning by contextualizing instruction and bringing the instructor closer to the participant.

A well-planned training session will utilize several of these resources in an alternating manner. The human brain cannot maintain attention for more than 20 minutes. Therefore, whenever participants are no longer paying close attention, it is necessary to pause or adjust the training pace.

Content Development

Once the previous matters (objectives, infrastructure, and instructional resources) are defined, one can proceed to develop the training itself. This phase involves aligning the available resources (people, time, and infrastructure) with the training objectives.

It is always advisable, at the beginning, to present participants with a psychological contract that addresses the following issues:

- Aligning expectations between the participants and the facilitator.
- Aligning the basic criteria to optimize learning, such as defining breaks, the roles of those involved, the use of mobile phones and other electronic devices, confidentiality, and ethics.

What is agreed upon does not come at a high cost. Therefore, prior alignment of these issues will help mitigate possible doubts and resistance.

It is essential to note that the developed content should not be rigidly structured. It is natural for the instructor to encounter unforeseen questions during the training. A good instructor must practice active listening and be flexible to optimize the students' learning.

Planning the evaluation process

This stage is often neglected, although it is one of the most critical and complex steps. Learning is not a punctual process but a continuous one. Therefore, if the training is designed as a one-time event, the desired objectives are unlikely to be achieved. Often, one participates in projects in which the final report presents the solution to the problem under study: a valuable training experience for those involved.

One must be very careful with this type of superficial recommendation: very few training programs are truly successful, since there is a mindset of "I did my part, and now it is up to you." To achieve substantive change among training participants, the evaluation process must also be well planned to ensure optimal content retention.

There are three forms of training evaluation: learning, reaction, and results.

Learning evaluation is the most common and checks how much the participant has assimilated from what was proposed during the training. It measures the acquisition of knowledge and skills. That is, it should be employed alone when the objective is only to inform the participants. If the training aims to achieve more concrete changes in participants' actions, other forms of evaluation should be used alongside it.

Reaction evaluation aims to understand the group's opinions on the training content, its effectiveness, duration, methodology, instructor's performance, and resources utilized. In other words, this type of evaluation serves as a source of feedback, enabling continuous improvement of the training.

Finally, results evaluation verifies the impact of the training on job performance and organizational outcomes. It involves measuring changes in behavior, performance indicators, and overall results before and after training, often through interviews or analysis of performance data.

Thus, it is recommended that training for motion and time studies utilize the three aforementioned types of evaluation (learning evaluation, reaction evaluation, and evaluation of training results) to optimize cognitive and motor learning. Moreover, if the objective of the training is to bring about behavioral change, special attention must be given to evaluating the results.

14.4 Training needs standardization!

Another key point in motion and time studies training is to encourage the use and update of standards. As already mentioned in the previous chapter, these standards must be "living" and therefore constantly updated as individual and organizational learning evolves. The training should bring employees closer to the standards and foster improvements in work, which in turn should result in updates to the standard and new training. With this, the aim is for motion and time studies to be a first step towards the continuous improvement of a workstation (Figure 14.7).

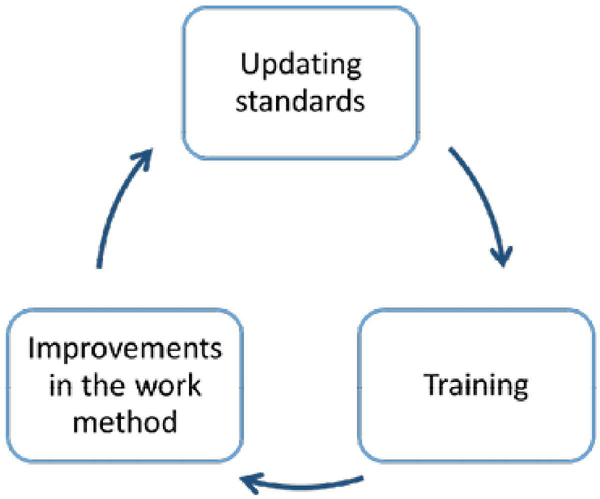

Figure 14.7 – Continuous cycle of improvement and learning

While the organizational culture has not yet reached a high level of continuous improvement, it is advisable to conduct periodic audits to ensure that operators and employees adhere to work standards. If the necessary resources to perform these audits are not available, priority should be given according to the Pareto principle: conduct audits in the few "vital" workstations and disregard the many workstations of lesser importance.

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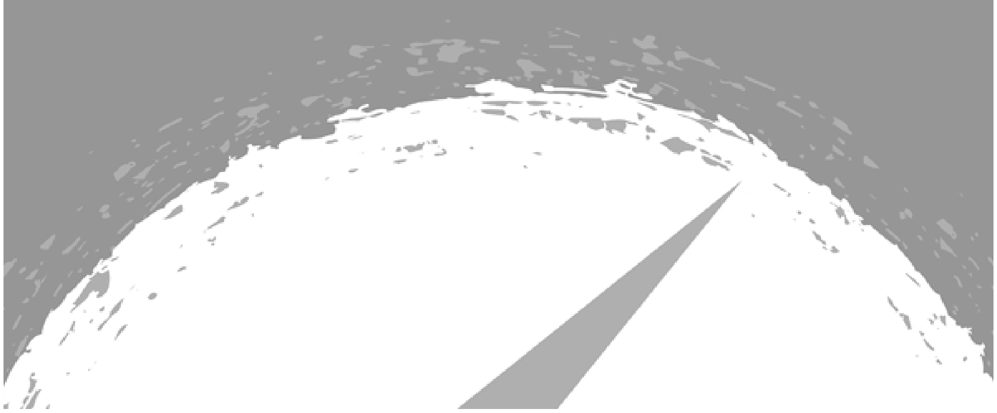
A FINAL REFLECTION



A FINAL REFLECTION

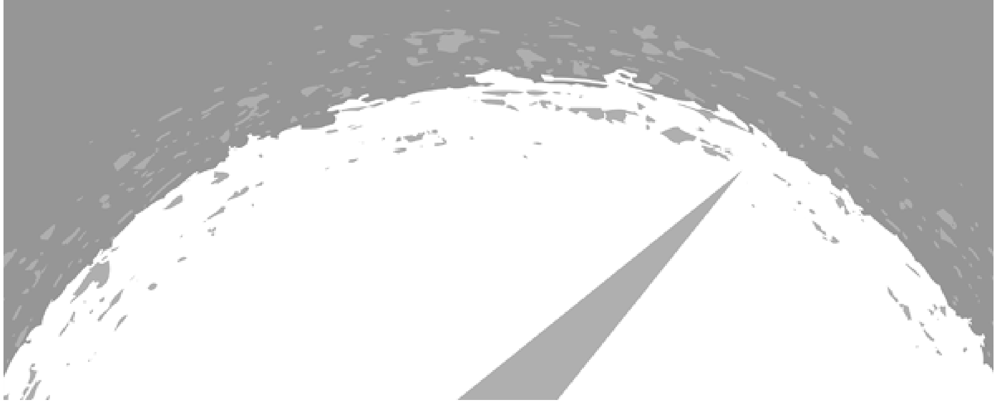
Finally, we have concluded this work. After discussing the fundamentals of motion and time studies, method design and improvement, work measurement procedures, and standardization and training, the reader now possesses the necessary knowledge to implement a motion and time study. Meanwhile, it is important to emphasize that practice is what will refine this theoretical foundation.

Furthermore, the lean approach advocated in this book emphasizes optimizing flow efficiency and eliminating waste, thereby creating a streamlined process in which everyone is responsible for continuous improvement and sustaining results. Ultimately, a motion and time study should not be a one-time effort but a continuous process of enhancement and learning, enabling the reader to achieve the mastery and critical insight required to execute this work proficiently.

Thus, rather than an end, this represents a beginning: let's get to work and do a great job!

APPENDICES

Appendix 1: Acronyms and abbreviations
Appendix 2: Lexicon
Appendix 3: Special tables
Appendix 4: Forms
Appendix 5: Answers to activities



APPENDIX 1: ACRONYMS AND ABBREVIATIONS

3DSSPP: 3D Static Strength Prediction Program

3M: Muda, Mura, and Muri

5S: Sort, Set in Order, Shine, Standardize, and Sustain (Seiri, Seiton, Seiso, Seiketsu, and Shitsuke)

5W2H: Who? What? Where? When? Why? How? How much?

ANMC: Australian Nurse Practitioner Competency Standards

AUSPRAC: AUStralian Nurse PRACtitioner Project

DMADV: Define, Measure, Analyse, Design, and Verify

DMAIC: Define, Measure, Analyse, Improve, and Check

DMEDI: Define, Measure, Explore, Develop, and Implement

FIFO: First In First Out

JIT: Just In Time

JSI: Job Strain Index

LOS: Length of Stay

MIT: Massachusetts Institute of Technology

MODAPTS: Modular Arrangement of Predetermined Time Systems

MOST: Maynard Operation Sequence Technique

MSDs: MusculoSkeletal Disorders

MTM: Methods-Time Measurement

NIOSH: National Institute for Occupational Safety and Health

OEE: Overall Equipment Effectiveness

OWAS: Ovako Working Posture Analysing System

PDCA: Plan, Do, Check, and Act

PPE: Personal Protective Equipment

PTSS: Predetermined Time Standards Systems

QC Story: Quality Control Story

REBA: Rapid Entire Body Assessment

RULA: Rapid Upper Limb Assessment

SDCA: Standardize, Do, Check, and Act

SMCT: Single Minute Cycle Time

SMED: Single Minute Exchange of Die

SOP: Standard Operating Procedure

SPSS: Statistical Package for the Social Sciences

SWCS: Standard Work Combination Sheet

SWI: Standard Work Instructions

SWS: Standardized Work Sheet

TMU: Time Measurement Units

TPS: Toyota Production System

TT: Takt Time

WHO: World Health Organization

WIP: Work In Progress

APPENDIX 2: LEXICON

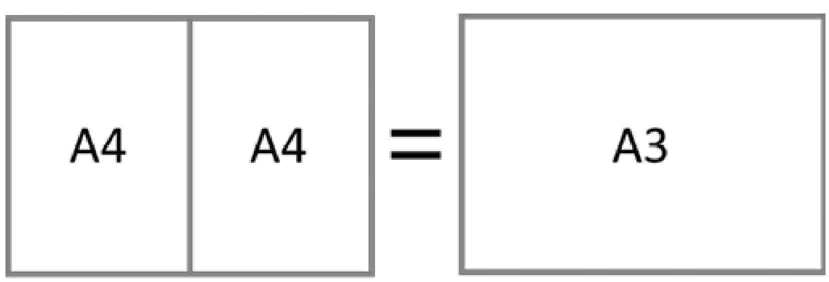
5S A Japanese philosophy aimed at eliminating workplace waste. Its name originates from the initials of five Japanese words beginning with the letter "S" (Seiri, Seiton, Seiso, Seiketsu, and Shitsuke).

5W2H A tool that can be employed to develop a more precise plan regarding a specific objective or to construct an action plan. It is essentially based on answering the following questions: Who? What? Where? When? Why? How? How often?

5 Whys A simple problem-solving tool that consists of asking the question "Why?" five times until the root cause of a problem is identified.

A

A3 A document that summarizes and records a project on a single A3 sheet (29.7 cm × 42 cm), equivalent to two A4 sheets. The A3 sheet should describe the problem, analysis, corrective actions, and the action plan, following the DMAIC steps, and use figures and charts whenever possible.



Activity Encompasses all tangible and intangible aspects inherent to a task. It refers to the actual work being carried out in practice, including an individual's gestures, postures, communication, behavior, and thoughts. Thus, activity seeks to answer the following question: HOW should the work be performed?

Andragogy In contrast to pedagogy (the science concerned with the education of young people), andragogy is the science that studies best practices for guiding adults in learning. According to andragogical principles, individuals are motivated to learn as they encounter needs and interests that satisfy them.

Autonomous Maintenance This strategy from Total Productive Maintenance (TPM) aims to empower equipment operators to perform small, daily maintenance tasks, such as cleaning and tightening screws.

B

Backup A copy of data from one storage device to another, aimed at mitigating the risk of data loss.

Benchmarking A process of identifying and adopting best practices by comparing against reference standards from other companies or equipment manufacturers. This process enhances an organization's internal methods and leads to superior performance.

Bottleneck Similar to the neck of a bottle, this term refers to a bottleneck or constraint in a production or service process. Production is limited by the capacity or speed of the bottleneck, which is the "slowest" step in the process. This can be attributed to a resource, such as equipment or a person.

Brainstorming A group discussion technique designed to stimulate the spontaneous contribution of ideas from all participants, to solve a problem or engage in creative work.

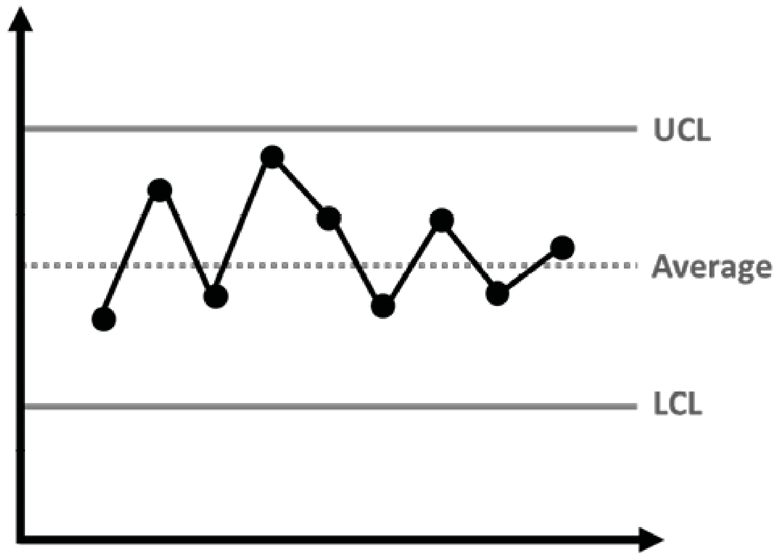
Breakpoint It refers to specific moments when a stopwatch should be activated to begin timing the next element. The use of visual and auditory signals as breakpoints is recommended.

C

Checklist A tool used to collect, organize, and present data collection results.

Continuous Flow Continuous flow involves making a process increasingly fluid and less interrupted. The goal is to continuously produce and process as few items as possible through a series of steps, minimizing intermediate inventory.

Control Chart A graphical tool developed by Walter A. Shewhart that is used to monitor a process relative to its upper and lower control limits (UCL and LCL). The objective is to determine, from the chart, whether the process is under control (free from special causes of variation).



Cycle Time The time required to complete one work cycle, that is, the time spent per unit produced.

D

DMAIC (Define, Measure, Analyze, Improve, Check) A managerial problem-solving methodology applied in Six Sigma and Lean projects. Its name derives from the initials of its six phases: Define, Measure, Analyze, Improve and Check.

Downstream In industry, it refers to the final production processes and storage areas closest to the customer, such as finished goods inventory.

E

Element Temporal subdivisions of an operation that represent the smallest increment of work that can be transferred from one person to another.

Ergomotricity A noun that originates from the French *Ergomotricité*, which encompasses the study of movements performed during work, involving both the motor and psychological potential of a person, as well as their gestural and postural movements. Ergomotricity proposes principles for applying in activities to adapt the work pattern to the individual performing them.

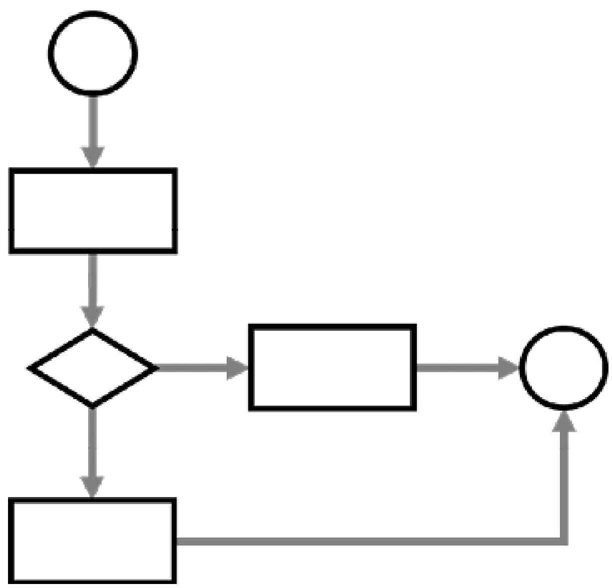
Ergonomics The science of adapting the workplace to human needs. It encompasses the study of the workstation, the environment, and the flows in which it is embedded.

F

Fatigue Tiredness or exhaustion resulting from continuous work. Fatigue may be physical or psychological.

Feedback An English term meaning to "feed back" or respond to a given stimulus. In a business environment, it refers to the evaluation provided to an individual or group of employees regarding actions taken or results achieved.

Flowchart A flowchart is a schematic representation of a process, with steps illustrated in sequential order using symbols.



Flow Diagram A combination of a flow process chart and a spaghetti diagram, which can be represented in two or three dimensions on a building layout or on the shop floor where a given operation takes place.

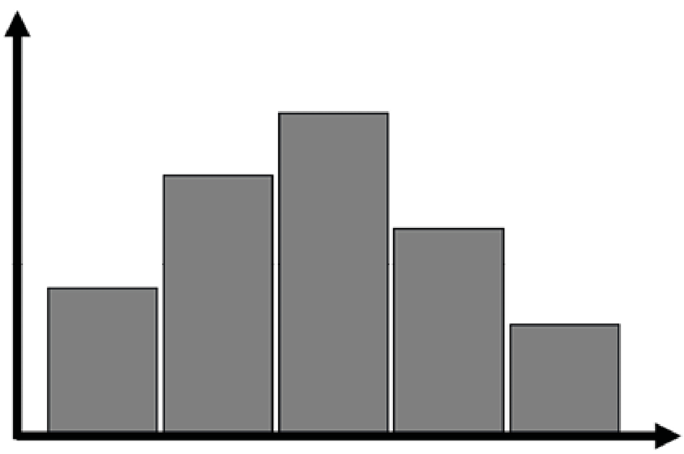
Flow Process Chart This chart presents the activities of an operation in a sequence using symbols that represent operations, inspections, inventories, transports, and delays.

G

Gemba A Japanese term meaning the actual place or the place where things happen. It is commonly used on the production floor or in any location where work that adds value to a product or service is performed.

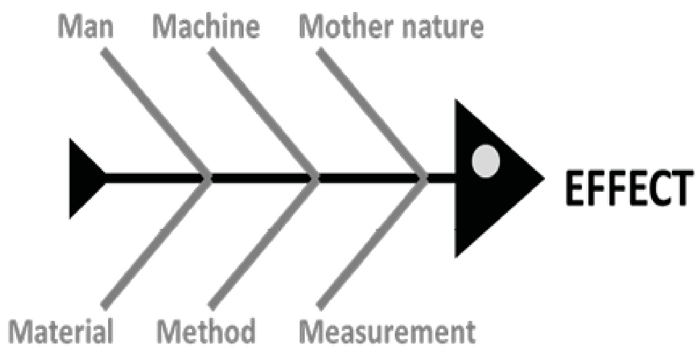
H

Histogram A frequency graph that illustrates how a given sample or population of data is distributed.



I

Ishikawa Diagram A tool used to present the relationship between the result of a process (the effect or problem) and the process factors (causes) that may technically affect the outcome. It is also known as a cause-and-effect diagram or fishbone diagram.



J

Jidoka One of the pillars of the Toyota Production System is the concept of equipping machines and operators to autonomously prevent problems. In other words, it is the ability to detect an abnormal condition and immediately stop the process. Taiichi Ohno defined autonomation as automation with a human touch.

Job Strain Index (JSI) A method for analyzing a worker's risk of developing musculoskeletal disorders in the distal part of the upper limbs due to repetitive movements.

Just-in-Time (JIT) Another pillar of the Toyota Production System, this term means producing the right product, in the correct quantity, at the right time.

K

Kaizen A Japanese term that can be translated as continuous improvement, which can encompass an entire value stream or an individual process, to add more value while simultaneously reducing waste.

Kanban A Japanese term that can be translated as "signals" or "signboard." These are signaling devices that authorize and provide instructions for the production or withdrawal of items in a pull production system.

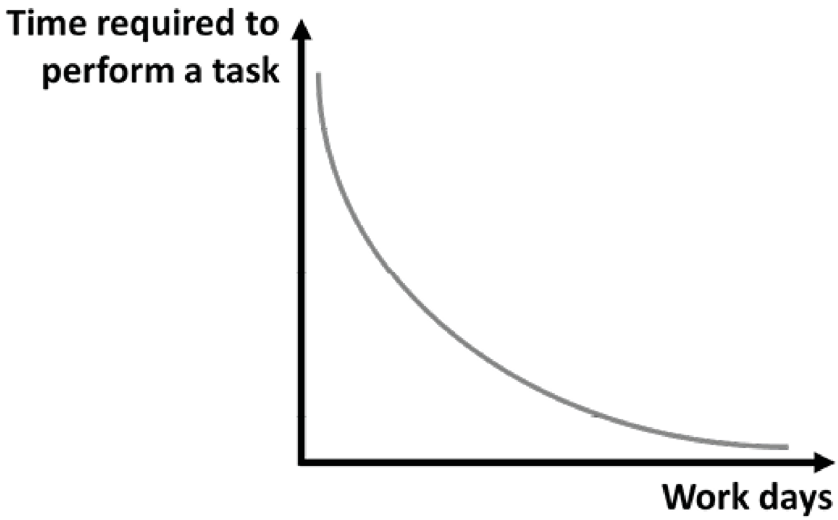
L

Layout This word refers to the spatial organization of equipment, machines, tools, inventory, and labor within a company.

Lead Time This term refers to the time required to complete a process from start to finish. In industrial production, for example, it is the time between a customer's order being placed and the product being shipped.

Lean Manufacturing Management philosophy inspired by the practices and results of the Toyota Production System and other quality tools. Its name was popularized by the 1990 book, "The Machine That Changed the World."

Learning Curve A phenomenon observed both at the individual and organizational levels. Individual learning refers to improvements in the time required to perform a task, primarily resulting from the individual's execution, for example, through enhanced motor and/or cognitive coordination, reduced errors, and faster reaction time. Organizational learning, in contrast, refers to improvements in task execution time resulting from changes in manufacturing processes, such as modifications to tools, equipment, or work methods.



Line Balancing A method designed to achieve a more equitable distribution of workload among workers or equipment. Consequently, line balancing enables a smoother and more uniform production flow.

M

Management Standard Specifies the actions to be taken when work deviates from the standard or a problem arises.

Maslow's Hierarchy of Needs A concept developed in the 1950s by American psychologist Abraham H. Maslow aimed at identifying the set of conditions necessary for an individual to achieve satisfaction, whether personal or professional. Human needs are broken down into five categories: physiological, safety, social, esteem, and self-actualization.

Muda Waste that generates inefficiencies in processes.

Mura Unevenness or variability that generates waste.

Muri Overburden that generates waste.

N

NIOSH Equation An equation used to calculate the recommended weight limit in repetitive tasks involving static load lifting.

O

OEE (Overall Equipment Effectiveness) An indicator used to monitor the total effectiveness of equipment. OEE expresses, as a percentage, the proportion of time the equipment was actually producing relative to the total available time. This indicator highlights losses in availability (breakdowns, setups, pauses, breaks, and meetings), performance (reduced speed and idling), and quality (defects).

Operating Procedures Defines the standardized work method to be followed, such as SWI, SWCS, and SWS.

On-the-job Training On-the-job training takes place in the workplace, where a more experienced colleague trains a new employee. During this process, employees become familiar with the working environment they will be part of, through the practical use of machines, equipment, tools, and materials required for a specific function.

Outliers Atypical values in a dataset should be excluded to avoid inconsistent interpretations of results.

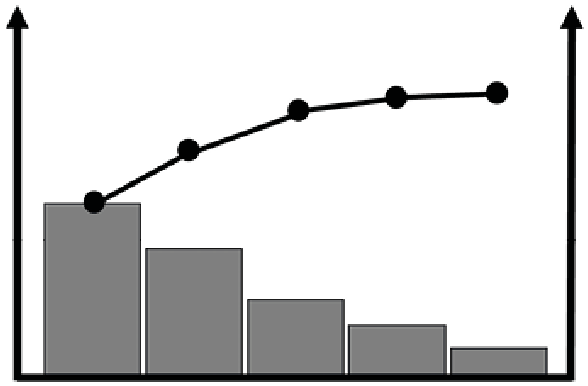
Outputs The outcomes of a transformation process, such as products or services and their characteristics, that add value to customers (e.g., quality) or to the company (e.g., profit).

OWAS (Ovako Working Posture Analysing System) A practical tool for posture analysis developed by the Finnish company Ovako.

P

Paradigms Mental models that are adopted by individuals, whose validity is rarely questioned.

Pareto Chart A chart that organizes information to concentrate improvement efforts in areas where the most significant gains can be achieved. Defect (or failure) types are arranged in descending order of frequency of occurrence during the observed process period. The category with the highest frequency appears first. The chart displays both the percentage observed for each defect type and the cumulative percentage.



PDCA (Plan, Do, Check, Act) PDCA, also known as the Deming Cycle, is a managerial method used for decision-making and implementing improvements to achieve objectives. This improvement cycle, based on scientific methods, consists of four stages: Plan, Do, Check, and Act.

Poka-yoke A Japanese expression translated as "mistake-proofing" or "error-proofing." It refers to methods that help prevent errors, such as incorrect component assembly, forgetting a part, or even workplace accidents. An example is the USB flash drive, which can only be inserted into a computer in a predetermined position.

Predetermined Time Standards Systems (SPSS) Standardization systems that transform patterns of movements into predetermined time values.

Production Leveling (Heijunka) The balancing of production by type and quantity of products over a fixed period of time. This practice provides several advantages: it prevents excess inventory, reduces costs, labor, and lead time across the entire value stream.

Pull Scheduling A production control method in which downstream activities signal their needs to upstream activities. The aim is for customer demand to “pull” what must be produced. Pull scheduling seeks to eliminate overproduction and is a core element of a complete just-in-time production system.

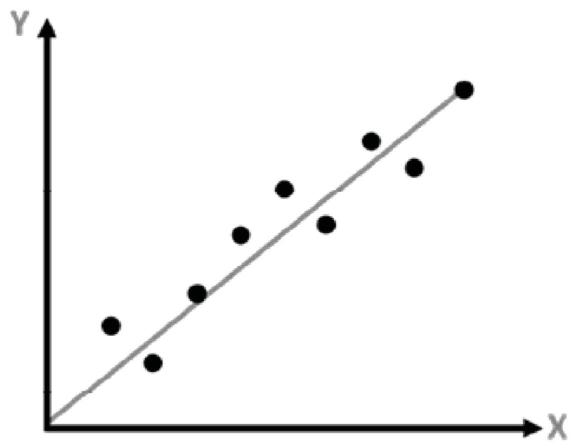
R

REBA (Rapid Entire Body Assessment) A method developed based on RULA, OWAS, and NIOSH, designed to assess unpredictable working postures.

RULA (Rapid Upper Limb Assessment) A rapid assessment method for identifying the risk of musculoskeletal disorders, with emphasis on the upper limbs.

S

Scatter Plot A graphical representation of an independent variable (X) in relation to a dependent variable (Y) to determine if a cause-and-effect relationship exists between these two quantitative variables.



Setup It refers to the time elapsed between the production of the last good piece of a batch and the first good piece of the next batch, produced at normal speed.

Six Sigma A set of practices originally developed by Motorola to systematically improve processes. The methodology's name refers to a process capability measure that aims to reduce defects to 3.4 per million opportunities.

SMCT (Single Minute Cycle Time) A five-step methodology that uses man–machine charts to optimize cycle time.

SMED (Single Minute Exchange of Die) A five-step methodology that uses man–machine charts to optimize tool changeover time, also known as setup time.

Spaghetti Diagram A tool used for the visual representation of the workflow across processes, facilitating the identification of wasted movements and transportation.

Standardized Muda Work that does not add value but is necessary under the current operating conditions.

Standard Work Combination Sheet (SWCS) A standard that presents the workflow in chart form, allowing for the identification of waiting times, movements, equipment usage time, cycle time, and takt time.

Standard Work Instructions (SWI) A document that aims to organize work elements in a predefined sequence, highlighting the necessary time so that this cyclical standard can be successfully repeated by all who perform it.

Standard Work Sheet (SWS) An operational standard aimed at representing the workflow of operator(s) within a layout.

Stopwatch Time Study A time measurement procedure that employs a stopwatch and statistical techniques to determine the standard time of an operation.

Stress The influence of the environment on the body. It refers to a set of biological and psychological disturbances caused by stressors—for example, time constraints, workplace conditions (such as lighting, noise, and other workstation-related factors), or product and service characteristics (including weight, repetition, and shape).

T

Takt Time The German word takt can be translated as beat. Takt time is therefore the pace at which production should operate to meet customer demand.

Task Refers to the activity a person is required to perform in their role. In other words, it is the prescribed work defined in operational procedures, essentially answering the question: WHAT is the work to be done?

Tension The body's natural reaction to environmental stress. It encompasses all effects on the body resulting from the body's attempt to adapt to a new stressor, such as pain, discomfort, fatigue, reduced sensitivity threshold, and even functional loss.

Therblig An inverted anagram of the surname Gilbreth. This term refers to the smallest unit of movement used to determine the motion and time of workers and to define a work method.

Toyota Production System (TPS) A production system developed by Toyota, also known as Toyotism, with two main pillars: just-in-time and jidoka.

Trade-off This English expression, often translated as a "win-lose" relationship, refers to choosing one thing at the expense of another.

U

Upstream This term refers to the source of a river, which, in an industrial context, represents the initial storage and transformation processes for a product or service, such as the raw material inventory.

V

Value-added Characteristics of a product, service, or its production process that add value to the customer, reflected in its selling price and market demand.

Value Stream A value stream is the set of actions, both value-adding and non-value-adding, required to transform a product or service from raw materials into a finished good for the customer.

Value Stream Mapping (VSM) A diagram that presents all the necessary steps to meet customer requirements, covering both material and information flows, from order placement to final delivery.

Visual Management Visual management facilitates the display of tools, parts, standards, and performance indicators. Its purpose is to clearly communicate the standard conditions that everyone should follow.

Visual Standard Supports visual management of operations, enabling the identification of deviations from standard practices at a glance.

W

Waste Any activity that consumes resources without creating value for the customer. The seven main types of waste are: overproduction, waiting, transportation, unnecessary processing, inventory, motion, and defects.

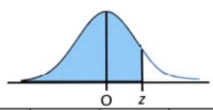
Work Sampling A method developed to determine the proportion of time a worker spends performing different skills or activities.

Y

Yamazumi A Japanese term for a stack or pile. A yamazumi chart is a stacked bar chart used to balance an operation.

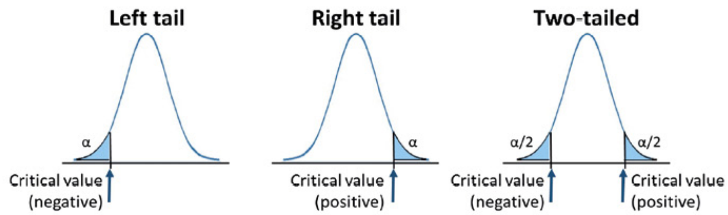
APPENDIX 3:
SPECIAL TABLES

Table 1: Cumulative standard normal distribution



z	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0	0.5000	0.5040	0.5080	0.5120	0.5160	0.5199	0.5239	0.5279	0.5319	0.5359
0.1	0.5398	0.5438	0.5478	0.5517	0.5557	0.5596	0.5636	0.5675	0.5714	0.5753
0.2	0.5793	0.5832	0.5871	0.5910	0.5948	0.5987	0.6026	0.6064	0.6103	0.6141
0.3	0.6179	0.6217	0.6255	0.6293	0.6331	0.6368	0.6406	0.6443	0.6480	0.6517
0.4	0.6554	0.6591	0.6628	0.6664	0.6700	0.6736	0.6772	0.6808	0.6844	0.6879
0.5	0.6915	0.6950	0.6985	0.7019	0.7054	0.7088	0.7123	0.7157	0.7190	0.7224
0.6	0.7257	0.7291	0.7324	0.7357	0.7389	0.7422	0.7454	0.7486	0.7517	0.7549
0.7	0.7580	0.7611	0.7642	0.7673	0.7704	0.7734	0.7764	0.7794	0.7823	0.7852
0.8	0.7881	0.7910	0.7939	0.7967	0.7995	0.8023	0.8051	0.8078	0.8106	0.8133
0.9	0.8159	0.8186	0.8212	0.8238	0.8264	0.8289	0.8315	0.8340	0.8365	0.8389
1	0.8413	0.8438	0.8461	0.8485	0.8508	0.8531	0.8554	0.8577	0.8599	0.8621
1.1	0.8643	0.8665	0.8686	0.8708	0.8729	0.8749	0.8770	0.8790	0.8810	0.8830
1.2	0.8849	0.8869	0.8888	0.8907	0.8925	0.8944	0.8962	0.8980	0.8997	0.9015
1.3	0.9032	0.9049	0.9066	0.9082	0.9099	0.9115	0.9131	0.9147	0.9162	0.9177
1.4	0.9192	0.9207	0.9222	0.9236	0.9251	0.9265	0.9279	0.9292	0.9306	0.9319
1.5	0.9332	0.9345	0.9357	0.9370	0.9382	0.9394	0.9406	0.9418	0.9429	0.9441
1.6	0.9452	0.9463	0.9474	0.9484	0.9495	0.9505	0.9515	0.9525	0.9535	0.9545
1.7	0.9554	0.9564	0.9573	0.9582	0.9591	0.9599	0.9608	0.9616	0.9625	0.9633
1.8	0.9641	0.9649	0.9656	0.9664	0.9671	0.9678	0.9686	0.9693	0.9699	0.9706
1.9	0.9713	0.9719	0.9726	0.9732	0.9738	0.9744	0.9750	0.9756	0.9761	0.9767
2	0.9772	0.9778	0.9783	0.9788	0.9793	0.9798	0.9803	0.9808	0.9812	0.9817
2.1	0.9821	0.9826	0.9830	0.9834	0.9838	0.9842	0.9846	0.9850	0.9854	0.9857
2.2	0.9861	0.9864	0.9868	0.9871	0.9875	0.9878	0.9881	0.9884	0.9887	0.9890
2.3	0.9893	0.9896	0.9898	0.9901	0.9904	0.9906	0.9909	0.9911	0.9913	0.9916
2.4	0.9918	0.9920	0.9922	0.9925	0.9927	0.9929	0.9931	0.9932	0.9934	0.9936
2.5	0.9938	0.9940	0.9941	0.9943	0.9945	0.9946	0.9948	0.9949	0.9951	0.9952
2.6	0.9953	0.9955	0.9956	0.9957	0.9959	0.9960	0.9961	0.9962	0.9963	0.9964
2.7	0.9965	0.9966	0.9967	0.9968	0.9969	0.9970	0.9971	0.9972	0.9973	0.9974
2.8	0.9974	0.9975	0.9976	0.9977	0.9977	0.9978	0.9979	0.9979	0.9980	0.9981
2.9	0.9981	0.9982	0.9982	0.9983	0.9984	0.9984	0.9985	0.9985	0.9986	0.9986
3	0.9987	0.9987	0.9987	0.9988	0.9988	0.9989	0.9989	0.9989	0.9990	0.9990
3.1	0.9990	0.9991	0.9991	0.9991	0.9992	0.9992	0.9992	0.9992	0.9993	0.9993
3.2	0.9993	0.9993	0.9994	0.9994	0.9994	0.9994	0.9994	0.9995	0.9995	0.9995
3.3	0.9995	0.9995	0.9995	0.9996	0.9996	0.9996	0.9996	0.9996	0.9996	0.9997
3.4	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9997	0.9998

Table 2: Student t-distribution



	Amount of area in one tail						
	0.25	**0.125**	**0.05**	**0.025**	**0.0125**	**0.005**	**0.0025**
Graus de	Amount of area in two tails						
Liberdade (*n*)	**0.50**	**0.25**	**0.10**	**0.05**	**0.025**	**0.01**	**0.005**
1	1.000	2.414	6.314	12.706	25.452	63.657	127.321
2	0.816	1.604	2.920	4.303	6.205	9.925	14.089
3	0.765	1.423	2.353	3.182	4.177	5.841	7.453
4	0.741	1.344	2.132	2.776	3.495	4.604	5.598
5	0.727	1.301	2.015	2.571	3.163	4.032	4.773
6	0.718	1.273	1.943	2.447	2.969	3.707	4.317
7	0.711	1.254	1.895	2.365	2.841	3.499	4.029
8	0.706	1.240	1.860	2.306	2.752	3.355	3.833
9	0.703	1.230	1.833	2.262	2.685	3.250	3.690
10	0.700	1.221	1.812	2.228	2.634	3.169	3.581
11	0.697	1.214	1.796	2.201	2.593	3.106	3.497
12	0.695	1.209	1.782	2.179	2.560	3.055	3.428
13	0.694	1.204	1.771	2.160	2.533	3.012	3.372
14	0.692	1.200	1.761	2.145	2.510	2.977	3.326
15	0.691	1.197	1.753	2.131	2.490	2.947	3.286
16	0.690	1.194	1.746	2.120	2.473	2.921	3.252
17	0.689	1.191	1.740	2.110	2.458	2.898	3.222
18	0.688	1.189	1.734	2.101	2.445	2.878	3.197
19	0.688	1.187	1.729	2.093	2.433	2.861	3.174
20	0.687	1.185	1.725	2.086	2.423	2.845	3.153
21	0.686	1.183	1.721	2.080	2.414	2.831	3.135
22	0.686	1.182	1.717	2.074	2.405	2.819	3.119
23	0.685	1.180	1.714	2.069	2.398	2.807	3.104
24	0.685	1.179	1.711	2.064	2.391	2.797	3.091
25	0.684	1.178	1.708	2.060	2.385	2.787	3.078
26	0.684	1.177	1.706	2.056	2.379	2.779	3.067
27	0.684	1.176	1.703	2.052	2.373	2.771	3.057
28	0.683	1.175	1.701	2.048	2.368	2.763	3.047
29	0.683	1.174	1.699	2.045	2.364	2.756	3.038
30	0.683	1.173	1.697	2.042	2.360	2.750	3.030
40	0.681	1.167	1.684	2.021	2.329	2.704	2.971
60	0.679	1.162	1.671	2.000	2.299	2.660	2.915
120	0.677	1.156	1.658	1.980	2.270	2.617	2.860
∞	0.675	1.150	1.645	1.960	2.241	2.576	2.807

Table 3: MOST

GENERAL MOVE: Get (ABG) + Put (ABP) + Return (A)				
Index	**A** Action distance	**B** Body motion	**G** Gain control	**P** Placement
0	≤ 2 in. (5 cm)	No body motion	No gain control Hold	No placement Hold Toss
1	Within reach		Grasp light objects	Lay aside Loose fit
3	1-2 steps	Sit without adjustments Stand without adjustments Bend and arise (50% occ.)	Get heavy/bulky Get obstructed Disengage Collect	Loose fit blind Place with adjustments, light pressure OR double placement
6	3-4 steps	Bend and arise		Position with care, precision, blind, obstructed, with heavy pressure OR with intermediate moves
10	5-7 steps	Sit Stand		
16	8-10 steps	Bend and sit Climb on OR climb off Stand and bend Through door		

Index	Steps	Distance (ft.)	Distance (m.)
24	11-15	38	12
32	16-20	50	15
42	21-26	65	20
54	27-33	83	25
67	34-40	100	30
81	41-49	123	38
96	50-57	143	44
113	58-67	168	51
131	68-78	195	59
152	79-90	225	69
173	91-102	255	78
196	103-115	288	88
220	116-128	320	98
245	129-142	355	108
270	143-158	395	120
300	159-174	435	133
330	175-191	478	146

CONTROLLED MOVE: Get (ABP) + Move/Actuate (MXI) + Return (A)				
Index	M – Move controlled		X Process time	I Alignment
	Push/Pull/Pivot	Crank		
0	No action	No action	No process time	No alignment
1	Push/Pull/Pivot ≤ 12 in. (30 cm.) Push button Push/Pull switch Rotate knob		0.5 sec.	Align to 1 point
3	Push/Pull/Pivot > 12 in. (30 cm.) Push/Pull with resistance Push/Pull with high control Seat OR Unseat Push/Pull (2 stages) ≤ 12 in. (30 cm.) Push/Pull (2 stages) ≤ 24 in. Total	1 Rev.	1.5 sec.	Align to 2 points ≤ 4 in. (10 cm.)
6	Push/Pull (2 stages) > 12 in. (30 cm.) Push/Pull (2 stages) > 24 in. Total Push with 1-2 steps	2-3 Revs.	2.5 sec.	Align to 2 points > 4 in. (10 cm.)
10	Push/Pull (3-4 stages) Push with 3-5 steps	4-6 Revs.	4.5 sec.	
16	Push with 6-9 steps	7-11 Revs.	7 sec.	Align with precision

TOOL USE: Get tool (ABG) + Put tool (ABP) + Tool action (*) + Aside tool (ABP) + Return (A)					
FASTEN OR LOOSEN					
Index	Finger action	Wrist action			
	Spins	Turns	Strokes	Cranks	Taps
	Fingers, screw-driver	Hands, screw-driver, ratchet, t-wrench	Wrench, allen key	Wrench, allen key, ratchet	Hand, hammer
1	1	-	-	-	1
3	2	1	1	1	3
6	3	3	2	3	6
10	8	5	3	5	10
16	16	9	5	8	16
24	25	13	8	11	23
32	35	17	10		30
42	47	23	13		39
54	61	29	17		50

TOOL USE: Get tool (ABG) + Put tool (ABP) + Tool action (*) + Aside tool (ABP) + Return (A)							
FASTEN OR LOOSEN							
Index	Tool action	Arm action					
	Screw diameter	Turns		Strokes	Cranks	Strikes	
	Power wrench	Ratchet	T-wrench, 2-hands	Wrench, allen key	Wrench, allen key, ratchet	Hand, hammer	
1	-	-	-	-	-	-	
3	1/4” (6 mm)	1	-	1	-	1	
6	1” (25 mm)	2	1	-	1	3	
10		4	-	2	2	5	
16		6	3	3	3	8	
24		9	6	4	5	12	
32		12	8	6		16	
42		15	11	8		21	
54		20	15	10		27	

TOOL USE: Get tool (ABG) + Put tool (ABP) + Tool action (*) + Aside tool (ABP) + Return (A)							
CUT OR SURFACE TREAT							
Index	Cut				Surface treat		
	Pliers		Scissors	Knife	Air-clean	Brush-clean	Wipe
	Twist/bend	Cutoff Wire	Cut(s)	Slice(s)	Sq. ft. (0,1 m.^{2})	Sq. ft. (0,1 m.^{2})	Sq. ft. (0,1 m.^{2})
1	Grip		1	-	-	-	-
3		Soft	2	1	-	-	1/2
6	Twist Bend-loop	Medium	4	-	1 Spot 1 Point 1 Cavity	1 small object	-
10		Hard	7	3	-	-	1
16	Bend Cotter pin		11	4	3	2	2
24			15	6	4	3	-
32			20	9	7	5	5
42			27	11	10	7	7
54			33				

<table>
<tr><th colspan="7">TOOL USE: Get tool (ABG) + Put tool (ABP) + Tool action (*) + Aside tool (ABP) + Return (A)</th></tr>
<tr><th colspan="7">RECORD (write and mark) OR THINK (inspect and read)</th></tr>
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<tr><th colspan="2">Write</th><th>Mark</th><th>Inspect</th><th colspan="2">Read</th></tr>
<tr><th>Digits</th><th>Words</th><th>Digits</th><th>Points</th><th>Digits
Single
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Mark</td><td>1</td><td>1</td><td>3</td></tr>
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Gauge</td><td>8</td></tr>
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Touch for heat</td><td colspan="2">6 15
Date OR Time</td></tr>
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Feel for defect</td><td>12</td><td>24</td></tr>
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Signature OR Date</td><td>5</td><td>14</td><td></td><td>38</td></tr>
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</table>

APPENDIX 4: FORMS

Form 1: Flow process chart and flow diagram

FLOW PROCESS CHART

Current method ☐ **New method** ☐

Activity:

Date:

SYMBOLS

○ **Operation** □ **Inspection** ⇨ **Transportation** ▽ **Storage** D **Delay**

DISTANCE	TIME	SYMBOLS	EVENT DESCRIPTION
		○ □ ⇨ ▽ D	
		○ □ ⇨ ▽ D	
		○ □ ⇨ ▽ D	
		○ □ ⇨ ▽ D	
		○ □ ⇨ ▽ D	
		○ □ ⇨ ▽ D	
		○ □ ⇨ ▽ D	
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		○ □ ⇨ ▽ D	
		○ □ ⇨ ▽ D	
		○ □ ⇨ ▽ D	
		TOTAL	

Form 2: Value stream mapping

VALUE STREAM MAPPING FORM

Activity:

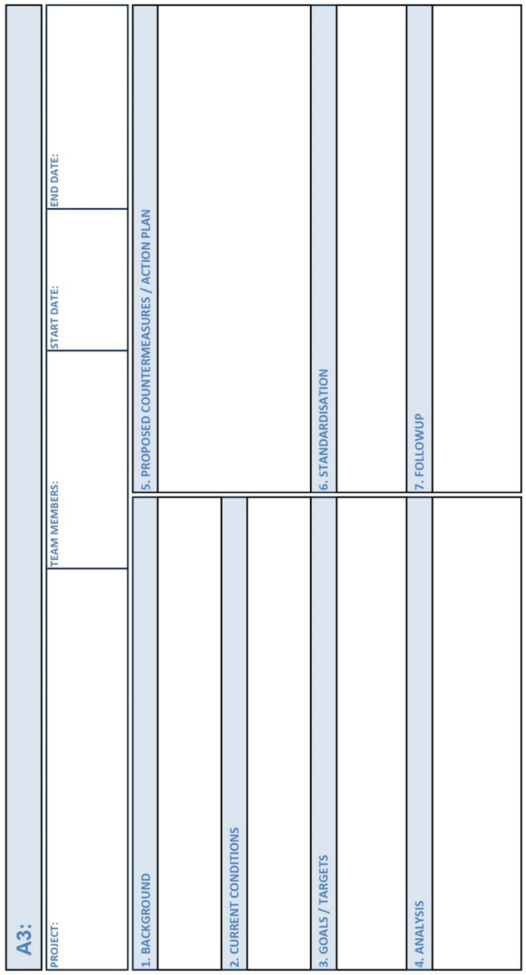
Date:

SYMBOLS

○ **Operation** □ **Inspection** ⇨ **Transportation** ▽ **Storage** D **Delay**

○ Time	□ Time	⇨ Distance	▽ Quantity	D Time	EVENT DESCRIPTION

Form 3: A3


A3:

PROJECT:

TEAM MEMBERS:

START DATE:

END DATE:

1. BACKGROUND

2. CURRENT CONDITIONS

3. GOALS / TARGETS

4. ANALYSIS

5. PROPOSED COUNTERMEASURES / ACTION PLAN

6. STANDARDISATION

7. FOLLOWUP

Form 4: Time study observation form (Lean approach)

Observer:		
Worksite:	Operator:	Product:
Operation:		Date:

Cycle	Work element	1	2	3	4	5	6	7	8	9	10	Min	Mean	Max	Lowest Repeatable	MACHINE cycle time	Notes
1																	
2																	
3																	
4																	
5																	
6																	
7																	
8																	
														Sum			

Form 5: Time study observation form (Methods engineering approach)

Observer:			
Location:	Operator:	Product:	
Operation:		Date:	

No.	Work element	Cycle	1	2	3	4	5	6	7	8	9	10	Average NT	% Allowance	Standard Time	Notes
1		Observed Time (OT)														
		Rating (R)														
		Normal Time (NT)														
2		Observed Time (OT)														
		Rating (R)														
		Normal Time (NT)														
3		Observed Time (OT)														
		Rating (R)														
		Normal Time (NT)														
4		Observed Time (OT)														
		Rating (R)														
		Normal Time (NT)														
5		Observed Time (OT)														
		Rating (R)														
		Normal Time (NT)														
														TOTAL STANDARD TIME		

Form 6: Standard Work Instructions (SWI)

Standard Work Instructions (SWI)				DEPARTMENT:	
TASK #:		TASK DESCRIPTION:		DATE:	REV:
EQUIPMENT DESCRIPTION:		SYMBOLS	Safety / Critical / Ergonomics / Quality / Environmental		CYCLE TIME:

No.	SYMBOL	ELEMENT	ELEMENT DESCRIPTION	TIME	PICTURE

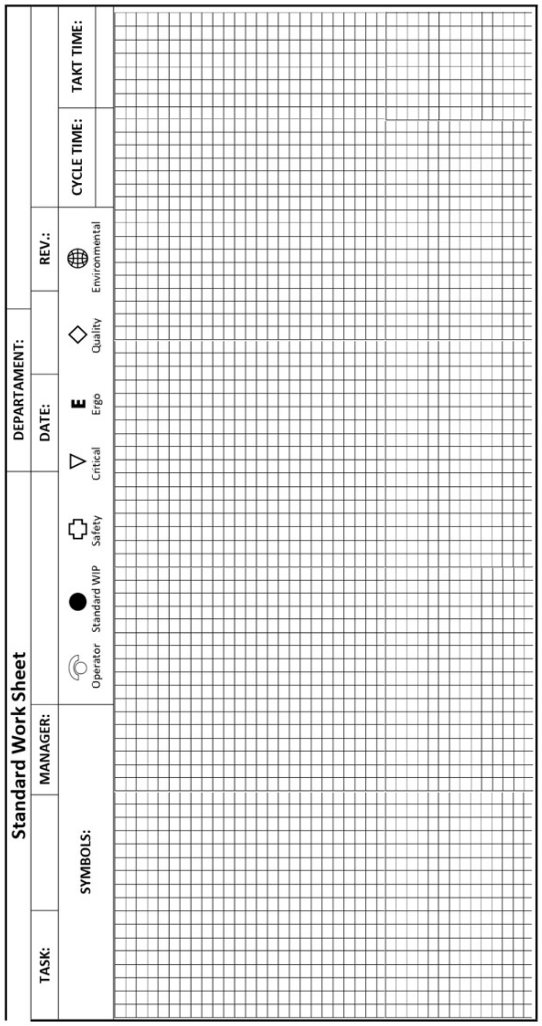
Form 7: Standard Work Combination Sheet (SWCS)

Standard Work Combination Sheet

TASK:	TASK DESCRIPTION:	DEPARTMENT:	
CYCLE TIME:	TAKT TIME:	DATE:	REV.:
SYMBOLS:	Manual	Automatic	Walking	Waiting

STEP #	STEP DESCRIPTION	TIME: Manual	TIME: Automatic	TIME: Walking	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100	105

Form 8: Standard Work Sheet (SWS) draft



Standard Work Sheet

TASK: | MANAGER: | DEPARTAMENT: | DATE: | REV.:

SYMBOLS: Operator | Standard WIP | Safety | Critical | Ergo | Quality | Environmental | CYCLE TIME: | TAKT TIME:

Form 9: Standard Work Sheet (SWS)

Standard Work Sheet

TASK:	MANAGER:	DATE:	REV.:
		DEPARTMENT:	
SYMBOLS	Operator, Standard WIP, Safety, Critical, Ergo, Quality, Environmental	CYCLE TIME:	TAKT TIME:

No.	Step

APPENDIX 5:
ANSWERS TO ACTIVITIES

CHAPTER 2 (CASE STUDY: DIGITAL TRANSFORMATION – PART 1)

QUESTION 1

	Process BEFORE digital transformation	Process AFTER digital transformation
% value added time	41%	0.35%
Focus (flow unit or resources)	Flow unit	Resources

QUESTION 2

The low percentage of value-added time would be verified in the form of three symptoms:

- Extended lead time: A long time for analysis of a request from its submission until its approval or rejection.
- Many flow units: A long virtual queue of requests to be analyzed.
- Many restarts per flow unit: The demand for requirements necessitates constant resumption. For example, every time a request returns with a resolved pending issue, the analyst spends considerable time re-studying it, as the high volume of requests analyzed per day means he no longer remembers much about the one just resolved.

QUESTION 3

Before digitalization, the process accounted for a high percentage of value-added time (41%). Accordingly, it focused on the unit flow, ultimately benefiting all parties involved: the analysts, the applicants, and the organization itself.

After digitalization, however, a low percentage of value-added time (<1%) was observed, indicating a process that focuses on the efficient use of its resources.

That is, if we were to evaluate the productivity of its resources, in this case, the analysts, we would conclude that they analyze many requests daily. Nevertheless, they complete a few per day, which means they are efficient reworkers, in other words, inefficient workers.

This low percentage of value-added time is due to the process's main bottleneck: rework caused by requests for new requirements for the applicant. If the process were done "right the first time," these requirements would be unnecessary. Thus, these requests constitute rework, which, in addition to significantly increasing the process lead time, create activities that confer "waste" of time on the analyst.

CHAPTER 3 (CASE STUDY: DIGITAL TRANSFORMATION – PART 2)

QUESTION 1

The neglected stage was the first one, the planning stage of the PDCA cycle.

This first stage is a critical and strategic phase because it reduces the risk of rework in a given project. Therefore, it is necessary to conduct the planning phase properly to increase the project's success rate. Consequently, if more resources (time, studies, and personnel) had been invested in the project's planning stage, the problem could have been anticipated. Thus, one would conclude that, before mapping and time-analyzing the processes, the wastes should be identified and eliminated.

In this sense, a prior study should have been conducted solely for the initial service process to ensure the quality of data entry into the system and determine the time required to provide an adequate service. Furthermore, it would be essential to determine which training is required for those who perform this service.

Only after these studies and the implementation of the appropriate actions should the other processes be mapped and time-analyzed.

QUESTION 2

One suggestion is to conduct an in-depth study to identify the critical factors or requirements for process inputs. The purpose of this study is to address the following question: "How can the quality of input data be improved to enhance overall efficiency?"

Accordingly, it is recommended that a project be undertaken to thoroughly document all mandatory and potentially necessary documents for this process. In this regard, the leading causes of rework should be analyzed to mitigate the risk of their occurrence. To this end, it is suggested that decision flowcharts be developed to clearly outline all critical factors and input requirements for each process, as well as their interdependencies (Figure 3.13).

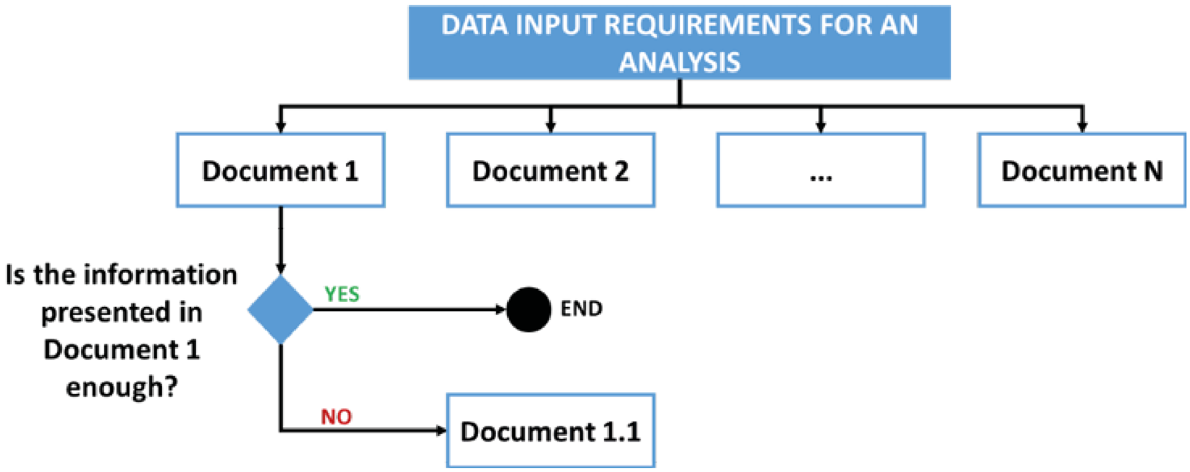


Figure 3.13 – Hypothetical flowchart of critical factors or input requirements

This case study is presented in detail in the e-book "Lean Flow: A quick guide to transform with lean digital," also written by Elisa Granha Lira (Figure 3.14).

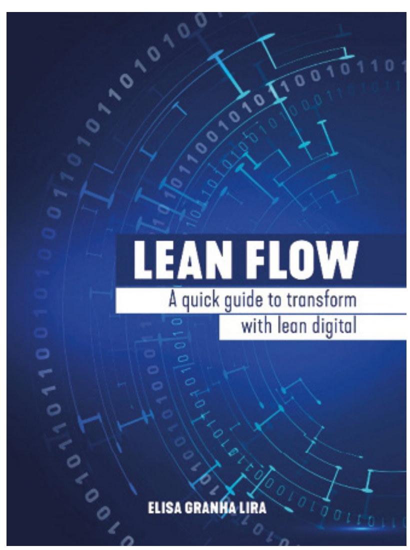


Figure 3.14 – Lean Flow e-book